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# A New Indicator of Technological Capabilities for Developed and Developing Countries (ArCo)

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**Summary.** — This paper devises a new indicator (ArCo) of technological capabilities that aims at accounting for developed and developing countries. Building on similar attempts as those devised by UN Agencies, including the UNDP Human Development Report's Technology Achievement Index (TAI) and UNIDO's Industrial Performance Scoreboard, this index takes into account a number of other variables associated with technological change. Three main components are considered: the creation of technology, the technological infrastructures and the development of human skills. Eight subcategories have also been included. ArCo also allows for comparisons between countries over time. A preliminary attempt to correlate ArCo to GDP is also presented.


*Key words* — technology creation, infrastructures, human skills, development index

## 1. INTRODUCTION: SCOPE, RELEVANCE AND ASSUMPTIONS

Technological capabilities have always been a fundamental component of economic growth and welfare. One of their key characteristics is that they are far from being uniformly distributed across countries, regions and firms. Knowledge production is largely concentrated in a few highly industrialized countries. The access to new and old knowledge, in spite of international trade, communications, foreign direct investment, public policies promoting scientific cooperation and many other channels of technology transfer, is a long way away from being geographically homogenous. A few countries constantly upgrade their knowledge-base while the majority of them lag behind and have many difficulties absorbing capabilities that are already considered obsolete in other parts of the world.

The determinants of the generation, transmission and diffusion of technological innovation have been studied both from the theoretical and empirical viewpoint in a large body of literature (Pietrobelli, 2000). But the

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current understanding of the devices of technology creation and transfer is still inadequate, in part due to the lack of detailed indicators of technological change. This paper presents a new index of technological capabilities, ArCo, for a large number of countries. It builds on many lessons learned of the nature of technological change and on other previous attempts to measure it, including the latest Technology Achievement Index (TAI) presented by the UN's Human Development Report (UNDP, 2001) and the UN Industrial Performance Scoreboard (UNIDO, 2003).

Among the lessons learned on the measurement of technological capabilities, we wish to recall the following:

—The technological capabilities of a country are composed of a variety of sources of knowledge and of innovation. A comprehensive measure should be able to account for the activities that are codified as well as for those that are tacit (Lundvall, 1992). Some of the capabilities are disembodied, such as new ideas and inventions. Others are embodied in equipment, machinery and infrastructures, while still others are embodied in human skills (Evangelista, 1999; Pianta, 1995; Smith, 1997).

—Technological capabilities are composed of clusters of innovations associated with different waves of industrial development (Freeman & Louta, 2001).

—The integration of new technology systems requires the mastering of previous technologies, allowing economic agents to build competencies in a cumulative manner (Bell & Pavitt, 1997; Pavitt, 1988a). Often new systems make previous ones obsolete (Juma & Konde, 2002). As Schumpeter remarked, "add as many mail-coaches as you please, you will never get a railroad by doing so."

—The various sources of technological capability are more likely to be complementary rather than interchangeable. First rate infrastructures devoid of a sufficiently qualified labor force will be useless and *vice versa* (Abramovitz, 1989, Maddison, 1991). Moreover, successful integration among the various waves of innovations has the effect of multiplying its economic and social impact (Antonelli, 1999; Amable & Petit, 2001).

—The creation and improvement of technological capabilities involve a crucial element of technological "effort." Access to advanced technology is a necessary condition, but it needs to be accompanied by substantial and purposeful investments for it to be absorbed, adopted and learned (Pietrobelli, 1994; Lall, 2001a).

—Since the differences across countries' technological capabilities are colossal, a measure to account for them meaningfully should consider the components that are specific to both developed and developing countries (Lall, 2001a).

Our work has been inspired by a variety of attempts to generate measures of technological capabilities. Even when we departed from previous statistical exercises, we benefited from their methodology. In particular, we wish to mention, besides the already cited Technology Achievement Index (UNDP, 2001) and the Industrial Development Scoreboard (Lall & Albaladejo, 2001; UNIDO, 2003), also the Technology Index of the World Economic Forum's *Global Competitiveness Report* (WEF, 2002), and the critical analysis by Lall (2001b). Throughout the paper, we specify when we have followed these approaches and when, and why, we have opted for alternative paths. [1]

It should be noted that statistics of technological activities for the restricted group of the 30 most developed countries could be much more sophisticated in terms of coverage and significance. For this group of leading countries, many more indicators are available (and the quality of the data is much more satisfactory than for other countries). If we were to limit our analysis to this restricted number of countries, we would have used different indicators and methodology (for a discussion of the various attempts to measure scientific and technological capabilities of advanced countries see Archibugi & Pianta, 1992; Patel & Pavitt, 1995). It is hardly surprising that data for the selected number of countries that concentrate the bulk of inventive and innovative activities are much richer. The attempt here is to provide measures for a much larger group of countries which, as a whole, have a much more limited level of technological capabilities. Monitoring the existing capabilities will permit, to identify of the nature and intensity of the technology gap and the appropriate strategies to bridge it.

This analysis is based upon a number of assumptions. First, we assume that a comparative analysis *across* countries is meaningful (Sirilli, 1997). In spite of the enormous difference across countries (how can one describe in a single number the technology gap between

Switzerland and Somalia?), countries can be compared. But we also assume that a battery of indicators could provide a more comprehensive picture of the differences than a single indicator would. The statistics produced achieve greater significance when considering homogeneous groups of countries and allow comparisons between countries geographically, culturally and economically close to each other, (such as, for example, Switzerland and Germany, Somalia and Ethiopia. For a discussion, see Pietrobelli, 1994).

Second, we assume that a country-level analysis still proves useful despite the enormous differences found *within* countries. Synthetic indicators for countries as large as China or India inevitably overestimate the technological capabilities of certain areas and underestimate the capabilities of others. This also applies to countries with much higher technological capabilities such as, for example, the United States and Japan. Moreover, recent research on technological agglomerations (Cantwell & Iammarino, 2003) showed that technological activities tend to cluster in a few hubs even in the most technologically advanced countries. Still, the notion of national systems of innovation (see Andersen, Lundvall, & Sorrn-Friese, 2002; Edquist, 1997; Freeman, 1997; Lundvall, 1992; Nelson, 1993) indicates that it makes sense to analyze the technological capabilities of territorial states, since these provide one of the main institutional settings for know-how generation and diffusion The same analysis has already been successfully applied to developing countries (see Cassiolato & Lastres, 1999, and Sutz, 1997, for Latin America; Hobday, 1995, for Asia; Lall & Pietrobelli, 2002 for Africa).

Third, although we measured technological capabilities with a variety of indicators, we made an attempt to provide a synthetic indicator. Other exercises made an effort to estimate countries' technological capabilities by aggregating data at the firm level. Unfortunately, this approach has not yet been able to generate data for larger groups of countries. Our measure is typically a macro-economic one and, at the country level, it is composed of a selected number of indicators. In spite of the limitations of a synthetic indicator, we share with the UNDP, UNIDO and WEF the belief that the various components singled out could be added up in order to provide a more comprehensive measure of technological activities.

## 2. CHANGES COMPARED TO PREVIOUS ANALYSES

We built upon the TAI attempt developed by UNDP (Desai, Fukuda-Parr, Johansson, & Sagasti, 2001; UNDP, 2001), and the Industrial Development Scoreboard developed by UNIDO (Lall & Albaladejo, 2001; UNIDO, 2003). The TAI takes into account many indicators, by classifying them in four categories: the creation of technology, the diffusion of new technology, the diffusion of old technology, and human skills. We considered this a more effective starting point than the index suggested by the WEF (2002). The UNIDO Industrial Development Scoreboard divides a battery of indicators into two broad groups: the first deals with competitive industrial performance (including manufacturing value-added per capita, manufactured exports per capita, share of medium- and high-tech industries in manufacturing value-added and share of medium- and high-tech in manufactured exports); the second concerns industrial capabilities (including foreign direct investment per capita, foreign royalty payments per capita, tertiary technical enrolments, enterprise financed R&D per capita, and the infrastructure as measured by telephone main lines). The main modifications we introduced to these two indexes are the following.

### (a) *Enlarge the number of countries examined*

In order to enlarge the number of countries examined, without losing data and source coherence, we focused on indicators whose coverage was more satisfactory. We took into account both the availability of data and the dimension of population: we neglected countries with less than 500,000 inhabitants, except for those countries (Luxembourg, Malta, Cyprus and Suriname) for which we retained sufficient data. For those countries for which data proved analytically insufficient (as for most African countries), missing values were estimated on the basis of national sources, interviews with country experts, and performance in comparatively similar countries and indicators. In extreme cases, minimum values were taken for groups of comparable countries (often equivalent to zero, due to the conditions of extreme poverty of some of the countries analyzed). Our pool is comprised of 162 countries in total.

### (b) *Allowing comparisons over time*

In addition to crosscountry comparisons, we attempted time-series comparisons. The purpose of the TAI was not to compare countries at different time points but to perform cross-country comparisons at particular time points. Standardized indicators from 0 to 1 were built according to the following formula:

$$\frac{\text{Observed value} - \text{Minimum observed value}}{\text{Maximum observed value} - \text{Minimum observed value}}.$$

In TAI, all observed values referred to the same time period. Since maximum and minimum observed values are subject to change over time, time comparisons are impossible. In addition, the Industrial Development Scoreboard presents a time-series comparison for 1985–98.

In order to allow for time-series comparisons, a maximum and a minimum value were fixed for ArCo, so that both would result identical for both the time points considered (a current period which oscillates from 1997 to 2000 and a past period from 1987 to 1990). Given that during the two time points considered the majority of countries under observation experienced progress of some kind, the minimum observed value was taken from the past period, while the maximum observed value was taken from the most current one. Consequently, homogeneous indicators for all time periods were devised with the certainty that no country would express a passed minimum value higher than the more recent one. In other words, no index in the past could ever overcome the value of 1. The formula for this new indicator can be summarized as:

$$I_x = \frac{\text{Obs}_{\text{present}} - \text{Min}_{\text{past}}}{\text{Max}_{\text{present}} - \text{Min}_{\text{past}}}$$

Since the literacy rate indicator is known to oscillate between the values of 0% and 100%, these were taken automatically as the minimum and maximum goalposts (therefore eliminating the need for minimum and maximum observed values for this indicator).

## 3. THE ARCO TECHNOLOGY INDEX

Three main dimensions of technological capabilities were considered:

—the creation of technology;
—the technological infrastructures;
—the development of human skills.

