Measuring Technological Capabilities at The Country Level: A Survey and a Menu for Choice

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Measuring technological capabilities at the country level: A survey and a menu for choice

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Abstract

Several new measures of national technological capabilities have recently been developed. These attempts are a result of an often-implicit theoretical consensus about the nature of technology. The aim of this article is to compare their methodologies and results. The World Economic Forum (WEF), the UN Development Program (UNDP), the UN Industrial Development Organisation (UNIDO), and the RAND Corporation are the institutions that have provided the measures examined here. We compare these authoritative attempts with our own measure of technological capability, ArCo. The results provide a broadly comparable ranking of countries, although a few significant differences do emerge.

Keywords: Innovation measurement; Technological infrastructure; Diffusion of innovations; Human skills; Economic and social indicators

1. Introduction and scope

Some significant attempts to build aggregate indicators of technological capabilities at the country level have recently been made. The purpose of this article is to illustrate the methodologies followed by each of them, to explore their similarities and differences, and to compare the results. These recent empirical attempts are the offspring of a certain consensus on the nature of technology that has emerged over the last quarter of a century, and that is today shared by different disciplines such as institutional economics, social studies in science and technology, and management studies.

Both policy analysts and academic researchers need new and improved measures of technological capabilities on the performance of nations to understand economic and social transformations. With regard to policy analysis, this has relevance for public and business practitioners. Governments constantly require information about the performance of their own country, and this is often better understood in comparison to the performance of their partners and competitors. Businesses must make decisions on the geographical scope

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of their investments, trade, and joint ventures based on technical expertise embedded in the various national innovation systems.

Not surprisingly, countries are more and more ranked according to various statistics of performance in science and technology activity (this is a standard practice of many international organizations; see, for example, European Commission, 2003; OECD, 1999; NSF, 2002). The interpretation of statistical data, however, is not uniform and policy makers are often inclined to read data on science and technology as a sort of Olympic Medals Table, with the assumption that the countries with higher levels of performance, either in absolute or in relative terms, are better off. We do not, of course, dispute that activities in the field of technological knowledge are a positive factor in social and economic life. But a better understanding of the effects of knowledge on economic and social variables should still be gathered.

In recent years, there has been an increasing academic interest in the varying explanations of differences across countries in growth rates, composition of trade, competitiveness, human development, and employment. This huge and mounting literature has often assumed that these differences are dependent on the level of technological expertise, and in turn new efforts have been made towards understanding, measuring, and explaining the latter. However, to measure technological capabilities is more complicated than to measure other economic and social indicators. The very nature of technology makes it difficult to aggregate its heterogeneous aspects and components into a single meaningful indicator. Despite these limitations, the available statistical sources have grown during the last decade, and we expect that this growth will continue for the next few years. This paper has a two-fold aim: firstly, it aims to compare the similarities and differences between the various methodological approaches; and secondly, to test the consistency of these results. This paper is not devoted to exploring the impact of technological capabilities on economic and social variables, but simply to check the consistency of the various measures, under the assumption that a better understanding of the measures used will be helpful in order to assess casual links between technology and performance.

The investigations taken into account here are at the aggregate level only, and therefore do not consider the nature of technological capabilities available in each country. Many scholars are uneasy, and with good reason, with the idea that a single "number" could be used to describe the technological activities of a country. We are aware that one of the key features of technology is precisely its variety; research activities, infrastructures, human skills, the stock of capital, and many other components constitute the technological capabilities of a country, and it is a hard task to aggregate them in a logically meaningful way. The notion of national innovation systems (Lundvall, 1992; Nelson, 1993; Freeman, 1997), which has become increasingly popular over the last 15 years, requires identifying the qualitative as well as the quantitative differences across countries and it explicitly assumes that each national system is the outcome of a large number of institutions and of geographical components, each of which is characterized by uneven capabilities. While some attempts to measure sectoral differences in national innovation systems have already been carried out (see Archibugi and Pianta, 1992; Patel and Pavitt, 1994; Pietrobelli, 1994), we share the view that there is no single number that can provide comprehensive information of the whole technological capabilities of a country.

But in spite of these limitations, synthetic indicators can help. This is certainly not the first time that aggregate indicators have been used for economic and social analysis. Take, for example, the most widely employed economic aggregate indicator, the gross domestic product (GDP). Although GDP has the great advantage in converting each aspect of economic life into a monetary yardstick (an advantage that only very few technological indicators have), it is equally evident that it highlights some aspects of economic and social life (such as income) and obscures others (such as well being). Not surprisingly, other social indicators are becoming more frequently used to guide strategic decisions (see Anderson, 1991). Take the recent example of the Human Development Index (HDI) (UNDP, 2003), a relatively young statistical index, which has become increasingly popular. By aggregating three measures—life expectancy, education, and GDP—this indicator has even a higher and wider ambition than GDP since it aims to describe a large aspect as human development. However, its three components are expressed in different yardsticks and are aggregated on the grounds of a score conversion. Despite the limitations, and if taken with due caution, these indicators help to understand the reality of certain situations, and can assist in devising strategic decisions.

2. What theory behind the measurement of technological capabilities?

The works considered in this paper have many commonalities both in terms of their understanding of technological change, and of the statistical methods applied. These assumptions are often implicit rather than explicit and this may generate the impression that the results produced are somehow "beauty contests" where the countries ranked play the role of contenders. The danger of providing "measurement without theory" has been highlighted long ago (see the classic paper by Koopmans, 1947). In this influential article, Koopmans reviewed the seminal book *Measuring Business Cycle* by Burns and Mitchell (1946) and, while recognizing the major contribution, it provided to statistical economics, he criticised it for not offering adequate theoretical background on the human behaviour that leads to changes in economic activity.

In our view, however, Koopmans partly misunderstood the real purpose of the work by Burns and Mitchell (1946). These authors, in fact, considered their work as an attempt to provide a new instrument that could potentially be used to test any theory. Can the various attempts to measure technological capabilities reviewed here be compared to an instrument of scientific research? In some sense, yes, they can. In fact, the various statistical measures are not devoted to explore causal connections between technology on the one hand and economic and social performance on the other. Some of them (and in particular, WEF, 2001; UNIDO, 2002) have taken into account also an indicator of performance such as competitiveness, but our purpose here is to investigate the consistency of these statistics as faithful measures of *technological capabilities*. If valuable, they can be used to test different and even competing hypothesis.

But in another sense, these attempts do not limit themselves to the production of new statistical sources. Since they share the view that knowledge has a heterogeneous nature, all of them try to account for this heterogeneity by taking into account a battery of indicators, and even by summing them. When any two indicators are summed, subtracted, multiplied or divided, the outcome can be meaningful only when there is an underlying theory that justifies the algorithm. On the other hand, the selection of the ingredients depends heavily on the value judgement of the scholars[1] as well as on the availability of the data. Since this paper compares a handful of approaches, what needs clarifying are the commonalities that justify a comparison.