The choice was based on the assumption that the three components play a comparative role in the making of a country's technological capabilities. Thus, the overall Technology Index (ArCo) has been built upon the equal weighting of the three mentioned categories (each of which is indexed). [2] The ArCo index formula can therefore be sketched as:

$$\text{ArCoTI} = \sum_{i=1}^{3} \lambda_i I_i,$$

where $I_i$ represents the three indexes (technology creation, actual technology infrastructures and actual human skills) for each country and $\lambda_i$ are the constants of 1/3.

The index of each category is calculated by the same procedure used for the overall index, that is, through the simple mean of certain subindicators. In total we considered eight basic indicators: two for the first category and three for the second and the third. The eight subindexes are the following:

(a1) patents;
(a2) scientific articles;
(b1) Internet penetration;
(b2) telephone penetration;
(b3) electricity consumption;
(c1) tertiary science and engineering enrolment;
(c2) mean years of schooling;
(c3) literacy rate.

The following is a detailed explanation of each indicator:

### (a) *Creation of technology*

#### (i) *(a1) Patents*

Patents are one measure of accounting for the technological innovations generated for commercial purposes. They represent a form of codified knowledge generated by profit-seeking firms and organizations. Among the various patent sources (for surveys on patents as internationally comparable indicators, see Archibugi, 1992; Pavitt, 1988b), we considered patents granted in the United States. Since the latter is the largest and technologically more developed market of the world, it is reasonable to assume that important inventions and innovations are legally protected in the US market. The TAI considers those patents that are taken out by individuals in their home country. Such data were not used here since countries exhibit significant legal differences—for example, the very high number of patented inventions registered by Japanese and Korean inventors at their national patent offices is also associated with the legal practice that requires inventors to file an application for each claim.

The patent index is based on utility patents (that is, invention patents) registered at the US Patent and Trademark Office (USPTO, 2002). Patents taken out in the United States by the inventor's country of residence were considered. The USPTO receives a greater number of foreign patent applications than any other patent office. Despite the fact that many inventions are never patented, especially in developing countries, patents represent nevertheless a good proxy for commercially exploitable and proprietary technological inventions.

The propensity of US inventors to register inventions in their own national patent office is higher than that of foreign inventors. To eliminate the bias toward US domestic patents, we replaced the effective number of domestic patents with our own estimation. The latter is based on a comparison between the Japanese and the US patents registered at the European Patent Office (EPO), which represents a foreign institution both for Japanese and American inventors. We used the following estimation:

Estimated US domestic patents

$$= (JAP_{USA} \times USA_{EPO})/JAP_{EPO},$$

where $JAP_{USA}$ is the effective number of patents granted to Japanese inventors in the United States, and $USA_{EPO}$ and $JAP_{EPO}$ are the effective number of patents granted to US and Japanese inventors at the European Patent Office. Proportions for patents granted in Japan to European inventors were also estimated and appeared not to exhibit any major differences.

The number of patents for each country was normalized by dividing it for the country's respective population (the number of patents was expressed for a million people). In order to account for the effects that yearly fluctuations might have on the results obtained from small- and medium-sized countries, a four-year moving average for 1987–90 and 1997–2000 was considered.

The goal posts were set as the maximum and the minimum observed value for 1997–2000 (230 for the maximum value—corresponding to Japanese patents for a million people—and zero for the minimum value) and the standardized patent activity index was constructed by application of the general formula, with values oscillating between zero and one. As explained above, in order to allow for comparisons to be made across time as much as across geographical borders, the same goal-posts were kept for the previous years, so that a comparable index for 1987–90 could be calculated while allowing us to evaluate each country's growth rate during the two points in time.

(ii) *(a2) Scientific articles*

Scientific literature is another important source of codified knowledge. It represents the knowledge generated in the public sector, and most notably in universities and other publicly funded research centres, although researchers working in the business sector also publish a significant share of scientific articles.

There is no single source of information concerning all the scientific literature published in the world. We were forced to rely on the available, if limited, sources. Among them, the most comprehensive and validated is the Science Citation Index generated by the Institute for Scientific Information. The index reports information concerning the scientific and technical articles published in a sample of about 8,000 journals selected among the most prestigious in the world. The fields covered are: physics, biology, chemistry, mathematics, clinical medicine, biomedical research, engineering and technology, and earth and space sciences.

It is often argued that the journals in this sample are biased toward English-speaking countries. Although there is some evidence supporting this claim, it might be more accurate to state that journals reflect the most visible part of the scientific literature, while they ignore other important components in both developed and developing countries—though we believe the data source do not discriminate heavily against developing countries. It is certainly significant that late industrializing countries have begun to be active in both patenting and scientific publications (see Amsden & Mourshed, 1997).

Data were taken from the US National Science Foundation's most recent publications (NSF, 2000, 2002) and the World Bank's database. [3] Article counting was based on fractional assignments: for example, an article written by two authors in two different countries was counted as one-half article to each country. [4] Switzerland scored the highest number of articles for 1997–99 with 977 annual articles per million people, while the minimum goal post was zero for many countries with no published scientific articles.

Data on R&D would have nicely complemented the measure of national technological creation, especially since they document developing countries' learning effort for acquiring scientific and technological expertise. This source however, was not employed due to a lack of available data for all countries (see UNESCO, 2002; World Bank, 2003, Table 5.12). UNIDO (2003) reported these data for 87 countries only, and for 16 of them the values prove negligible. Moreover, some developing countries tend to include some activities in R&D statistics that do not fit the standard OECD Frascati Manual definitions (OECD, 2002). The advantage of using patents and scientific articles consists of both sets of data being validated by external sources as much as by national ones (the US Patent Office in the first case, and the academic journals monitored by the Institute for Scientific Information in the second). This guarantees that individual observations are collected according to standard criteria. A rank correlation was calculated between the hierarchy of countries according to US patents per million population and the enterprise financed R&D per capita (employed in UNIDO, 2003). The result for the 61 countries with available data proved very high, with a value of 0.92 (Archibugi & Coco, 2004), demonstrating that a combination of patents and scientific articles provide a robust measure of national technological efforts also comprising R&D inputs.

### (b) *Technological infrastructures*

We considered three different indicators of technological infrastructures: Internet, telephony and electricity. They correspond to three major industrial revolutions of the 20th century (Freeman & Louta, 2001). They are basic infrastructures for economic and social life. Although they are not necessarily connected to industrial capabilities, production knowledge is strongly associated to their availability and diffusion.

#### (i) *(b1) Internet penetration*

The Internet is a vital infrastructure not only for business purposes, but also for access to knowledge. Internet users access a worldwide network. They differ from Internet hosts, which are computers with active Internet Protocol (IP) addresses connected to the Internet. The data on users, when available, are preferable to those on hosts for two reasons: first, they give a more precise idea about the diffusion of Internet among the population; second, some hosts do not have a country code identification and in statistics are assumed to be located within the United States, therefore causing a bias. The source here used was the World Bank (see also World Bank, 2003, Table 5.11), which extracted the data from ITU (2001) (the same data are employed in UNDP, 2001).

In order to compare the penetration of the Internet among the different countries we divided the number of users by population. The maximum goal post is 540 per 1,000 people, value belonging to Iceland, while the minimum is zero, observed both in the recent and in the past period for some very poor countries. The internet is a new technology that has quickly become the keystone of the Information and Communication Technology, but it was not yet commercially available in 1989–90. For this reason, we postponed the past period to 1994 so that data referred to a time interval of five instead of 10 years.

#### (ii) *(b2) Telephone penetration*

Telephony, besides its civilian component, is also a fundamental infrastructure for business purposes, and it allows tracing populations with human skills and acquiring technical information. Telephone mainlines are telephone lines connecting a customer's equipment to the public switched telephone network. They are another fundamental infrastructure for economic and social life. Data are presented per 1,000 people for the entire country (for more information, see World Bank, 2003, Table 5.10) both by World Bank database and UNDP (2001), which both collected the data from ITU (2001). To main lines, we added mobile phones per 1,000 people, since they represent the natural evolution of telecommunication. An equal weight was assigned to older and newer telephonic component since they share the same function despite incorporating different degrees of technology.

As telephony represents a definitively acquired form of technology for a large number of countries (the developed ones), we expressed the sums between fixed and mobile lines in natural logarithms. This ensures that, as the level of telephony increases (therefore as we move toward the more developed countries), the difference between the new and the old (lower) value expressed in logarithms decreases, consequently reducing the gap among countries, for the exception of those countries with very low initial values. In other words, the use of log creates a threshold above which the technological capacity of a country is no longer enriched by the use of telephones.

Furthermore, since many countries can said to have reached the desired level of telephony penetration, the chosen goal value for the calculus of the index was not taken as the maximum observed value, but the OECD average (960 telephones for 1,000 people). This not only increases the index for all countries, but also allows to eliminate useless differences among all those countries whose telephony share is superior to the mean one (they all get the value one). Therefore, as the minimum observed value is zero (transformed to one due to the use of logarithms), the formula becomes:

$$\frac{\text{Ln (observed value)}}{\text{Ln (OECD average)}}.$$

(iii) *(b3) Electricity consumption*

Electric power consumption (kilowatt per hour per capita) measures the production of power plants and combined heat and power plants, less distribution losses, and own use by heat and power plants (for more information, see World Bank, 2003, Table 5.10). This indicator accounts for the oldest technological infrastructure. Electricity consumption is also a proxy measure for the use of machinery and equipment, since most of it is generated by electric power. Although we are aware that this is likely to be larger for capital-intensive industries than for services, we believe that the use of logs provides values that respond to the real use of machinery and equipment. Other valuable measures of industrial capacity developed, for example, by Lall and his colleagues (see Lall & Albaladejo, 2001; UNIDO, 2003) are available for a smaller number of countries only.

The observations on the telephony index over the use of logarithms and the adoption of the OECD average as the maximum goalpost, apply *a fortiori* for the electricity consumption index. The OECD average corresponded to 8,384 kwh per capita, whilst Ethiopia (1989–90) produced the minimum value of 17 kwh per capita. For those other low-income countries whose data were not available a minimum estimate was calculated.

Data on high technology production and trade were not included. Although various sources provide this kind of data (UNDP, 2001; UNIDO, 2003; World Bank, 2003), some problems emerge. Concerning high-tech production, data for many countries are missing. Moreover, available data are not always reliable, especially concerning production, since they are derived from national sources, which often apply different criteria for defining high-tech sectors. Concerning high-tech trade, high exports can simply imply high imports (as in the case of Singapore and Hong Kong). Moreover trade, including high-tech, is strongly associated to the size of a country's economy: large countries have a lower propensity to trade than small ones do, and *vice versa*. It was not possible to produce an index able to account for intraindustry trade and size, however a comparison of ArCo with high-tech imports data is attempted in Section 7.

Measures of capital equipment and machinery were not included either, despite these representing a key component of embodied technological capacity vital both for developed and developing countries (Evangelista, 1999; Pianta, 1995; Scott, 1989). The closest substitute would be gross fixed capital formation, which is also available for a large number of countries in the World Bank data base (World Bank, 2003, Table 4.9). This measure, however, was not accounted for either since: (i) it is not possible to separate the component of gross capital formation devoted to investment in capital equipment and machinery from other forms of investment; and (ii) the indicator is expressed in monetary values, which would make it difficult to link ArCo to other currency-based economic variables.

### (c) *The development of human skills*

Technological capabilities are strongly associated with human skills. Disembodied knowledge (as measured by patents and scientific literature) and technological infrastructures (as measured by the Internet, telephony and electricity) have little value unless used by experienced people. To complement our index, we took into account three different measures of human skills.

(i) *(c1) Tertiary science and engineering enrolment*

The indicator considered the share of university students enrolled in science and engineering related subjects in the population of that age group. This indicator provides an estimate of the science and technology human capital, through the creation of a skilled human base. It is obtained by multiplying two percentages, which are gross tertiary enrolment ratio and percentage of tertiary students in science and engineering.

The gross tertiary enrolment ratio is the ratio of total enrolment at the tertiary level, regardless of age, to the population of the age group that officially corresponds to the level of education considered. Tertiary education, whether or not to an advanced research qualification, normally requires, as a minimum condition for admission, the successful completion of education at the secondary level (for more information, see World Bank, 2003, Table 2.12). Data were gathered from the World Bank data set—originally produced by UNESCO (2002).

Science and engineering students include students at the tertiary level in the following fields: engineering, natural science, mathematics and computers, and social and behavioral science. By multiplying the two percentages, we obtained the desired indicator. The maximum value was scored by Finland in 1998 with a value of 32.6%, while the minimum value scored was zero for more than one country. This indicator rests on an implicit assumption, namely that the quality of education provided across countries is comparable. On the contrary, we are aware that the quality of education, and the successful completion of education, is subject to great variation across countries. The capability of developing countries is probably overestimated in our analysis, while the capability of developed countries is probably subject to underestimation. The completion of courses is not accounted for since it is assumed that enrolment in science- and engineering-related subjects contributes to the technological capability of a country independently as to whether courses are completed.

(ii) *(c2) Mean years of schooling*

They represent the average number of years of school completed in the population over 14. Although this indicator does not consider differences in the quality of schooling, it gives an indication of the human skill level (the "stock"). The sources are the UNDP (2001), which collected an elaboration by Barro and Lee (2001), [5] and World Bank (2003, Table 2.13). The maximum goalpost is 12 and corresponds to United States' mean years of schooling, while the minimum value (0, 7) was observed in Mali (zero index was extended to other poor countries without available data). Even for this indicator we had to implicitly assume the level of education to be comparable across countries.

(iii) *(c3) Literacy rate*

Literacy rate represents the percentage of people over 14 who can, with understanding, read and write a short, simple statement about their everyday life. Data were collected from World Bank (2003) and UNDP (2001) (for more information, see World Bank, 2003, Table 2.14). This indicator allows performing a better distinction between the less-developed countries. We considered the literacy rate as a necessary condition for the development of human ability. In this case the index oscillates between zero and 100%, which consequently represent the minimum and the maximum goalpost.

A final note about *population*, which is the base for the calculus of the pro capita indexes. It is based on the *de facto* definition of population, which counts all residents regardless of legal status or citizenship, except for refugees not permanently settled in the country of asylum, who are generally considered part of the population of their country of origin (for more information, see World Bank, 2003, Tables 1.1 & 2.1).

An interesting feature of the indicator here devised is that none of the eight individual components is based, directly or indirectly, on monetary values. This means that it could be matched by indicators expressed in monetary value without any risk of collinearity. For instance, it could be compared to indicators such as international trade (including trade in high-tech products), value added per employee (which is often used as a measure for productivity), gross capital formation (a measure of investment, including investment in capital goods), and, of course, GDP and its growth. The full database can be freely downloaded at http://www.danielearchibugi.org/pdf/Theory_Measurement_Techn_Change/ArCo_Index.xls.

## 4. THE RESULTS AT THE COUNTRY LEVEL

Results do not differ in a revolutionary manner from other similar studies, but a number of fresh considerations can be made. First of all, we tried, as in the TAI case, to group the 162 examined countries in different blocks, by classifying them along with the level of the overall

Table 1. *A composite index of technological capabilities across countries (ArCo), 1990–2000*

| Actual ranking | | Current ArCo Technology Index | Past ArCo Technology Index | Past ranking | Growth rate from the last decade (%) |
|---|---|---|---|---|---|
| 1 | Sweden | **0.867** | 0.681 | 2 | 27.2 |
| 2 | Finland | **0.831** | 0.614 | 6 | 35.2 |
| 3 | Switzerland | **0.799** | 0.735 | 1 | 8.7 |
| 4 | Israel | **0.751** | 0.669 | 4 | 12.2 |
| 5 | United States | **0.747** | 0.663 | 5 | 12.6 |
| 6 | Canada | **0.742** | 0.678 | 3 | 9.4 |
| 7 | Norway | **0.724** | 0.581 | 9 | 24.6 |
| 8 | Japan | **0.721** | 0.569 | 12 | 26.8 |
| 9 | Denmark | **0.704** | 0.584 | 8 | 20.6 |
| 10 | Australia | **0.684** | 0.561 | 14 | 21.9 |
| 11 | Netherlands | **0.683** | 0.571 | 10 | 19.7 |
| 12 | Germany | **0.682** | 0.593 | 7 | 15.0 |
| 13 | United Kingdom | **0.673** | 0.562 | 13 | 19.8 |
| 14 | Iceland | **0.666** | 0.484 | 18 | 37.8 |
| 15 | Taiwan | **0.665** | 0.436 | 22 | 52.6 |
| 16 | New Zealand | **0.645** | 0.570 | 11 | 13.3 |
| 17 | Belgium | **0.642** | 0.523 | 15 | 22.7 |
| 18 | Austria | **0.619** | 0.502 | 16 | 23.4 |
| 19 | Korea, Rep. | **0.607** | 0.415 | 31 | 46.3 |
| 20 | France | **0.604** | 0.499 | 17 | 21.0 |
| 21 | Singapore | **0.573** | 0.397 | 37 | 44.5 |
| 22 | Hong Kong, China | **0.569** | 0.435 | 24 | 30.8 |
| 23 | Ireland | **0.567** | 0.450 | 20 | 26.0 |
| 24 | Italy | **0.526** | 0.444 | 21 | 18.5 |
| 25 | Spain | **0.516** | 0.410 | 34 | 25.8 |
| 26 | Slovenia | **0.507** | 0.412 | 33 | 23.1 |
| 27 | Greece | **0.489** | 0.416 | 30 | 17.5 |
| 28 | Luxembourg | **0.486** | 0.426 | 27 | 13.9 |
| 29 | Slovak Republic | **0.481** | 0.428 | 26 | 12.3 |
| 30 | Russian Federation | **0.480** | 0.464 | 19 | 3.4 |
| 31 | Czech Republic | **0.475** | 0.432 | 25 | 9.9 |
| 32 | Estonia | **0.472** | 0.413 | 32 | 14.4 |
| 33 | Hungary | **0.469** | 0.402 | 36 | 16.8 |
| 34 | Poland | **0.465** | 0.393 | 39 | 18.3 |
| 35 | Portugal | **0.450** | 0.346 | 53 | 30.0 |
| 36 | Bulgaria | **0.449** | 0.435 | 23 | 3.2 |
| 37 | Cyprus | **0.440** | 0.384 | 41 | 14.4 |
| 38 | Latvia | **0.439** | 0.423 | 29 | 3.7 |
| 39 | Belarus | **0.431** | 0.403 | 35 | 6.8 |
| 40 | Argentina | **0.426** | 0.379 | 45 | 12.5 |
| 41 | Chile | **0.424** | 0.336 | 57 | 26.2 |
| 42 | Ukraine | **0.417** | 0.426 | 28 | −2.2 |
| 43 | Uruguay | **0.417** | 0.348 | 52 | 19.9 |
| 44 | Croatia | **0.414** | 0.376 | 46 | 10.3 |
| 45 | Bahrain | **0.410** | 0.355 | 49 | 15.4 |
| 46 | Lithuania | **0.408** | 0.380 | 43 | 7.4 |
| 47 | Kuwait | **0.405** | 0.380 | 44 | 6.7 |
| 48 | Moldova | **0.395** | 0.394 | 38 | 0.2 |
| 49 | United Arab Emirates | **0.394** | 0.321 | 63 | 23.1 |
| 50 | Romania | **0.393** | 0.383 | 42 | 2.5 |
| 51 | Panama | **0.382** | 0.337 | 56 | 13.3 |

(*continued next page*)