First of all, a certain consensus emerges on the understanding of technological capabilities. Although the literature discussed here is aware that technological capabilities and production capacity are strictly interconnected, it broadly shares the view that the former is a stock of knowledge which should be kept conceptually separated from the latter (see Bell and Pavitt, 1997, pp. 88–90; Lall, 1990). The two phenomena are clearly interdependent since technological capabilities generate production capacity and vice versa. However, since one of the main purposes of the economics of technological change is to quantify and specify the nature of this linkage, it is useful and necessary to separate the two concepts and finding independent measurement tools for each of them.

Second, the literature here discussed shares the view that technological capabilities are composed of heterogeneous elements, which can be summarised in the following three contrasts: (a) Embodied/Disembodied, (b) Codified/Tacit, and (c) Generation/Diffusion. To expand:

(a) *Embodied/Disembodied*: It is recognized that technological capabilities are embodied in capital goods, equipment, infrastructures, and in disembodied forms such as human skills and scientific and technical expertise. There is ongoing debate on the relative importance of capital goods and disembodied knowledge (see, for example, Scott, 1989; Evangelista, 1999), but there is a shared belief that both types of capability contribute vitally to the technological base of a country.
(b) *Codified/Tacit*: Likewise, it should be stressed that the codified component of knowledge represented

[1] It has long ago been recognized that the empirical data and statistics used to study socially sensitive issues such as poverty or inequality are strongly dependent upon the value judgements and the ideology of the various scholars. See, for example, Atkinson (1970) and more broadly, Sen (1992). The impossibility of avoiding value judgements in social sciences has forcefully been argued by Myrdal (1953).

by manuals, blueprints, patents, and scientific publications are as important as the tacit components associated with learning by doing and by using (Lundvall and Johnson, 1994). While it is relatively easy to quantify codified sources of knowledge, it is much more difficult to find reliable measures of tacit components: if they were easily quantifiable and measurable they would no longer be tacit! Yet, concentrating on the codified knowledge may overlook fundamental components of the knowledge used in production. One way of quantitatively capturing these capabilities is by looking at the qualifications of the labour force, under the assumption that better educated employees have a higher learning potential.

(c) *Generation/Diffusion*: Last but not least, it has long been recognized that both the production of knowledge and its diffusion and imitation provide a valuable technological resource. Some countries can be heavy producers of new knowledge but may be slow to apply it to production, while other countries may benefit disproportionately from the knowledge generated elsewhere. This implies that technological capabilities should be measured according not only to indicators of the generation of inventions and innovations, but also indicators of their application and dissemination.

Third, these works share the methodological view that the various statistics describing the different aspects of technological capabilities can be summed together. Besides the numerical aspect of summing different statistical data, this practice has deeper theoretical implications: it is assumed that the various components of technological capabilities are complementary and not substitutes (for a discussion, see Antonelli, 2003, Chapter 4). It is commonly supposed that the position of a country is more favourable when its range of technological activities is wide and intense. In fact all approaches, in spite of the methodological differences, add the various components: to use again the metaphor of the Olympic medals table, these works assume that gold, silver, and bronze medals obtained by each nation can be summed and that the position of a country can be related to the number of medals won.

But this will still leave open the method of aggregation. Another similarity shared by the approaches considered here is, in fact, that the relative importance of each component singled out is attributed by the various research teams rather than by a statistical technique. In other words, the scholars take the discretionary decision to attribute a weight to gold, silver, and bronze medals. This is a fundamental assumption, which is very informative about the purpose of these works: it is to *rank* countries rather than mapping their *similarities* and *differences*. Even when two indicators are strongly and positively correlated, they are added up, since it is assumed that both contribute to the technological capability of a country. This implies that the indicators considered should somehow inform different aspects of technological capabilities.

Fourth, these approaches also share the view that inter-country comparisons are meaningful, in spite of the social, cultural, and regional variety encountered in each of them. The technological capabilities of California are substantially different from those of Montana, and the same can be said for the regions of large countries such as China and India. However, the analyses surveyed here share the belief that nations are still a meaningful statistical unit with which to measure technological capabilities. Of course, these works are fully aware of the differences inside nations, and of the existence of significant institutions within nations that should be considered with their own technological profile. Take the case of large multinational corporations, their technological capabilities are sometimes more relevant than those of a nation, but none of the approaches reviewed here take into account units of analysis or institutions different from geographically delimited states.[2] Since nations vary considerably in terms of size, all of these attempts have provided measures that weights absolute values by the dimension of nations, either in terms of population or of GDP. We are therefore considering measures of *intensity* rather than of *size*.

Fifth, the attempts reviewed consider both developed and developing countries. This places a number of limitations on the statistical sources that can be used, since both the data available and their reliability are much less satisfactory for developing countries. In fact, the selection of the factors to construct a composite indicator is directly associated with the number of coun-

[2] For a recent attempt to connect national and regional technological capabilities to the activities of multinational corporations, see Cantwell and Iammarino (2003).

tries taken into account: the more countries considered, the more problematic it becomes to find satisfactory measures. For a restricted group of developed capitalist countries (i.e. the OECD countries), there is a high number of indicators available and high reliability of data. (For an overview of these indicators, see OECD (2003). Relevant international comparisons for these countries are carried out in NSF (2002) and European Commission (2003). For a discussion on the nature of individual indicators, see Sirilli (1997). A comprehensive theoretical analysis is provided in Grupp (1998).) But the method applied for OECD countries cannot be used for developing countries for the simple reason that relevant data are not available; rather, one can choose indicators that are available for more countries and be aware that the data are not as satisfactory and as accurate as they are for the OECD countries. Moreover, the nature of technological change differs at the various levels of development (see Bell and Pavitt, 1997). This implies that the selection of indicators should be able to differentiate between countries that are at the top and at the bottom of the scale.

3. The composition of the indexes

We consider five different attempts to measure technological capabilities: the World Economic Forum (WEF) Technology Index (WEF, 2001, 2002, 2003; Furman et al., 2002), the United Nations Development Program (UNDP) Technology Achievement Index (TAI) (UNDP, 2001; Desai et al., 2002), our own ArCo (Archibugi and Coco, 2004), the United Nations Industrial Development Organization (UNIDO) Industrial Development Scoreboard (UNIDO, 2002; Lall and Albaladejo, 2001), and finally the Science and Technology Capacity Index developed by the RAND Corporation and associated partners (Wagner et al., 2004). Throughout this piece, they will be referred as WEF, UNDP, ArCo, UNIDO, and RAND. We also draw our attention on the work carried out by the World Bank Institute programme “Knowledge and Development” Knowledge Assessment Methodology (KAM), although this is not strictly comparable with the others.

3.1. The WEF Technology Index

The first indicator considered is the Technology Index by the WEF Report 2001–2002 (WEF, 2001). The WEF Report contains a wealth of data and sophisticated statistical analyses. Moreover, it is continuously updated and improved on a yearly basis, the most recent being the Report 2003–2004 (WEF, 2003).[3] WEF has introduced two main measures for competitiveness and economic development, the first devoted to the medium-term (Growth Competitiveness Index (GCI)) and the second to the short-term (Current Competitiveness Index (CCI)). The first index (GCI) is based on a battery of variables linked to growth grouped in three components: (1) the level of technology, (2) the quality of public policies, and (3) the macroeconomic environmental conditions. The second index (CCI) considers variables that concentrate on microeconomic aspects, such as the business environment around a firm, and the strategy and organisation inside a company. Competitiveness is a largely used and abused concept in economics (for a review, see Cantwell, 2004). Although there is a general consensus that technology is an important component of competitiveness at the micro, sectoral, regional, and national levels, it is clear that it is not the only component. For this reason, we concentrate our attention on the component of the GCI directly linked to technology, the WEF Technology Index. The other aspects considered in the GCI and in the CCI are certainly valuable, but are beyond the scope of this paper.

The WEF Technology Index includes three main categories of technology: (a) *innovative capacity* (measured by a combination of: patents granted at USPTO, tertiary enrolment ratio, and survey data); (b) *ICT diffusion* (measured by internet, telephone, PCs, and survey data); and (c) *technology transfer* (measured by non-primary exports and survey data). These are weighted differently for a set of 75 countries,[4] divided into two groups according to the number of patents produced: 21 *core* countries and 54 *non-core* countries. WEF considers the first two categories as a sufficient source of information for the *core* countries since it is assumed that those countries are much less reliant on technology transfer. All three categories are considered for the *non-core* group, but a lower weight is assigned to the indicators of *innovative capacity*. The theoretical jus-

[3] Our statistical analysis refers to the WEF (2001) version because the years covered are closer to the other attempts.

[4] In should be noted that the latest version of WEF has enlarged the countries considered to 102.

tification for this asymmetric measurement of technology is that *non-core* countries are supposed to derive competences from technology use and imitation rather than production and innovation (for a critical analysis of this approach, see Lall, 2001b).

It should be noted that, although WEF was produced by a non-governmental organisation, it is the only index that it is annually updated, and that, so far, it has also managed to increase the number of countries covered.

3.2. The UNDP Technology Achievement Index

The second index considered is the Technology Achievement Index elaborated by Desai et al. (2002), and reported in the Human Development Report (UNDP, 2001). The authors consider four dimensions of technology achievement, each of which is based on two indicators: (a) *creation of technology* (based on patents registered by residents at their national offices and receipts of royalty and license fees); (b) *diffusion of newest technologies* (based on internet hosts and medium- and high-technology exports); (c) *diffusion of oldest technologies* (based on telephone mainlines and electricity consumption); (d) *human skills* (based on years of schooling and tertiary science enrolment). These indicators are aggregated to define a synthetic index for a set of 84 countries.

The 2003 and 2004 versions of the Human Development Report have discontinued the production of data of TAI, although data on the eight basic indicators are reported.

3.3. The Technological Capabilities Index (ArCo)

The third index is our own ArCo Technological Capabilities Index (Archibugi and Coco, 2004). It takes three dimensions of technology into account: (a) *innovative activity* (based on patents registered at US patent office and scientific publications); (b) *technology infrastructure* (including old and new ones and based on internet, telephone mainlines and mobile, and electricity consumption); (c) *human capital* (based on scientific tertiary enrolment, years of schooling, and literacy rate). We also extend the analysis by examining 162 countries and attempting to provide data for two different periods (1990 and 2000).

In Archibugi and Coco (2004), pp. 646–648, we also presented an index with an additional component, namely import technology, based on the assumption that an important source of technological capabilities is also represented by the possibility of a country to access technology developed elsewhere. This index considered three other indicators derived from Lall and Albaladejo (2001), namely inward foreign direct investment (FDI), technology licensing payments, and import of capital goods. This was possible for 86 countries only. This fourth component, imported technology was given equal weight compared to the others and the overall index was labelled “Global Technology Index”. For the 86 countries, for which both the values of ArCo and of the Global Technology Index are available, the linear and the rank correlation coefficients where, respectively, 0.990 and 0.995. For this reason, we have limited our analysis in the remaining sections of this paper to the ArCo index.

So far, the ArCo database has no periodicity, although we plan to update ArCo and to complete the time-series. Data are freely available and downloadable at http://www.danielearchibugi.org.

3.4. Industrial Development Scoreboard UNIDO

The fourth study examined is from UNIDO (2002), and is strongly inspired by the work of Lall and Albaladejo (2001). It collates a wealth of indicators for 87 countries. The components and the drivers of competitive industrial performance are taken into account. Lall and Albaladejo (2001) consider four categories: (a) *technological effort* (based on patents at the US patent office and enterprise financed R&D); (b) *competitive industrial performance* (based on manufactured value added (MVA), medium- and high-technology share in MVA, manufactured exports, and medium- and high-technology share in exports); (c) *technology imports* (based on FDI, foreign royalties payments, and capital goods); and (d) *skills* and *infrastructures* (based on tertiary technical enrolment and telephone mainlines). Lall and Albaladejo (2001) and UNIDO (2002) create some indexes for each of the individual categories cited above, but do not produce a synthetic indicator that aggregates the various components into a combined index. This choice is probably dictated by the scepticism surrounding the compression of many variables into a single aggregate measure (see above), and at the same time points to the fact that data on the various components can be as useful and informative as an aggregate indicator. However, the lack of a synthetic indicator prevents statistical comparisons between the UNIDO report and the other works presented here.

There are no update to the UNIDO (2002) report, and it is therefore difficult to know if the indexes will become periodical.

3.5. Science and Technology Capacity Index (STCI), RAND Corporation

The last study considered here is by Wagner et al. (2004) for the RAND Corporation. For a set of 76 countries, eight indicators are aggregated and divided into three categories: (a) *enabling factors* (based on GDP and tertiary science enrolment); (b) *resources* (based on R&D expenditure, number of institutions and number of scientists and engineers); (c) *embedded knowledge* (based on patents, S&T publications and co-authored scientific and technical papers). A synthetic index is created through a standardised formula, with different outcomes occurring according to the weights assigned to the three categories.

This work was inspired by previous research carried out at the RAND Corporation (see, in particular, Wagner et al., 2001). At the moment, there are no plans to make this index periodical.