Table 1—(*continued*)

| Actual ranking | | Current ArCo Technology Index | Past ArCo Technology Index | Past ranking | Growth rate from the last decade (%) |
|---|---|---|---|---|---|
| 52 | Kazakhstan | **0.381** | 0.393 | 40 | −2.8 |
| 53 | Trinidad and Tobago | **0.380** | 0.348 | 51 | 9.3 |
| 54 | Qatar | **0.380** | 0.353 | 50 | 7.6 |
| 55 | Georgia | **0.379** | 0.371 | 47 | 2.3 |
| 56 | South Africa | **0.372** | 0.334 | 58 | 11.1 |
| 57 | Lebanon | **0.370** | 0.292 | 72 | 26.5 |
| 58 | Malaysia | **0.369** | 0.295 | 69 | 25.2 |
| 59 | Venezuela, RB | **0.369** | 0.328 | 60 | 12.4 |
| 60 | Costa Rica | **0.361** | 0.322 | 62 | 12.2 |
| 61 | Malta | **0.361** | 0.325 | 61 | 10.9 |
| 62 | Yugoslavia, Fed. Rep. | **0.358** | 0.334 | 59 | 7.2 |
| 63 | Mexico | **0.358** | 0.320 | 64 | 11.8 |
| 64 | Tajikistan | **0.356** | 0.369 | 48 | −3.6 |
| 65 | Turkey | **0.347** | 0.286 | 75 | 21.4 |
| 66 | Jamaica | **0.346** | 0.264 | 85 | 30.8 |
| 67 | Peru | **0.345** | 0.292 | 74 | 18.2 |
| 68 | Thailand | **0.342** | 0.278 | 80 | 23.3 |
| 69 | Jordan | **0.341** | 0.300 | 67 | 13.6 |
| 70 | Azerbaijan | **0.337** | 0.342 | 54 | −1.4 |
| 71 | Colombia | **0.331** | 0.286 | 76 | 15.6 |
| 72 | Brazil | **0.330** | 0.280 | 77 | 17.6 |
| 73 | Armenia | **0.326** | 0.339 | 55 | −3.6 |
| 74 | Puerto Rico | **0.326** | 0.293 | 71 | 11.4 |
| 75 | Saudi Arabia | **0.326** | 0.280 | 78 | 16.4 |
| 76 | Paraguay | **0.323** | 0.269 | 84 | 20.0 |
| 77 | Philippines | **0.322** | 0.277 | 81 | 16.4 |
| 78 | Cuba | **0.322** | 0.313 | 65 | 2.8 |
| 79 | Ecuador | **0.319** | 0.294 | 70 | 8.3 |
| 80 | Uzbekistan | **0.319** | 0.313 | 66 | 1.9 |
| 81 | Iran, Islamic Rep. | **0.313** | 0.241 | 90 | 29.9 |
| 82 | Libya | **0.312** | 0.274 | 83 | 13.7 |
| 83 | El Salvador | **0.311** | 0.236 | 93 | 31.9 |
| 84 | Dominican Republic | **0.308** | 0.258 | 86 | 19.4 |
| 85 | China | **0.306** | 0.227 | 97 | 34.7 |
| 86 | Kyrgyz Republic | **0.306** | 0.300 | 68 | 1.9 |
| 87 | Bolivia | **0.305** | 0.254 | 88 | 19.8 |
| 88 | Fiji | **0.304** | 0.278 | 79 | 9.1 |
| 89 | Oman | **0.300** | 0.238 | 91 | 26.0 |
| 90 | Macedonia, FYR | **0.300** | 0.276 | 82 | 8.5 |
| 91 | Turkmenistan | **0.289** | 0.292 | 73 | −1.2 |
| 92 | Tunisia | **0.288** | 0.227 | 98 | 26.8 |
| 93 | Mauritius | **0.285** | 0.231 | 95 | 23.6 |
| 94 | Syrian Arab Republic | **0.282** | 0.256 | 87 | 10.2 |
| 95 | Sri Lanka | **0.280** | 0.227 | 96 | 23.0 |
| 96 | Zimbabwe | **0.279** | 0.248 | 89 | 12.2 |
| 97 | Algeria | **0.277** | 0.221 | 100 | 25.1 |
| 98 | Guyana | **0.271** | 0.226 | 99 | 20.0 |
| 99 | Egypt, Arab Rep. | **0.269** | 0.219 | 101 | 22.6 |
| 100 | Indonesia | **0.265** | 0.190 | 108 | 39.7 |
| 101 | Suriname | **0.264** | 0.219 | 102 | 20.1 |
| 102 | Honduras | **0.258** | 0.218 | 103 | 18.3 |
| 103 | Botswana | **0.255** | 0.189 | 109 | 34.8 |
| 104 | Albania | **0.251** | 0.231 | 94 | 8.5 |

Table 1—(*continued*)

| Actual ranking | | Current ArCo Technology Index | Past ArCo Technology Index | Past ranking | Growth rate from the last decade (%) |
|---|---|---|---|---|---|
| 105 | Iraq | **0.246** | 0.238 | 92 | 3.4 |
| 106 | Zambia | **0.240** | 0.213 | 104 | 12.3 |
| 107 | Vietnam | **0.239** | 0.164 | 118 | 45.5 |
| 108 | Nicaragua | **0.238** | 0.202 | 106 | 17.8 |
| 109 | Guatemala | **0.234** | 0.187 | 110 | 25.2 |
| 110 | Gabon | **0.231** | 0.204 | 105 | 13.1 |
| 111 | India | **0.225** | 0.169 | 116 | 32.9 |
| 112 | Swaziland | **0.222** | 0.184 | 111 | 20.4 |
| 113 | Morocco | **0.217** | 0.169 | 117 | 28.5 |
| 114 | Namibia | **0.217** | 0.184 | 112 | 17.6 |
| 115 | Congo, Rep. | **0.207** | 0.195 | 107 | 6.4 |
| 116 | Kenya | **0.204** | 0.177 | 114 | 15.1 |
| 117 | Ghana | **0.203** | 0.163 | 119 | 24.3 |
| 118 | Mongolia | **0.197** | 0.176 | 115 | 11.6 |
| 119 | Cameroon | **0.192** | 0.163 | 120 | 18.0 |
| 120 | Pakistan | **0.191** | 0.158 | 121 | 20.9 |
| 121 | Korea, Dem. Rep. | **0.187** | 0.179 | 113 | 4.9 |
| 122 | Myanmar | **0.179** | 0.135 | 123 | 32.2 |
| 123 | Lesotho | **0.178** | 0.154 | 122 | 15.4 |
| 124 | Tanzania | **0.155** | 0.126 | 124 | 23.2 |
| 125 | Senegal | **0.151** | 0.109 | 130 | 38.1 |
| 126 | Papua New Guinea | **0.146** | 0.119 | 125 | 22.4 |
| 127 | Togo | **0.145** | 0.097 | 133 | 48.8 |
| 128 | Nigeria | **0.141** | 0.114 | 127 | 23.6 |
| 129 | Sudan | **0.140** | 0.096 | 136 | 46.3 |
| 130 | Yemen, Rep. | **0.140** | 0.112 | 128 | 24.2 |
| 131 | Côte d'Ivoire | **0.136** | 0.080 | 141 | 69.8 |
| 132 | Malawi | **0.134** | 0.106 | 131 | 26.4 |
| 133 | Uganda | **0.133** | 0.097 | 134 | 37.6 |
| 134 | Haiti | **0.129** | 0.117 | 126 | 10.4 |
| 135 | Congo, Dem. Rep. | **0.125** | 0.110 | 129 | 13.6 |
| 136 | Gambia | **0.123** | 0.070 | 146 | 76.1 |
| 137 | Bangladesh | **0.123** | 0.086 | 138 | 43.2 |
| 138 | Djibouti | **0.122** | 0.099 | 132 | 22.3 |
| 139 | Nepal | **0.121** | 0.070 | 145 | 72.9 |
| 140 | Madagascar | **0.116** | 0.096 | 135 | 20.8 |
| 141 | Benin | **0.114** | 0.078 | 143 | 46.3 |
| 142 | Rwanda | **0.113** | 0.081 | 140 | 39.5 |
| 143 | Mauritania | **0.111** | 0.077 | 144 | 43.6 |
| 144 | Central African Republic | **0.110** | 0.081 | 139 | 36.1 |
| 145 | Angola | **0.107** | 0.088 | 137 | 21.7 |
| 146 | Bhutan | **0.103** | 0.063 | 148 | 65.2 |
| 147 | Lao PDR | **0.098** | 0.057 | 151 | 73.6 |
| 148 | Mozambique | **0.098** | 0.069 | 147 | 41.6 |
| 149 | Cambodia | **0.096** | 0.047 | 156 | 103.3 |
| 150 | Liberia | **0.095** | 0.079 | 142 | 20.5 |
| 151 | Eritrea | **0.093** | 0.048 | 154 | 92.8 |
| 152 | Guinea | **0.079** | 0.045 | 158 | 73.9 |
| 153 | Burundi | **0.078** | 0.057 | 152 | 38.2 |
| 154 | Guinea-Bissau | **0.076** | 0.061 | 149 | 26.2 |
| 155 | Sierra Leone | **0.075** | 0.060 | 150 | 24.4 |

(*continued next page*)

Table 1—(*continued*)

| Actual ranking | | Current ArCo Technology Index | Past ArCo Technology Index | Past ranking | Growth rate from the last decade (%) |
|---|---|---|---|---|---|
| 156 | Chad | **0.071** | 0.050 | 153 | 42.6 |
| 157 | Ethiopia | **0.067** | 0.047 | 155 | 41.1 |
| 158 | Mali | **0.066** | 0.032 | 159 | 108.2 |
| 159 | Afghanistan | **0.056** | 0.046 | 157 | 20.5 |
| 160 | Burkina Faso | **0.050** | 0.028 | 160 | 79.2 |
| 161 | Niger | **0.031** | 0.017 | 162 | 84.0 |
| 162 | Somalia | **0.028** | 0.024 | 161 | 13.9 |

*Sources*: CSRS (1996a, 1996b), EPO (2002), ITU (2001), NSF (2000, 2002), UNESCO (2002), USPTO (2002) and World Bank (2003).

ArCo Technology Index (Table 1). We identified four groups, [6] according to the existence of a significant gap among the last country of a group and the first of the subsequent

—*leaders* (from 1 to 25 ranking);
—*potential leaders* (from 26 to 50);
—*latecomers* (from 51 to 111);
—*marginalized* (from 112 to 162).

### (a) *Leaders (from 1 to 25 ranking)*

The first group includes those countries able to create and sustain technological innovation. This is the group that concentrates the bulk of the creation of technology. Seven considerations can be made:

(i) What can be immediately noted is the excellent performance of Nordic European countries: Sweden ranks first, Finland second, Norway seventh. These countries hold extraordinary technological infrastructures, and highly qualified human resources. In addition to the static picture, is noteworthy their trend: all but Denmark improved their ranking with respect to a decade ago, with rates of growth beyond 20%.

(ii) Still more pronounced is the growth of Newly Industrialized Countries, the so-called Asian tigers: Taiwan, South Korea, Hong Kong, Singapore. In a decade, their index has grown by 52% in Taiwan and 31% in Hong Kong. A huge growth occurred in the category of the creation of technology (1100% in South Korea and 200% in Singapore).

(iii) North American countries are more or less stable in the top positions: the United States ranks fifth and Canada sixth, losing a few positions. The United States has a more prominent position in the creation of technology than it did in the other two categories.