3.6. World Bank Institute, Knowledge Assessment Methodology

It should also be mentioned that the World Bank supplies the largest database on development indicators, including indicators of technological capabilities. Many of the studies cited above rely on original data produced by the World Bank, which are constantly updated, and which are also freely available on the web (World Bank, 2003). More recently, Carl Dahlman and his colleagues have developed, under the auspices of the "Knowledge for Development" programme, a detailed database, *Knowledge Assessment Methodology* (World Bank Institute, 2004) that includes also statistics produced by other institutions. Overall, the programme contains 76 variables, of which 20 relate to the innovation system, 16 to education and training, and 13 to information infrastructures. The programme has also made available a new on-line user-friendly statistical tool, which allows comparisons among countries for any of the variables listed. It also allows comparisons among groups of countries according to geographical location, income level, human development level, etc. The exercise, however, does not provide aggregate measures comparable to the other discussed above and for this reason is not taken into account in the next sections.

Such a relevant programme, however, leads to some considerations. KAM shows that a sort of "do-it-yourself" approach to economic and social indicators is technically feasible. On the one hand, this has considerably lowered barriers to data access. Policy makers, analysts, students, and journalists have become less dependent upon the availability of data and on the methodological choices of data producers. They could today choose the variables that fit better their needs and their preferences *à la carte* from a huge menu. On the other hand, the way in which data are freely available leaves open the question of the significance of statistics. It becomes more relevant that the various users of statistical sources make explicit the theoretical assumptions that lead to the use of some indicators (and to make some comparisons) rather than others.

4. The factors: similarities and differences

A synopsis of the main features of the indexes that we are dealing with is presented in Table 1, and shows at a glance that the various approaches contain significant similarities. In fact, many indicators are identical, signalling the achievement of a certain consensus amongst scholars on what are the most significant components of technological capacity. The discussion below considers the strengths and weaknesses of these measures *as internationally comparable indicators*, and does not address their properties for other comparisons (such as inter-industry or inter-firm comparisons).

4.1. Patents

All of the attempts use patent statistics as a solid indicator of *national innovative capacity* (Furman et al., 2002). This is also related to the ease of availability of patent data for all countries (in contrast, data on R&D is available for a more limited set of countries). However, we are also aware of the limitations of patents (for surveys on patents as internationally comparable indicators, see Pavitt, 1988; Archibugi, 1992). Firstly, the

Table 1
Attempts to measure technological capabilities: a synopsis

Acronym	WEF	UNDP	ArCo	UNIDO	RAND
Full name	WEF Technology Index	UNDP Technology Achievement Index (TAI)	ArCo Indicator of Technological Capabilities	UNIDO Industrial Development Scoreboard	Science and Technology Capacity Index
Generation of technology and innovation	*Innovation sub-index*: patents at USPTO; tertiary enrolment; survey data	*Technology creation*: national patents; receipts of royalty and license fees	*Technology creation sub-index*: patents at USPTO; scientific articles	*Technology effort index*: patents at USPTO; enterprises financed R &D	*Embedded knowledge:* patents at USPTO; scientific articles. *Resources*: R&D expenditure
Infrastructure and technology diffusion	*ICT sub-index*: internet, PCs, telephone, survey data. *Technology transfer sub-index*: non-primary exports; survey question	*Diffusion of recent innovations*: internet hosts; medium- and high-technology exports. *Diffusion of old innovations*: telephone; electricity consumption	*Technology infrastructure sub-index*: internet, telephone, electricity consumption	*Technology imports:* FDI; foreign royalty payments; capital goods. *Infrastructure*: telephone main lines	*Resources*: number of institutions. *Embedded knowledge*: internationally co-authored papers
Human capital	Included in *Innovation sub-index*	*Human skills*: years of schooling; tertiary science enrolment	*Human skills sub-index*: scientific tertiary enrolment; years of schooling; literacy rate	*Skills*: tertiary technical enrolment	*Enabling factors*: tertiary science enrolment. *Resources*: number of scientists and engineers
Competitiveness	Considered out of the Technology Index: public institutional and macroeconomic conditions in the GCI; firms strategies and microeconomic environment in the CCI	Not explicitly considered	Not explicitly considered	*Competitive Industrial Performance Index*: manufactured value added; medium- and high-technology share in MVA; manufactured exports; medium- and high-technology share in manufactured exports	*Enabling factors*: GDP
Years covered	1997–2000[a]	1995–2000	1987–1990; 1997–2000	1997–1998	1995–2000
Number of countries	75[a]	72	162	87	76
Connected indicators or links	Growth Competitiveness Index (GCI); Current Competitiveness Index (CCI)	Human Development Report other Indexes	None	Competitive Industrial Performance Index	None
Sources	WEF (2001), Furman et al. (2002)	UNDP (2001), Desai et al. (2002)	Archibugi and Coco (2004)	UNIDO (2002), Lall and Albaladejo (2001)	Wagner et al. (2004)

[a] Although our comparison takes into account the data reported in the table, we remind readers that WEF publishes a report every year; therefore, the years covered and the number of countries are continuously up-dated. The last available WEF Report was made in 2003, covering 1999–2002 and the number of countries was increased to 102.

quality of patents varies substantially across countries for legal and economic reasons, namely that the procedures to receive a patent and the protection accorded to an invention vary significantly across countries. In order to have an internationally patent-based reliable indicator, it is preferable to consider the patents registered by all countries in a specific patent institution. We are aware that the propensity to patent in a foreign country varies from nation to nation depending on a variety of factors that include the intensity of commercial relations, the similarities among the legal systems, and the linguistic diversity. However, it is assumed that the most valuable inventions are patented in the most important countries; in fact WEF, UNIDO, ArCo, and RAND all use patents granted at the US Patent Trademark Office (USPTO). We believe that this is the best patent institution to take into account since the USA market is the largest and most technologically developed in the world (although the European Patent Office, a quarter of a century after its inauguration, is becoming a more frequently reliable and employed statistical source). However, the number of patents granted to American citizens and firms should be adjusted given that they are registering inventions in their home market, while all other citizens and firms patent in a foreign institution. This adjustment is carried out in ArCo, but not in the WEF, UNIDO, and RAND attempts. For this reason, we believe that these attempts over-estimate the technological performance of the US economy.

UNDP takes into account the patents registered by inventors and firms at their national offices. We do not consider this source of information reliable due to the substantial institutional differences present between national legislations. For example, according to UNDP, Japan and South Korea emerge as leading countries in terms of “technology creation”, due to the very high number of patents registered by domestic inventors. However, this is due in some degree to the fact that the legislation of these two countries does not allow two or more priorities to be grouped together in the same patent application; Japanese and South Korean inventors, must therefore complete a separate patent application for each claim.

4.2. R&D resources

Another source of technology generation is R&D expenditure, which is considered by UNIDO (enterprise-financed R&D) and RAND (total R&D expenditure). This is a very relevant indicator, which is easily comparable over time and across countries since it is measured in monetary values. Moreover, R&D intensities can be compared across countries by taking into account the R&D/GDP ratio; since both the nominator and the denominator are expressed in national currencies, there is no need for exchange rate adjustments. R&D also provides information on public investment for the generation of knowledge. Unfortunately, as this indicator is available for a restricted number of countries (UNIDO considers 87 nations, RAND considers 76) it is not possible to use it in ArCo as this would imply a reduction of half of the countries considered.

4.3. Scientific publications

Another way to take into account the role of academic institutions is to use the number of scientific publications. This can be considered as an output indicator, which is closely associated to the public R&D expenditure input. The limitations of this indicator are similar to those for patents in that quality and sectoral distribution varies from country to country. Moreover, English-speaking nations are likely to be over-represented, since the vast majority of the journals monitored by the Institute for Scientific Information are in English. The advantage is that, as for US and EPO patents, the data are collected homogeneously for all countries and from reliable sources. Scientific publications are used in ArCo as one of the two measures of technology creation. They are used also in RAND, in addition to two other measures of production of knowledge, R&D and patents. RAND also uses a co-authorship index as a source of information on the international integration of countries’ academia.

4.4. Royalties and license fees

Both UNDP and UNIDO include data on royalties and license fees. While UNDP uses the “receipts” as an indicator of the *creation* of technology, UNIDO uses payments as an indicator of the *acquisition* of technology. In principle, the data are a reliable indicator of both creation and acquisition of technology. However, they are too often biased by financial transactions carried out amongst different branches of the same corporation, and for this reason, we do not take them into account for ArCo.

4.5. Infrastructures

In terms of infrastructures and diffusion of technologies, there is a certain convergence amongst the various approaches. This is especially true for the indicators related to ICT, the sector most closely associated with the concept of a "new economy". Four approaches (all but RAND) include telephone lines; three approaches (WEF, UNDP, and ArCo) include internet; two (UNDP and ArCo) include electricity consumption; and WEF comprises PCs as well. RAND uses none of these measures, although an original indicator of technology infrastructures through the number of research institutions of each country is presented.

4.6. Trade indicators

Data on international trade are highly accurate and can easily be disaggregated according to the technological intensity of the various product groups. Three of the approaches use trade-based indicators. WEF considers non-primary exports for *non-core* economies as a source of active "technology transfer". UNDP includes medium- and high-technology exports as diffusion of recent innovations. UNIDO, which considers manufactured exports per capita and the share of medium- and high-technology exports on total exports as a component of the competitive industrial performance index, provide the widest use of trade-based information. RAND and our ArCo do not use any trade-based indicator. The reason for the exclusion from ArCo is that all other indicators taken into account are weighted for the size of the economy (in terms of population). Trade is strongly associated with the size of the economy and small countries are more open to trade than larger ones. We have not been able to generate an index able to simultaneously control the size of the economy, the balance between exports and imports, and the composition of trade between high, medium, and low technology. Besides this statistical problem, we were also uncertain about how to interpret the data; for example, a strong component of high-technology import represents an important way of acquiring technology which might help to upgrade the national capabilities, yet may also signal dependence on foreign sources.

4.7. Human resources

All teams take into account statistics of human resources; this is unsurprising given that human capital is one of the most important drivers of the growth of a nation. ArCo and UNDP consider human skills as a separate category on the ground of, three and two indicators, respectively. UNIDO and WEF use one measure only (tertiary enrolment), although we are not comfortable with the fact that WEF includes it in the category of "innovative activity". RAND makes use of two measures of education: tertiary science enrolment and the number of scientists and engineers, which are included in the categories "enabling factors" and "resources", respectively. All of the five works contain tertiary scientific education, and UNDP and ArCo also consider the mean years of schooling. ArCo introduces an additional indicator, literacy rate, particularly helpful when discriminating among the poorest countries. Since ArCo includes a larger number of countries, many of which have very low technological capabilities, literacy rate helps to highlight differences at the bottom of the scale.

4.8. Economic indicators

Although it is beyond the scope of this article, WEF and UNIDO pay particular attention to other economic indicators (especially that of competitiveness) although their approaches differ substantially (for a comparison, see Lall, 2001b). While UNIDO links competitiveness to the performance of the manufacturing industry, WEF utilises a large set of microeconomic and macroeconomic environmental variables including measures about the level of national public institutions. WEF and UNIDO associate competitiveness with technological innovation, and both studies allow separation of the indicators of competitiveness from those indicators that are strictly technological. ArCo and UNDP do not take any specific indicator of competitiveness into account since they concentrate on narrowly defined technological capabilities. However, prospective indicators such as UNDP and ArCo can be easily used to econometrically explore the interplay between competitiveness and technology, given that the measures of the latter do not include any measure of the former. RAND also uses GDP as an indicator, under the heading "enabling factors". We find this choice questionable; while

GDP does not necessarily include technological components, it is also more difficult to compare their index with GDP and other GDP-based indicators (such as, for example, GDP growth).

4.9. The use of survey data

WEF also makes extensive use of survey data in addition to quantitative information. WEF conducts global opinion surveys (4600 respondents chosen among executives) in order to gather information on the technological capabilities and the competitiveness of each country. The information attained is aggregated to hard data using sophisticated statistical methodology. However, survey data may produce doubtful results and the method of aggregation with hard data is questionable (Lall, 2001b).

5. Statistical approaches

After the examination of the factors incorporated in the five attempts, we now compare the statistical approaches to aggregation. We focus on four attempts: WEF, UNDP, ArCo, and RAND (UNIDO is excluded since it has not generated a synthetic index, see above). The methodology of aggregating the sub-indexes in a final indicator is rather similar and consists of simple or weighted means of the various components. As already argued, none of these attempts have tried to weigh and combine the various components by means of a statistical technique such as factor or principal component analysis: each team has taken responsibility for deciding what the relative importance of each component of technological capabilities is. However, significant differences lie on the weighting systems used initially to combine the single variables within the sub-indexes, and then to combine the sub-indexes within the final indicator.

The UNDP and the ArCo Indexes maintain a symmetric structure in the weighting of the sub-indexes. The UNDP computes the simple mean of the four sub-indexes (one for each category of technology), while each sub-index is calculated as a simple mean of two indicators. Consequently, each component contributes 1/8 to the total value of the index. ArCo is the result of the simple mean of three sub-indexes (one for each category of technology) and each sub-index is the simple mean of the indicators belonging to each category (two indicators for the creation of technology category, three indicators for each of the other two). Therefore, UNDP and ArCo attribute the same importance to the sub-indexes composing the final indicator.

RAND offers different combinations of weights for the three sub-indexes analysed. The ranking considered here weights 1/2 the resources category and 1/4 of the other two categories (enabling factors and embedded knowledge). Inside each category, each component is given the same weight. The authors also suggest three other weighting schemes.