(iv) Japan occupies the eighth place (gaining four positions in a decade), fruit of an excellent performance in technology creation, very good in technological infrastructures, and relatively poor in human skills.

(v) Western Europe shows a slowdown: Germany, France, Belgium, Austria, and Italy fell behind during the decade, not so much due to a slow growth, as much as due to better performance by other countries (this is particularly the case in technological infrastructures). Switzerland ranked first a decade ago and now finds itself in third position. Germany is now 12th, losing five positions. The United Kingdom is stable at the 13th position, while Ireland (23rd) lost two ranks. Only Spain gained a few positions, resting on the borderline (25th rank), between the first and the second grouping.

(vi) Australia and New Zealand almost exchanged places: the first gained rank (from 14th to 10th) while the second lost rank (from 11th to 16th).

(vii) Finally, Israel ranks fourth, even ahead of the United States. This apparently surprising result is attributable to the high number of patents granted in the United States, accompanied by an excellent achievement in the formation of human capital.

### (b) *Potential leaders (from 26 to 50 ranking)*

The second group comprises countries that have, on the one hand, invested in the formation of human skills and developed standard technological infrastructures, and on the other they have achieved little innovation.

(i) The largest number of countries in this group comes from the former Socialist Eastern European countries. Predictions here are particularly risky, especially since the economic and social conditions of these countries have been particularly turbulent. Data and trends for the ex-Soviet or ex-Yugoslavian new states are not entirely reliable. In spite of turmoil, these countries show a good performance in human skills. Russia lost position considerably in the last decade in all three categories as a consequence of the transition to a market economy. Bulgaria and Romania lost meaningful positions too, while Hungary and Poland have gained a few positions.

Greece and Portugal, the countries to have always lagged behind in technological capabilities within the European Union, are slowly bridging the gap. The latter, with a growth rate of 30%, climbed from the 53rd up to the 35th rank. Greece gained a few positions by reaching the 27th position.

(ii) Some South American countries have also gained positions during the decade: Argentina, Uruguay and especially Chile had a grow rate of 26%, with Argentina reaching 40th.

(iii) Within the Arab countries the performance of United Arab Emirates is noteable: thanks to a good availability of infrastructures it gained 14 positions and almost reached Kuwait, which remains the leader of the Arabic countries for technological progress at the 47th place.

(c) *Latecomers (from 51 to 111 ranking)*

The third group, the largest, is composed of countries which, in one way or another, try to stimulate their technology growth parallel to their development efforts: technological infrastructure and formation of human skills.

(i) Central and South American countries deserve a special comment since none of them, with the exception of Cuba, have shown a downgrading trend compared to a decade ago (Panama, Venezuela, Costa Rica, Mexico, Jamaica, Peru, Colombia, Brazil, Paraguay and Bolivia). These countries have developed particularly good technological infrastructure (growth rates around 20%), though human skills have not grown as effectively (not superior to 10%).

(ii) A similar trend can be observed among Asian countries, where Malaysia and Thailand (both with a growth rate beyond 20%) are in the top positions, followed by the Philippines (growth rate of 16%). Although placed at the bottom of this list (100th), Indonesia shows the highest growth rate since the previous decade (40%).

(iii) In Asia, China and India deserve a separate comment: China has shown an extraordinary growth rate of technological infrastructures (71%) but has remained almost stable in human skills wise. Overall, it has shown one of the highest growth rates in the last 10 years (35%, second only to Indonesia), by gaining 12 positions (from 97th to 85th).

(iv) India closes the third grouping by ranking at 111th. This may seem unfair but, apart from some African countries and Vietnam—which do not have reliable data relating to the past—India is the country that shows the highest growth rate (33%), driven, like China, by the development of technological infrastructure.

(v) In the Middle East, Lebanon climbed to the 57th position (growth rate of 26%), placing behind Qatar (54th) and ahead of Jordan (69th), while Saudi Arabia increased its rank to the 75th position.

(vi) Finally, a restricted set of African countries showed signs of catching up, with South Africa (56th) in the lead and North African countries Tunisia (92nd), Algeria (97th) and Egypt (99th) just behind. These countries show a delay in the development of technology infrastructures, but are growing in terms of human skills.

(d) *Marginalized (from 112 to 162 ranking)*

The fourth and last group is composed of marginalized countries, which do not have large access even to the oldest technologies, such as electricity and telephony. In this group, relative position is not particularly meaningful, due mainly to the lack of available data. Even high growth rates can simply be due to the very low values in both periods. These countries are practically lacking the first category—creation of technology—and have poor technological infrastructures and human skills. Many African countries fall within this grouping where the low technological level is associated to the very low income levels.

## 5. SOME STATISTICS ON THE INDICATORS

After having commented the results at the country level, we wish to report some simple statistics about the indicators. In Table 2 we calculated the correlation matrix across the eight indicators presented. As expected, all correlation coefficients are positive. The values are different, however, indicating that the various indicators taken into account highlight different aspects of technological capabilities.

As predictable, the correlation is greater across indicators belonging to the same category of technology (creation, infrastructures or human skills), but with some exceptions. For example, the correlation between Internet users and scientific publications is high. At the same time the Internet is less correlated with the traditional infrastructures (telephony and electricity). The latter are more highly correlated with literacy rate and years of schooling. So it would appear that more traditional forms of technology remain closer to each other: the indices of technology creation (patents, scientific articles) have little correlation with literacy rate, telephony and electricity.

It is also interesting to note the degree to which each indicator is correlated with the final ArCo Technology Index. Since the ArCo Technology Index represents the mean of the eight components, it is natural to expect a high correlation between them. This is indeed the case, although patents show the weakest correlation and schooling the strongest.

Different results emerge if we consider the correlation within each group. In particular, differences emerged within the group of *potential leaders* (Table 3): composed mainly of East European countries, it shows a negative correlation (although very weak) between indicators of human skills and those of technological infrastructure. In this group of countries there is no correlation between education performance on the one hand, and infrastructures and patenting activity on the other. Moreover, there is no connection between scientific articles and patents, confirming that the sources of codified knowledge creation from the business sector and the academic community are not necessarily complementary.

Table 4 reports the correlation matrix for the *latecomers*, which signals a practical independence between indicators of human skills and indicators of creation of technology. The former also exhibit little correlation with the technological infrastructures, although a positive correlation is found between indicators of creation and indicators of technology infrastructure. Correlation within the *leaders* group or within the *marginalized* group was not reported. While for the latter group data cannot be considered sufficiently reliable, countries within the group of *leaders* have already reached the maximum level for more than one indicator. The linear correlation coefficients would therefore prove less informative.

Table 5 reports the correlation matrix for the three category indexes. The category of technology creation is a little less correlated with the other two as well as with the final ArCo index. The intragroup analysis does not reveal any new information, though it is interesting to look at the indicators' coefficients of variation (Table 6), which signal different levels of polarization of technological capabilities across the 162 countries. As expected, the most significant dispersion occurs in the case of the generation of technology, which is very highly concentrated in a small cluster of countries. In addition, Internet users and, to a lesser extent, the scientific tertiary formation, are concentrated in just a small number of countries. Concerning infrastructures, we note that the older the technology is, the less its utilization is polarized. Literacy is the least dispersed indicator.

Historians who have taken into account the geographical location of inventions over 3,000 years would not be surprised that the generation of inventions and innovations is strongly concentrated in certain areas. They have in fact shown that in the past inventive activity was concentrated in what now we would call "hubs" such as the Greek cities, the Italian Renaissance republics and Britain during the industrial revolution (see Smithsonian Visual Timeline of Inventions, 1994). Today something similar is happening in Silicon Valley as well as in the Balgalore district. What might appear surprising to an historian is the geographical diffusion of contemporary innovation compared to its concentration in the past.

A comparison of the variation coefficients across the two periods allows also to test whether the 162 countries are somehow converging or diverging in their technological capabilities. All the indicators show a certain convergence from the past (that is, a reduction of the divergence signalled by the coefficients), especially with regard to Internet (many countries in the past did not possess it at all, while

Table 2. *Correlation coefficients across the various indexes of technological capabilities (all countries)*[a]

| | Patent index | Articles index | Internet index | Telephony index | Electricity index | Tertiary index | Schooling index | Literacy index | ArCo technology index |
|---|---|---|---|---|---|---|---|---|---|
| Patent index | 1.000 | 0.791 | 0.692 | 0.446 | 0.445 | 0.537 | 0.530 | 0.320 | **0.705** |
| Articles index | 0.791 | 1.000 | 0.833 | 0.571 | 0.567 | 0.699 | 0.665 | 0.420 | **0.828** |
| Internet index | 0.692 | 0.833 | 1.000 | 0.607 | 0.594 | 0.618 | 0.659 | 0.431 | **0.805** |
| Telephony index | 0.446 | 0.571 | 0.607 | 1.000 | 0.843 | 0.713 | 0.819 | 0.818 | **0.890** |
| Electricity index | 0.445 | 0.567 | 0.594 | 0.843 | 1.000 | 0.674 | 0.744 | 0.712 | **0.854** |
| Tertiary index | 0.537 | 0.699 | 0.618 | 0.713 | 0.674 | 1.000 | 0.707 | 0.617 | **0.837** |
| Schooling index | 0.530 | 0.665 | 0.659 | 0.819 | 0.744 | 0.707 | 1.000 | 0.805 | **0.903** |
| Literacy index | 0.320 | 0.420 | 0.431 | 0.818 | 0.712 | 0.617 | 0.805 | 1.000 | **0.788** |

*Sources*: CSRS (1996a, 1996b); EPO (2002), ITU (2001), NSF (2000, 2002), UNESCO (2002), USPTO (2002) and World Bank (2003).

[a] —Patent index: patents granted at the USPTO by country per million people (annual average for 1997–2000).
—Articles index: scientific articles by country per million people (annual average for 1997–99).
—Internet index: Internet users by country per million people (1999).
—Telephony index: fixed and mobile telephone lines by country per million people (1999).
—Electricity index: electricity consumption by country per million people (annual average for 1997–98).
—Tertiary index: gross tertiary science and engineering enrolment by country (annual average for 1996–98).
—Schooling index: mean years of schooling by country (2000).
—Literacy index: adult literacy rate by country (2000).
—ArCo technology index: weighted mean of the previous indexes.