The WEF Technology Index differently weights the various components by splitting the sample between *core* and *non-core* countries. For the group of the *core* countries, the Technology Index is obtained as a simple mean of two sub-indexes: innovation sub-index and ICT sub-index (therefore, they contribute 1/2 each). For the *non-core* economies, a third sub-index-technology transfer is introduced. Consequently, the relative weights change: while ICT continues to contribute 1/2, the innovation sub-index contributes only 1/8, and the other 3/8 is contributed by the technology transfer index. The use of survey data by WEF also has implications for the statistical methodology. For each of the three sub-indexes, the soft data from the qualitative assessment is added to the hard data through a system of score conversion. This methodology presents some weaknesses: the division between *core* and *non-core* countries, the reliability of opinion surveys, and the method of aggregating hard and soft data are all questionable.

6. Comparing the ranking

We now move on to check the consistency of the results. We are dealing with typical ordinal (not cardinal) values. The method of construction of the indexes only allows comparison between the rankings, and not the absolute values. The first issue is to check how similar the rankings of countries are for the various studies; for this purpose, a rank correlation (Spearman index) is employed. The second issue is to identify how the position of individual countries changes between the use of one index and another. In spite of the methodological differences, do the four approaches lead to similar results? If the results are broadly similar, it is less relevant to examine further the nature of dissimilar methodologies. If, however, the results are substantially divergent, further work is needed. As shown above each team has considered a different group of countries. We must therefore consider the countries included in all of the approaches in order to make comparisons. Only 49 countries are included in all of the four works.

Table 2 shows the rankings provided by the four indexes (columns 1–4). Columns 5 and 6 display the rank mean and the standard deviation. The latter statistic signals the main divergences at the country level. We note a significant divergence of the four indexes regarding the position of Israel. In our ranking, it is 3rd; but it ranks 7th for RAND, 21st according to WEF, and 18th according to UNDP. This divergent pattern is due to the high number of Israeli patents granted at the US Patent Office, and to the substantial number of scientific articles published (this last indicator not being considered by the latter two works). WEF Technology Index diverges heavily from the other three concerning Japan, which gets a much lower ranking (19th) compared to UNDP (4th), ArCo (7th), and RAND (5th). This is due to the opinion survey data employed by WEF, which is strongly influenced by short-term factors rather than by structural characteristics. Noticeable differences also emerge for South Korea, Singapore, Hong Kong, and Malaysia. This suggests that it is easier to gather diverging results when measuring the catching-up and fast growing Asiatic countries, rather than Western economies whose data are more reliable and performance more predictable.

Table 3 shows the co-graduation matrix among the 47 countries reported in the four studies. Despite the significant differences in the position of some individual countries, there is a high correlation between each pair of indexes. The highest correlation coefficients are found between ArCo and RAND (0.97) due to use of common indicators and between ArCo and UNDP (0.96), which share the same methodology and some infrastructure and human skills indicators. Overall, ArCo and UNDP are the indexes with most correlation in the group. The WEF is the index with the lowest correlation with the others. The minimum correlation is found between WEF and RAND (0.88).

Table 4 shows the correlations among the rankings for the countries available for each couple of Indexes. This allows consideration of 75 coun-

Table 2
Rank correlation among WEF, UNDP, ArCo, and RAND for the common 47 countries

	1	2	3	4	5	6
	WEF	UNDP	ArCo	RAND	Rank mean	Standard deviation
US	1	2	4	1	2.0	1.41
Finland	3	1	2	4	2.5	1.29
Sweden	5	3	1	3	3.0	1.63
Canada	2	9	5	2	4.5	3.32
Australia	4	10	8	8	7.5	2.52
Norway	6	12	6	10	8.5	3.00
Japan	19	4	7	5	8.8	6.95
UK	8	7	11	9	88	1.71
Netherlands	11	6	9	12	9.5	2.65
Germany	12	11	10	6	9.8	2.63
South Korea	7	5	15	16	10.8	5.56
Israel	21	18	3	7	12.3	8.62
Belgium	10	14	13	13	12.5	1.73
New Zealand	9	15	12	17	13.3	3.50
Singapore	15	8	17	15	13.8	3.95
Austria	13	16	14	14	14.3	1.26
France	14	17	16	11	14.5	2.65
Ireland	23	13	18	18	18.0	4.08
Spain	22	19	20	21	20.5	1.29
Czech Republic	16	21	24	23	21.0	3.56
Italy	26	20	19	20	21.3	3.20
Slovenia	25	23	21	19	22.0	2.58
Hungary	17	22	25	26	22.5	4.04
Slovakia	24	24	23	25	24.0	0.82
Portugal	20	26	27	24	24.3	3.10
Greece	30	25	22	22	24.8	3.77
Poland	28	28	26	27	27.3	0.96
Malaysia	18	29	33	38	29.5	8.50
Bulgaria	38	27	28	28	30.3	5.19
Argentina	36	31	29	29	31.3	3.30
Chile	33	34	30	30	31.8	2.06
Costa Rica	27	33	34	34	32.0	3.37
Romania	35	32	31	31	32.3	1.89
Mexico	29	30	35	36	32.5	3.51
South Africa	34	35	32	32	33.3	1.50
Thailand	31	36	37	41	36.3	4.11
Brazil	37	37	38	35	36.8	1.26
Philippines	32	38	39	42	37.8	4.19
China	39	39	41	33	38.0	3.46
Peru	42	41	36	40	39.8	2.63
Bolivia	45	40	42	39	41.5	2.65
Ecuador	46	42	40	44	43.0	2.58
Egypt	43	43	44	43	43.3	0.50
India	44	46	47	37	43.5	4.51
Sri Lanka	40	45	43	47	43.8	2.99
Indonesia	41	44	45	46	44.0	2.16
Nicaragua	47	47	46	45	46.3	0.96

Sources: WEF (2001), UNDP (2001), Archibugi and Coco (2004), and Wagner et al. (2004).

Table 3
Correlation matrix among WEF, UNDP, ArCo, and RAND indexes: 47 countries[a]

	WEF	UNDP	ArCo	RAND	Mean
WEF	1.00	0.93	0.90	0.88	0.91
UNDP	0.93	1.00	0.96	0.95	0.95
ArCo	0.90	0.96	1.00	0.97	0.95
RAND	0.88	0.95	0.97	1.00	0.94

Sources: As for Table 2.
[a] The countries considered are the 47 ones reported in Table 2 and Spearman correlation coefficient.

tries for ArCo–WEF, 72 for ArCo–UNDP, 76 for ArCo–RAND, 58 countries for WEF–UNDP as well as for WEF–RAND, and 53 for RAND–UNDP. The results do not change substantially: ArCo–UNDP becomes the highest correlated couple instead of ArCo–RAND (0.98 versus 0.96), while the other hierarchies remain the same. WEF and (to a lesser extent) RAND produce the most divergent rankings.

We finally try to compare the results for two restricted sub-samples of nations (Table 5). The first sub-sample includes the first 23 countries, jointly considered the *leaders* from each of the studies reported while the second one the 24 *latecomer* countries. The purpose for attempting linear correlation coefficients also for sub-groups of countries is to test if the overall high-correlation coefficients reported in Tables 3 and 4 are just an artefact due to high polarization of the values among the countries at the top and at the bottom of the league. But the results do not change substantially. As expected, the correlation values are slightly lower due to the sample restriction, although all values continue to be rather high (above 0.60). Among the leaders, the highest covariance is found between ArCo and RAND, and the lowest between WEF and RAND. Among the latecomers, the higher correlation is between ArCo and UNDP, and the lowest between WEF and RAND.

Table 4
Rank correlation among WEF, UNDP, ArCo and RAND indexes for the countries common to every couple of indexes[a]

	WEF	UNDP	ArCo	RAND	Mean
WEF	1.00	0.93	0.88	0.85	0.89
UNDP	0.93	1.00	0.98	0.95	0.95
ArCo	0.88	0.98	1.00	0.96	0.94
RAND	0.85	0.95	0.96	1.00	0.92

Sources: As for Table 2.
[a] Number of countries considered: 58 for WEF–UNDP; 72 for WEF–ArCo; 58 for WEF–RAND; 76 for UNDP–ArCo; 53 for UNDP–RAND; and 76 for Arco–RAND and Spearman correlation coefficient.

7. Discussion

Indicators of technological capabilities are increasingly needed to understand how and why countries differ. A satisfactory quantification of current levels of technological capacity is required in order to understand why some countries innovate and have a more satisfactory performance than others. Even very aggregate indicators, such as those reviewed in this article, help to highlight the differences across countries and to identify their strengths and weaknesses. From an analytical viewpoint, it is increasingly recognised that it is feasible and useful to develop measures of technology that combine different data. The attempts reviewed here share many similarities, and this is certainly encouraging. These similarities reflect a certain consensus on the nature of technology, although in some cases, the theoretical hypotheses were kept implicit rather than made explicit. We are also aware that in many cases, the choices have been dictated by availability of the sta-

Table 5
Rank correlation among WEF, UNDP, ArCo, and RAND technology indexes for two sub-samples[a]

	First 23 countries (*leaders*)					Last 24 countries (*latecomers*)				
	WEF	UNDP	ArCo	RAND	Mean	WEF	UNDP	ArCo	RAND	Mean
WEF	1.00	0.70	0.69	0.68	0.69	1.00	0.83	0.74	0.60	0.72
UNDP	0.70	1.00	0.73	0.75	0.72	0.83	1.00	0.94	0.85	0.88
ArCo	0.69	0.73	1.00	0.92	0.78	0.74	0.94	1.00	0.87	0.85
RAND	0.68	0.75	0.92	1.00	0.78	0.60	0.85	0.87	1.00	0.78

Sources: As for Table 2.
[a] For the list of countries considered, see Table 2 and Spearman correlation coefficient.

tistical sources rather than by theoretical preferences. For example, we are confident that all the authors would have been happy to include data on R&D and on the stock of machinery and equipment; unfortunately, these measures are either not available or are available for a smaller number of countries only. We are also aware that a synthetic index inevitably incorporates a certain level of randomness. In fact, the indexes differ concerning the choice of the various technological dimensions (technology creation, diffusion, infrastructure, human skills), even if some common 'keystones' are maintained: the use of patents as an indicator of technology creation, the recurrence of ICT indicators for technological infrastructure and diffusion, and tertiary education in science and engineering as an indicator of human skills.

We also showed that the results are too frequently divergent. There is clearly a strong similarity in the rank correlations, but a similar position of countries would emerge even if taking entirely different social indicators into account (e.g. health indicators). Greater similarity in results should be achieved in order to make them more reliable.

This leads to the need to increase the efforts, and also the coordination, amongst the different attempts. Sources of data have increased, and new information technologies make data available in real time and in friendly formats. All the attempts reviewed here are fully transparent about the data sources and the methodology employed. We do not expect, and nor it is desirable, to generate a unique measure of technological capabilities: methodological variety helps to create a better understanding of social phenomena. Clearly the various teams are interested in slightly different aspects of technological change, and this has emerged in their choices as well as in their results. But even different and competing approaches can take advantage from coordination on the elaboration of the original data, and we encourage international organizations to pursue this goal. In fact, it is somewhat surprising that none of the approaches discussed here, with the notable exception of WEF, is established on a firm basis or periodically updated. The only database so far that is periodically updated and maintained is that of the World Bank (2003). The recent "Knowledge and Development" programme under the auspices of the World Bank represents a milestone in the field, and hopefully it will be able to continue to lead the way under increased coordination among the works reviewed here.[5]

Although the comparison here made is limited to synthetic indicators, we wish to emphasize the importance of more detailed and disaggregated data. Our attempt to test the consistency of the various measures has been carried out for a single "number", but this is meant as a first step towards a more comprehensive assessment of national technological capabilities. We are aware that the various "ingredients" of technological capability can be as relevant as the final measure. As already stressed above, two relevant exercises, UNIDO and KEM, have not bothered to generate a synthetic indicator and have concentrated their attentions on the various components. None of the works reviewed here underestimate the importance of the various components. When these measures are used to assess the impact of technological capabilities on economic and social indicators, we strongly recommend taking into account also the individual indicators and the sub-indexes. Indeed, we expect that each component will play a different role in each country, also on the ground of its overall development stage. And there is no shortage of statistical techniques, which allow singling out the relevance of each component of technological capabilities.

Moreover, we also point to the importance of looking at the sectoral compositions of certain indicators. Data on trade, patents, and bibliometrics are available at a highly disaggregated level and can inform about the content of the technological capabilities developed in each country. Not all fields are likely to be associated with a similar performance, and past experience has shown that newly industrialized countries managed to develop their technological capabilities also selecting a specialization in fields and industries of increasing returns and market shares.

We have also concentrated on a level of analysis: the country. Although there are good reasons to do so, we are aware that, in a globalising world, countries are not the only meaningful entity to study technological change. Regions and multinational corporations are equally important *loci* for technological competences (Cantwell and Iammarino, 2003) and can be taken as meaningful statistical units.

[5] In fact, three of the attempts reviewed here derive from UN bodies: UNDP, UNIDO, and World Bank.

In the early XVII century, when the Italian peninsula was leading scientific investigation, our compatriot Paolo Sarpi discussed the differences between the deductive and the inductive approaches to scientific investigation:

"There are four ways to philosophise: the first is through reasoning alone, the second directly from experience, the third by beginning with reason before moving to the evidence of the sense, and the fourth by starting from experience and finishing with reason. The first is bad, because you know what you are looking for, but not what it really is; the third is quite bad, because many times it obtains what we would like to know, and not what it is in reality; the second is true, but primitive, and it allows one to know very little, and more of what it is than its course; the fourth is the best which in this poor life we can reach" (Sarpi, 1605; p.14).