Table 3. *Correlation coefficients across the various indexes of technological capabilities for the potential leaders (countries from 26 to 50)*[a]

| | Patent index | Articles index | Internet index | Telephony index | Electricity index | Tertiary index | Schooling index | Literacy index | ArCo technology index |
|---|---|---|---|---|---|---|---|---|---|
| Patent index | 1.000 | −0.018 | 0.519 | 0.385 | 0.401 | −0.318 | −0.258 | 0.095 | **0.325** |
| Articles index | −0.018 | 1.000 | 0.362 | 0.530 | 0.342 | 0.067 | 0.143 | 0.191 | **0.798** |
| Internet index | 0.519 | 0.362 | 1.000 | 0.768 | 0.580 | −0.532 | −0.194 | −0.236 | **0.447** |
| Telephony index | 0.385 | 0.530 | 0.768 | 1.000 | 0.606 | −0.435 | −0.188 | −0.207 | **0.531** |
| Electricity index | 0.401 | 0.342 | 0.580 | 0.606 | 1.000 | −0.309 | −0.475 | −0.575 | **0.325** |
| Tertiary index | −0.318 | 0.067 | −0.532 | −0.435 | −0.309 | 1.000 | −0.106 | 0.396 | **0.220** |
| Schooling index | −0.258 | 0.143 | −0.194 | −0.188 | −0.475 | −0.106 | 1.000 | 0.489 | **0.199** |
| Literacy index | 0.095 | 0.191 | −0.236 | −0.207 | −0.575 | 0.396 | 0.489 | 1.000 | **0.438** |

*Sources*: CSRS (1996a, 1996b), EPO (2002), ITU (2001), NSF (2000, 2002), UNESCO (2002), USPTO (2002) and World Bank (2003).

[a] —Patent index: patents granted at the USPTO by country per million people (annual average for 1997–2000).
—Articles index: scientific articles by country per million people (annual average for 1997–99).
—Internet index: Internet users by country per million people (1999).
—Telephony index: fixed and mobile telephone lines by country per million people (1999).
—Electricity index: electricity consumption by country per million people (annual average for 1997–98).
—Tertiary index: gross tertiary science and engineering enrolment by country (annual average for 1996–98).
—Schooling index: mean years of schooling by country (2000).
—Literacy index: adult literacy rate by country (2000).
—ArCo technology index: weighted mean of the previous indexes.

Table 4. *Correlation coefficients across the various indexes of technological capabilities for the latecomers (countries from 51 to 111)*[a]

| | Patent index | Articles index | Internet index | Telephony index | Electricity index | Tertiary index | Schooling index | Literacy index | ArCo Technology Index |
|---|---|---|---|---|---|---|---|---|---|
| Patent index | 1.000 | 0.508 | 0.631 | 0.476 | 0.374 | −0.012 | 0.001 | 0.161 | **0.431** |
| Articles index | 0.508 | 1.000 | 0.437 | 0.511 | 0.447 | 0.159 | −0.008 | 0.094 | **0.501** |
| Internet index | 0.631 | 0.437 | 1.000 | 0.723 | 0.236 | 0.035 | 0.097 | 0.141 | **0.500** |
| Telephony index | 0.476 | 0.511 | 0.723 | 1.000 | 0.244 | 0.311 | 0.087 | 0.332 | **0.686** |
| Electricity index | 0.374 | 0.447 | 0.236 | 0.244 | 1.000 | 0.169 | 0.079 | 0.022 | **0.627** |
| Tertiary index | −0.012 | 0.159 | 0.035 | 0.311 | 0.169 | 1.000 | 0.114 | 0.189 | **0.507** |
| Schooling index | 0.001 | −0.008 | 0.097 | 0.087 | 0.079 | 0.114 | 1.000 | 0.421 | **0.528** |
| Literacy index | 0.161 | 0.094 | 0.141 | 0.332 | 0.022 | 0.189 | 0.421 | 1.000 | **0.586** |

*Sources*: CSRS (1996a, 1996b), EPO (2002), ITU (2001), NSF (2000, 2002), UNESCO (2002), USPTO (2002) and World Bank (2003).

[a] —Patent index: patents granted at the USPTO by country per million people (annual average for 1997–2000).
—Articles index: scientific articles by country per million people (annual average for 1997–99).
—Internet index: Internet users by country per million people (1999).
—Telephony index: fixed and mobile telephone lines by country per million people (1999).
—Electricity index: electricity consumption by country per million people (annual average for 1997–98).
—Tertiary index: gross tertiary science and engineering enrolment by country (annual average for 1996–98).
—Schooling index: mean years of schooling by country (2000).
—Literacy index: adult literacy rate by country (2000).
—ArCo technology index: weighted mean of the previous indexes.

Table 5. *Correlation coefficients across the category indexes of technological capabilities*

| | Technology creation index | Technology diffusion index | Human skills index | ArCo technology index |
|---|---|---|---|---|
| Technology creation index | 1.000 | 0.667 | 0.627 | **0.819** |
| Technology diffusion index | 0.667 | 1.000 | 0.894 | **0.956** |
| Human skills index | 0.627 | 0.894 | 1.000 | **0.937** |

*Sources*: CSRS (1996a, 1996b), EPO (2002), ITU (2001), NSF (2000, 2002), UNESCO (2002), USPTO (2002) and World Bank (2003).

—Technology creation index: simple mean of Patent index and articles index.

—Technology diffusion index: simple mean of Internet index, telephony index and electricity index.

—Human skills index: simple mean of tertiary index, schooling index and literacy index.

—ArCo technology index: simple mean of the previous indexes.

it was already a common infrastructure in others), telephony and literacy rate. It also emerges that the propensity toward convergence is much faster in infrastructure, including new ones such as Internet, than in the creation of technology.

For the coefficients of variation we also decomposed the analysis at the group level, and we found clear evidence that within the groups there is more homogeneity than for the overall 162 countries. The ratios inside the groups are lower for every indicator, and this is particularly true for the final ArCo Index, which shows not only a lower absolute value, but also a faster rate of convergence at the group level with respect to the aggregate level.

## 6. ADDING UP ANOTHER COMPONENT: IMPORT TECHNOLOGY

So far, the ArCo has considered each country as if it were a closed economy. Of course, in a highly globalized world this is hardly the case (the relationship between globalization and technology is discussed in Archibugi & Lundvall, 2001; Archibugi & Michie, 1997). It is certainly an advantage for a country to receive information and know-how from other countries. We assumed that these exchanges should have an effect on some of the eight variables included in ArCo. In this section we try to take into account, in a separate manner, the contribution provided by import technology to national technological capabilities by adding a fourth category.

Following the suggestions of a referee, and the method applied by Lall and Albaladejo (2001), we added a measure of import technology. This measure is composed of three subindices: inward Foreign Direct Investment (FDI), technology licensing payments, and import of capital goods. We relied on a combined index of these three variables as developed by Lall and Albaladejo (2001, Table 9). The results are reported in column 2 of Table 7, with data available for 86 countries only (therefore, we confine here our analysis to this subset of countries). According to this measure, the countries with the highest import of technology are Singapore and Ireland.

We therefore added this component of "Import technology" as a fourth dimension to the ArCo Index. We gave it equal weight compared to the other three, that is one-quarter. The results are reported in column 4 of Table 7, while column 5 reports the new ranking, and column 6 the difference between the original ArCo and this more comprehensive measure of technological capabilities. The ranking of world countries according to this index does not differ substantially from the previous one. The first three positions remain unchanged. Very significant differences emerge for two countries only: Singapore, the top importer of technology, which gains 16 positions and reach the fourth place, and Ireland, which gains 10 positions moving its ranking from 22 to 12.

The largest economies lose some position: United States, Israel, Japan, Germany, Australia and United Kingdom downgrade. On the other hand, a few small and dynamic economies—Netherlands, Norway, Belgium—gain position. This reinforces the impression that this measure of global technology is affected by the size of the economy and, as is well known in international trade theory, small countries are more open to technology imports. As we move to the bottom part of

Table 6. *Coefficients of variation of the various indexes of technological capabilities*

| | Current | Past | Growth rate (%) |
|---|---|---|---|
| *Patent index* | | | |
| All countries | 2.787 | 3.087 | −9.7 |
| Leaders | 0.705 | 0.935 | −24.6 |
| Potential leaders | 3.251 | 3.374 | −3.6 |
| Latecomers | 1.822 | 2.684 | −32.1 |
| *Articles index* | | | |
| All countries | 1.999 | 2.172 | −8.0 |
| Leaders | 0.420 | 0.626 | −33.0 |
| Potential leaders | 0.654 | 0.672 | −2.6 |
| Latecomers | 1.004 | 1.227 | −18.2 |
| *Internet index* | | | |
| All countries | 1.831 | 2.642 | −30.7 |
| Leaders | 0.459 | 0.838 | −45.3 |
| Potential leaders | 0.737 | 1.330 | −44.6 |
| Latecomers | 1.158 | 4.108 | −71.8 |
| *Telephony index* | | | |
| All countries | 0.435 | 0.550 | −20.9 |
| Leaders | 0.010 | 0.039 | −73.7 |
| Potential leaders | 0.082 | 0.100 | −18.1 |
| Latecomers | 0.175 | 0.285 | −38.6 |
| *Electricity index* | | | |
| All countries | 0.497 | 0.536 | −7.4 |
| Leaders | 0.039 | 0.071 | −44.2 |
| Potential leaders | 0.109 | 0.109 | −0.2 |
| Latecomers | 0.286 | 0.338 | −15.5 |
| *Tertiary index* | | | |
| All countries | 1.018 | 1.034 | −1.5 |
| Leaders | 0.319 | 0.369 | −13.4 |
| Potential leaders | 0.501 | 0.664 | −24.6 |
| Latecomers | 0.665 | 0.765 | −13.0 |
| *Schooling index* | | | |
| All countries | 0.549 | 0.590 | −7.0 |
| Leaders | 0.161 | 0.187 | −14.2 |
| Potential leaders | 0.209 | 0.245 | −14.5 |
| Latecomers | 0.288 | 0.327 | −11.8 |
| *Literacy index* | | | |
| All countries | 0.279 | 0.352 | −20.8 |
| Leaders | 0.018 | 0.029 | −38.1 |
| Potential leaders | 0.062 | 0.079 | −22.2 |
| Latecomers | 0.132 | 0.183 | −27.8 |
| *Technology creation index* | | | |
| All countries | 2.151 | 2.289 | −6.0 |
| Leaders | 0.435 | 0.630 | −31.0 |
| Potential leaders | 0.707 | 0.712 | −0.8 |
| Latecomers | 1.006 | 1.249 | −19.4 |
| *Technology diffusion index* | | | |
| All countries | 0.561 | 0.586 | −4.2 |
| Leaders | 0.100 | 0.065 | 54.4 |