His views are certainly more widely shared today than four centuries ago, but it is not always easy to put into practice the scientific method he recommended. The works discussed in this paper are empirical in nature, but the very attempt they make to aggregate various components into a single measure relies upon theoretical hypotheses. Hopefully, this is just the beginning of the story since there is no statistical index that can prospered and improved without being used for analytical or policy purposes. These measures have been developed because there is an underlying assumption that technology is a crucial explanatory variable for aspects as different as growth rates, productivity, competitiveness, job creation, and well being (Juma et al., 2001). We hope that the new wealth of data will be used to gain a better understanding of the complex relationships between technology, development, and welfare. It would be highly advantageous if the current flourishing debate on technology and the wealth of nations were to be increasingly accompanied by empirical observations and not just by theoretical assumptions (Leontief, 1971).

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Appendix A

Annexure. Structure of the technological indexes

Authors	Synthetic index	Sub-indexes (weights)	Individual indicators (weights)	Sources	Formula to compare individual indicators	Years and countries
WEF (2001)	Technology Index for *core* countries (no. 21)	Innovation (1/2)	Patents granted at USPTO per capita (3/8)	USPTO (2001)	6[a](Observed value − minimum value)/(maximum value − minimum value) + 1; index range: [1,7]	[a]1997–2000; 75 countries
			Tertiary technical enrolment ratio (3/8)	UNESCO (2001)		
			Survey data (1/4)	WEF (2001)		
		ICT (1/2)	Internet hosts and users per capita (4/15)	World bank (2001)		
			Telephone mainlines and mobile per capita (4/15)	World bank (2001)		
			PCs per capita (2/15)	World bank (2001)		
			Survey data (1/3)	WEF (2001)		

Appendix A (*Continued*)

Authors	Synthetic index	Sub-indexes (weights)	Individual indicators (weights)	Sources	Formula to compare individual indicators	Years and countries
	Technology Index for *non-core* countries (no. 54)	Innovation (1/8)	Patents granted at USPTO per capita (3/8)	USPTO (2001)		
			Tertiary technical enrolment ratio (3/8)	UNESCO (2001)		
			Survey data (1/4)	WEF (2001)		
		ICT (1/2)	Internet hosts and users per capita (4/15)	World Bank (2001)		
			Telephone mainlines and mobile per capita (4/15)	World Bank (2001)		
			PCs per capita (2/15)	World Bank (2001)		
			Survey data (1/3)	WEF (2001)		
		Technology transfer (3/8)	Residual of non-primary exports on GDP (1/2)	UN (2000), Statistics Canada (1998)		
			Survey data (1/2)	WEF (2001)		
UNDP (2001), Desai et al. (2002)	Technology Achievement Index (TAI)	Technology creation (1/4)	National granted patents per capita (1/2)	WIPO (2001)	(Observed value − minimum value)/(maximum value − minimum value); index range: [0,1]	1995–2000; 72 Countries
			Royalties receipts and license fees per capita (1/2)	World Bank (2001)		
		Diffusion of new innovations (1/4)	Internet hosts per capita (1/2)	ITU (2001)		
			Medium- and high-technology exports share in total exports (1/2)	UN (2001), Lall (2001a)		
		Diffusion of old innovations (1/4)	Telephone mainlines and mobile per capita (1/2)	ITU (2001)		
			Electricity consumption per capita (1/2)	World Bank (2001)		
		Human skills (1/4)	Mean years of schooling over 14 (1/2)	Barro and Lee (2001)		
			Tertiary science, math, and engineering enrolment ratio (1/2)	UNESCO (1998–2001)		

Appendix A (*Continued*)

Authors	Synthetic index	Sub-indexes (weights)	Individual indicators (weights)	Sources	Formula to compare individual indicators	Years and countries
Archibugi and Coco (2004)	Indicator of technological capabilities (ArCo)	Technology creation (1/3)	Patents granted at USPTO per capita (1/2)	USPTO (2002)	(Observed value – minimum value)/(maximum value – minimum value); index range: [0,1]	1987–1990; 1997–2000; 162 countries
			S&T publications per capita (1/2)	NSF (2000, 2002)		
		Technology infrastructure (1/3)	Internet users per capita (1/3)	ITU (2001)		
			Telephone mainlines and mobile per capita (1/3)	ITU (2001)		
			Electricity consumption kWh per capita (1/3)	World Bank (2001)		
		Human skills (1/3)	Tertiary science & engineering enrolment ratio (1/3)	UNESCO (2002)		
			Mean years of schooling over 14 (1/3)	Barro and Lee (2001)		
			Literacy rate (1/3)	UNDP (2001)		
UNIDO (2002), Lall and Albaladejo (2001)	None	Technological effort	Patents granted at USPTO per capita (1/2)	USPTO (2002)	(Observed value – minimum value)/(maximum value – minimum value); index range: [0,1]	1997–1998; 72 countries
			Enterprise financed R&D per capita (1/2)	UNESCO (1994, 1998); OECD (1999)		
		Competitive industrial performance	Manufactured value added per capita (1/4)	UNIDO database		
			Medium- and high-technology share in manufactured value added (1/4)	UNIDO database		
			Manufactured exports per capita (1/4)	UN Comtrade database (2001)		
			Medium- and high-technology share in manufactured exports (1/4)	UN Comtrade database (2001)		
		Technology imports	FDI per capita (1/3)	UNCTAD (1999), World Bank (2000)		

Appendix A (*Continued*)

Authors	Synthetic index	Sub-indexes (weights)	Individual indicators (weights)	Sources	Formula to compare individual indicators	Years and countries
			Foreign royalties payments per capita (1/3)	World Bank (2000), IMF (1999)		
			Capital goods per capita (1/3)	UN Comtrade database (2001)		
		Skills	Tertiary technical enrolment ratio	UNESCO (1998)		
		Infrastructure	Telephone mainlines per capita	World Bank (2001)		
Wagner et al. (2003) RAND Corporation	Science and Technology Capacity Index (STCI)	Enabling factors (1/4)	GDP per capita (1/2)	UNDP (2003)	(Observed value – mean value)/(standard deviation); index range: [−∞, +∞]	1995–2000; 76 countries
			Tertiary science enrolment ratio (1/2)	UNDP (2003)		
		Resources (1/2)	R&D expenditure on GDP (1/3)	UNDP (2003)		
			Number of institutions per capita (1/3)	UNDP (2003)		
			Scientists and engineers per capita (1/3)	UNDP (2003)		
		Embedded knowledge (1/4)	Patents granted at USPTO per capita (1/3)	USPTO (2002)		
			S&T publications per capita (1/3)	NSF (2000)		
			Co-authored scientific articles (1/3)	NSF (2000)		

[a] WEF publishes a report every year; therefore, the covered years and the number of countries are continuously up-dated. In the last available one (2003), the last year considered is 2003 and the number of countries has been increased to 102.

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