(*continued next page*)

Table 6—(*continued*)

| | Current | Past | Growth rate (%) |
|---|---|---|---|
| Potential leaders | 0.119 | 0.091 | 31.0 |
| Latecomers | 0.190 | 0.268 | −28.9 |
| *Human skills index* | | | |
| All countries | 0.439 | 0.475 | −7.5 |
| Leaders | 0.097 | 0.108 | −10.3 |
| Potential leaders | 0.130 | 0.154 | −15.1 |
| Latecomers | 0.166 | 0.219 | −24.2 |
| *ArCo Technology Index* | | | |
| All countries | **0.578** | **0.589** | **−1.9** |
| Leaders | **0.133** | **0.177** | **−24.6** |
| Potential leaders | **0.077** | **0.089** | **−3.1** |
| Latecomers | **0.144** | **0.196** | **−26.7** |

*Sources*: CSRS (1996a, 1996b), EPO (2002), ITU (2001), NSF (2000, 2002), UNESCO (2002), USPTO (2002) and World Bank (2003).
—Patent index: patents granted at the USPTO by country per million people (annual average for 1997–2000 for the actual value and for 1987–90 from the past one).
—Articles index: scientific Articles by country per million people (annual average for 1997–99 for the actual value and for 1987–89 for the past one).
—Internet index: Internet users by country per million people (year 1999 for the actual value and year 1994 for the past one).
—Telephony index: fixed and mobile telephone lines by country per million people (year 1999 for the actual value and year 1989 for the past one).
—Electricity index: electricity consumption by country per million people (annual average for 1997–98 for the actual value and annual average for 1988–89 for the past one).
—Tertiary index: gross tertiary science and engineering enrolment by country (annual average for 1996–998 for the actual value and annual average for 1987–89 for the past one).
—Schooling index: mean years of schooling by country (year 2000 for the actual value and year 1990 for the past one).
—Literacy index: adult literacy rate by country (year 2000 for the actual value and year 1990 for the past one).
—Technology creation index: simple mean of patent and articles indexes.
—Technology diffusion index: simple mean of Internet, telephony and electricity indexes.
—Human skills index: simple mean of tertiary, schooling and literacy indexes.
—ArCo Technology Index: simple mean of the three previous (category) indexes.
—Coeff. of variation: ratio between standard deviation and simple mean of the observations. It signals the internal variability of each index.

the ranking, the differences vanish. Both linear correlation coefficient and rank correlations are very high, and equal to 0.990 and 0.995. We can deduce that, as a method to rank countries' technological capabilities, ArCo is a sufficiently robust measure even without including a separate category devoted to import technology.

## 7. TECHNOLOGICAL CAPABILITIES AND ECONOMIC PERFORMANCE

An important application of ArCo is to allow the investigation of the role played by technological capabilities in economic growth (for a review of the literature, see Fagerberg, 1994). In future research we will use a wider battery of statistical and econometric methods to explore this relationship. Here we limit ourselves to a preliminary analysis by linking the ArCo index to the economic growth proxied by the GDP per capita. Table 8 reports two sets of regressions designed to check the extent to which the two sets of data overlap. First, we considered the absolute levels, by regressing per capita current GDP expressed in US dollars at Purchasing Power Parities on the current ArCo index value; then we investigated the dynamics in the last decade, by regressing

Table 7. *Import Technology Index and its divergence to ArCo Technology Index: a comparison for 86 countries*[a]

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| | Ranking ArCo | Technology Import Index | Ranking Technology Import | Global Technology Index | Ranking Global Technology Index | Difference between ArCo and GTI ranking |
| Sweden | 1 | 0.193 | 6 | **0.698** | 1 | 0 |
| Finland | 2 | 0.091 | 15 | **0.646** | 2 | 0 |
| Switzerland | 3 | 0.172 | 7 | **0.642** | 3 | 0 |
| Singapore | 20 | 0.777 | 1 | **0.624** | 4 | 16 |
| Norway | 7 | 0.161 | 8 | **0.583** | 5 | 2 |
| Canada | 6 | 0.098 | 13 | **0.581** | 6 | 0 |
| Israel | 4 | 0.065 | 19 | **0.580** | 7 | −3 |
| United States | 5 | 0.066 | 18 | **0.576** | 8 | −3 |
| Netherlands | 11 | 0.199 | 5 | **0.562** | 9 | 2 |
| Denmark | 9 | 0.129 | 10 | **0.560** | 10 | −1 |
| Japan | 8 | 0.027 | 33 | **0.547** | 11 | −3 |
| Ireland | 22 | 0.480 | 2 | **0.545** | 12 | 10 |
| Belgium | 16 | 0.232 | 4 | **0.539** | 13 | 3 |
| Australia | 10 | 0.092 | 14 | **0.536** | 14 | −4 |
| United Kingdom | 13 | 0.101 | 12 | **0.530** | 15 | −2 |
| Germany | 12 | 0.052 | 21 | **0.525** | 16 | −4 |
| New Zealand | 15 | 0.141 | 9 | **0.519** | 17 | −2 |
| Taiwan | 14 | 0.060 | 20 | **0.514** | 18 | −4 |
| Hong Kong | 21 | 0.306 | 3 | **0.503** | 19 | 2 |
| Austria | 17 | 0.112 | 11 | **0.492** | 20 | −3 |
| France | 19 | 0.085 | 16 | **0.474** | 21 | −2 |
| Korea, Rep. | 18 | 0.035 | 28 | **0.464** | 22 | −4 |
| Italy | 23 | 0.031 | 30 | **0.402** | 23 | 0 |
| Spain | 24 | 0.051 | 22 | **0.400** | 24 | 0 |
| Slovenia | 25 | 0.044 | 25 | **0.391** | 25 | 0 |
| Greece | 26 | 0.030 | 31 | **0.374** | 26 | 0 |
| Czech Republic | 28 | 0.040 | 27 | **0.366** | 27 | 1 |
| Hungary | 29 | 0.047 | 23 | **0.364** | 28 | 1 |
| Russia | 27 | 0.004 | 63 | **0.361** | 29 | −2 |
| Poland | 30 | 0.020 | 36 | **0.353** | 30 | 0 |
| Portugal | 31 | 0.044 | 24 | **0.348** | 31 | 0 |
| Chile | 33 | 0.043 | 26 | **0.329** | 32 | 1 |
| Argentina | 32 | 0.029 | 32 | **0.327** | 33 | −1 |
| Uruguay | 34 | 0.013 | 42 | **0.316** | 34 | 0 |
| Bahrain | 35 | 0.010 | 50 | **0.310** | 35 | 0 |
| Malaysia | 39 | 0.079 | 17 | **0.296** | 36 | 3 |
| Romania | 36 | 0.006 | 55 | **0.296** | 37 | −1 |
| Panama | 37 | 0.032 | 29 | **0.295** | 38 | −1 |
| South Africa | 38 | 0.012 | 44 | **0.282** | 39 | −1 |
| Venezuela | 40 | 0.016 | 37 | **0.281** | 40 | 0 |
| Costa Rica | 41 | 0.023 | 34 | **0.276** | 41 | 0 |
| Mexico | 42 | 0.021 | 35 | **0.274** | 42 | 0 |
| Jamaica | 44 | 0.015 | 40 | **0.263** | 43 | 1 |
| Peru | 45 | 0.016 | 38 | **0.263** | 44 | 1 |
| Turkey | 43 | 0.008 | 52 | **0.263** | 45 | −2 |
| Thailand | 46 | 0.016 | 39 | **0.260** | 46 | 0 |
| Jordan | 47 | 0.006 | 54 | **0.257** | 47 | 0 |
| Colombia | 48 | 0.012 | 45 | **0.251** | 48 | 0 |
| Brazil | 49 | 0.011 | 46 | **0.250** | 49 | 0 |

(*continued next page*)

Table 7—(*continued*)

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| | Ranking ArCo | Technology Import Index | Ranking Technology Import | Global Technology Index | Ranking Global Technology Index | Difference between ArCo and GTI ranking |
| Saudi Arabia | 50 | 0.008 | 53 | **0.246** | 50 | 0 |
| Paraguay | 51 | 0.010 | 48 | **0.245** | 51 | 0 |
| Philippines | 52 | 0.006 | 56 | **0.243** | 52 | 0 |
| Ecuador | 53 | 0.010 | 47 | **0.242** | 53 | 0 |
| El Salvador | 54 | 0.003 | 66 | **0.234** | 54 | 0 |
| Bolivia | 56 | 0.009 | 51 | **0.231** | 55 | 1 |
| China | 55 | 0.005 | 59 | **0.231** | 56 | −1 |
| Oman | 57 | 0.014 | 41 | **0.229** | 57 | 0 |
| Tunisia | 58 | 0.010 | 49 | **0.218** | 58 | 0 |
| Mauritius | 59 | 0.013 | 43 | **0.217** | 59 | 0 |
| Sri Lanka | 60 | 0.002 | 69 | **0.210** | 60 | 0 |
| Zimbabwe | 61 | 0.003 | 67 | **0.210** | 61 | 0 |
| Algeria | 62 | 0.002 | 70 | **0.208** | 62 | 0 |
| Egypt, Arab Rep. | 63 | 0.004 | 60 | **0.203** | 63 | 0 |
| Indonesia | 64 | 0.005 | 58 | **0.200** | 64 | 0 |
| Honduras | 65 | 0.004 | 61 | **0.194** | 65 | 0 |
| Albania | 66 | 0.004 | 65 | **0.189** | 66 | 0 |
| Zambia | 67 | 0.001 | 71 | **0.180** | 67 | 0 |
| Nicaragua | 68 | 0.004 | 62 | **0.180** | 68 | 0 |
| Guatemala | 69 | 0.004 | 64 | **0.176** | 69 | 0 |
| India | 70 | 0.001 | 81 | **0.169** | 70 | 0 |
| Morocco | 71 | 0.005 | 57 | **0.164** | 71 | 0 |
| Kenya | 72 | 0.001 | 74 | **0.153** | 72 | 0 |
| Ghana | 73 | 0.001 | 76 | **0.153** | 73 | 0 |
| Cameroon | 74 | 0.001 | 80 | **0.144** | 74 | 0 |
| Pakistan | 75 | 0.001 | 75 | **0.144** | 75 | 0 |
| Tanzania | 76 | 0.001 | 77 | **0.116** | 76 | 0 |
| Senegal | 77 | 0.001 | 72 | **0.114** | 77 | 0 |
| Nigeria | 78 | 0.002 | 68 | **0.107** | 78 | 0 |
| Yemen, Rep. | 79 | 0.001 | 73 | **0.105** | 79 | 0 |
| Malawi | 80 | 0.000 | 83 | **0.100** | 80 | 0 |
| Uganda | 81 | 0.001 | 79 | **0.100** | 81 | 0 |
| Bangladesh | 82 | 0.000 | 84 | **0.092** | 82 | 0 |
| Nepal | 83 | 0.000 | 85 | **0.091** | 83 | 0 |
| Madagascar | 84 | 0.000 | 82 | **0.087** | 84 | 0 |
| Mozambique | 85 | 0.001 | 78 | **0.073** | 85 | 0 |
| Ethiopia | 86 | 0.000 | 86 | **0.050** | 86 | 0 |

Linear correlation coefficient ($n = 86$) between the Arco Index and Global Technology Index = 0.990.
Correlation coefficient ($n = 86$) between Arco ranking and Global Technology ranking = 0.995.
[a] (1) Ranking ArCo slightly differs from the values reported in Table 1 because we consider here 86 countries. (2) Data taken from Lall and Albaladejo (2001, Table 9). Period coveres: 1995–98. (4) Global Technology Index is the arithmetic mean of four components: the three from ArCo plus Import Technology Index.

the variation of GDP over 1990–2000 on the variation of the ArCo values in the same period.

The first part of the table signals a high correlation between the two indicators for the whole set of countries. The differences across countries are so wide that it is not surprising that there is a very strong association between per capita technological capabilities and GDP. But this relationship becomes weaker when we

Table 8. *Link between ArCo Technology Index and GDP per capita*

| | Correlation coefficient | Constant | Regression coefficient | Standard error | *t*-Statistic | $R^2$ |
|---|---|---|---|---|---|---|
| *Regression of current GDP per capita in PPP $ (99-01) on actual ArCo Technology Index (2000)* | | | | | | |
| All countries | 0.83 | −5007 | 40,518 | 5,162 | 7.85 | 0.69 |
| Leaders | 0.26 | 16,764 | 11,588 | 3,971 | 2.92 | 0.07 |
| Potential leaders | 0.31 | −25,722 | 87,105 | 9,261 | 9.41 | 0.10 |
| Latecomers | 0.29 | −2,555 | 26,117 | 3,880 | 6.73 | 0.08 |
| *Regression of the variation of GDP per capita in PPP $ in the last decade (1990–2000) on the variation of ArCo Technology Index in the same period* | | | | | | |
| All countries | 0.28 | 0.207 | 0.472 | 0.325 | 1.85[a] | 0.08 |
| Leaders | 0.46 | 0.207 | 1.082 | 0.213 | 5.08 | 0.21 |
| Potential leaders | 0.65 | −0.097 | 3.044 | 0.297 | 10.25 | 0.43 |
| Latecomers | 0.63 | −0.015 | 2.098 | 0.294 | 7.14 | 0.39 |

*Sources*: CSRS (1996a, 1996b), EPO (2002), ITU (2001), NSF (2000, 2002), UNESCO (2002), USPTO (2002) and World Bank (2003).

[a] The regression coefficient is not significant at a 5% confidence level.

look at more homogeneous groups: once we consider countries comparable in terms of technological capabilities, a larger variety of income levels emerges. The beta coefficients are all significant, although the square-*R* decreases as we focus on less-developed countries.

The bottom part of the table considers the dynamics: how is the variation in technological capabilities over a decade related to GDP variation? In this case, the relationship is weak for the full set of countries and the coefficient is not meaningful. But it becomes significant for every subgroup, especially for potential leaders and latecomers: improved technological capabilities are strongly associated to GDP growth. Of course, none of the results so far reported provide a unique interpretation on the causality between the two variables. Nor do they shed light on the impact of each component of the technological index (each subindex) on the GDP level and growth. The exploration of these links will be addressed in future research.

Elsewhere (see Archibugi & Coco, 2004) we ran a regression of the ArCo index on gross capital formation to explore whether the evolution of investments affected the technological capabilities in the different countries. The results show a slightly negative correlation, because the countries which invested more in the last decade are the poorer ones, therefore the ones with a lesser dowry of scientific and technological capability.

## 8. CONCLUSIONS

It is generally assumed that technological capabilities are a fundamental component for achieving substantive goals such as a satisfactory quality of life or a higher income. But in order to understand properly the role of technological capabilities in social and economic development, this should be conceptualized and quantified. As Kula (1986) showed, the conceptualization is necessarily associated to the quantification, and *vice versa*.

This paper presents a fresh attempt to develop an index of technological capabilities for a large number of countries and for two periods of time. It follows other similar attempts, although we some what modified the methodology. Our aim was to include a larger number of countries, and to rely on dependable data sources. This led to the inclusion of some indicators and to the exclusion of others. In the case of technology creation, resources devoted to R&D represent perhaps a better indicator than the combination of patents and scientific papers, but data for the majority of developing countries are either not reliable or not available. Further, we reported data on three technological infrastructures such as Internet, telephony and electricity, but we did not provide information about the stock of capital goods such as machinery and equipment. A careful scrutiny of the data indicates that they are either not available or not reliable for the number of countries we considered: on the one hand, we hope that electricity consumption can be a good proxy for capital machinery and equipment; on the other hand, this allowed us to keep ArCo entirely independent from any indicator expressed in monetary value. Finally, as regards human resources, an ideal indicator would have been the job qualifications, allowing us to capture learning-by-doing and learning-by-using in the working process (Archibugi & Lundvall, 2001). But, again, these data are available for a much more restricted number of countries and they are hardly comparable.

We are aware of the limitations of each of the indicators employed, but we believe that they provide a faithful picture of the capabilities of each country. Overall, the results achieved confirm expectations. A great deal can be done in order to improve the quality of the data and to refine the index. We hope that this attempt will be a further incentive to promote the production of statistics on science and technology, especially from those institutions, such as UNDP, UNCTAD, UNIDO, UNESCO, the World Bank and others, that pioneered and generated data in the field. In future research, we will test the similarities and differences between the measure here presented and other comparable technological indicators. The database will also allow mapping countries according to their technological characteristics (besides their aggregate technological level), and this will hopefully help science and technology policy analysis for development.

The creation of a database is a preliminary condition to study the determinants and the impact of technological change. We know that technological capabilities are multifarious, and that aggregate and macroeconomic measures do not provide a faithful account. But this database might help test a few hypotheses often discussed in the literature.

First, it might contribute to the vast literature on how technological capabilities are associated to economic growth. A large number of hypotheses discussed in the literature (see the review by Fagerberg, 1994) can be tested, and ours is but a preliminary attempt. It is widely debated whether the technological capabilities are a determinant or an effect of economic growth. As with the chicken and the egg dilemma, it is difficult to determine with a single answer. We expect the various sources of technological capability to have a different impact on economic growth, and this will also depend on the income level achieved by each country. Certainly the same component will have a different impact across countries with such a large differences in income level.

Second, it might be possible to relate this indicator to economic aspects such as production and employment. Again, there will be no overlap between the ArCo Technology Index and measures for these economic activities. The index could also allow relate international trade to technological capabilities since no trade indicators are included. This should be understood in two ways: the first is to explore how economic and social openness helps the development of technological capabilities, the second is how technological capabilities can be seen as a determinant of international competitiveness.

## NOTES

1. In a companion paper (Archibugi & Coco, 2004), we explore the similarities and differences between ArCo and these measures. In order to carry out these comparisons, we had to restrict the number of countries in the sample. While the overall ranking of countries is broadly comparable, a few significant differences emerge. This is associated to both the statistical method and indicators used and to the slightly different purposes of the various approaches.

2. In principle, this implies that the three categories can be perfect substitutes: a reduction in the level of technology creation, for example, independently from the starting level, can be perfectly compensated by an equal increase in the level of human skills. The arithmetic mean does not take into account the dispersion of the three subindexes. If we wanted to consider this aspect, we could use the geometric mean, which assumes as much higher values as closer the three subindexes are. Anyway we maintained the aggregation criteria of arithmetic mean used by other established indicators (including the Human Development Index), even because the geometric one results are too sensitive to code values, often caused by an incompleteness of data for some indicator and for the poorest countries.

3. See World Bank (2003). Data are reported in greater detail in the World Bank web site. In this paper, we will refer to the World Bank Report, although some of the information used is reported in the web site only.

4. The former USSR is the combination of the former republics. In 1986–88 we assigned articles to the ex-Soviet Republics according to their shares of the 1995–97 period; the same is true for Croatia, Slovenia, and Macedonia inside the ex-Yugoslavia and for Czech Republic and Slovakia inside the ex-Czechoslovakia. German data are combined for all years.

5. The data were obtained by multiplying in each country the proportion of the population over 14 who completed the primary, secondary and tertiary education by the duration of the respective education's levels. Not all the countries could be analyzed due to a shortage of data; we proceeded to estimate the data for Russia, by using Unesco data and the data made available by Russian Centre for Science Research and Statistics (CSRS, 1996a, 1996b). In Russia, three years of primary school, seven years of secondary school and from 6 to 9 years of higher education are contemplated. We used the gross enrolment ratio to the secondary level (93%) as a proxy of the proportion of the population who completed the primary school, and the enrolment to the tertiary level (58%) as a proxy of the population who completed the secondary school; finally we calculated the average between the proportion of graduated over the population and the proportion of enrolled at University in the population (1.2%). With these data we estimated the mean years of schooling for Russia according to the following expression:

$$MS = 3 \times 0.93 + 7 \times 0.58 + 9 \times 0.012 = 6.96.$$

In a similar manner, we estimated the other missing values, for some African, Asian and ex-USSR countries.

6. The classification of countries according to the ArCo values is, of course, arbitrary. But since this is the first presentation of our index, we show the ranking produced by this measure. In future research, we plan to take into account aggregations according to other criteria (regions, high, medium and low income, high-medium- and low-human development, etc.). We also plan to relate the technological position of countries, as measured by ArCo, with other measures of technological activity (Archibugi & Coco, 2004) as well as with other social and economic indicators.

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