Journal of Human Development, Vol. 3, No. 1, 2002

Carfax Publishing
Taylor & Francis Group

*Measuring the Technology Achievement of Nations and the Capacity to Participate in the Network Age**

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> Development in the network age without the Internet is like industrialization without electricity. (Castells, 2000)

Introduction

The technological transformations of the past decade and the emergence of the global marketplace have raised the stakes for all countries to become technologically connected — to be able to create, adapt and use global technological innovations. Yet the challenges of competing in the technology-based global marketplace and of harnessing technology as a tool for human development are very different across countries, which vary greatly in their technological capacity and needs. This paper presents a measurement approach to assess the technological achievements of a country, as an aid to policy-makers in identifying policy priorities. It sets out the rationale for and uses of the Technology Achievement Index (TAI),[1] a composite measure of technological progress that ranks countries on a comparative global scale.

A new paradigm of technology and development

As we enter the network age, some two billion people still do not have access to electricity, the basic technology of the industrial age. Global technological innovation is very concentrated in the high-income OECD countries. These countries, with 14% of world population, accounted for 86% of the 836 000 patent applications filed globally in 1998, and 85% of 437 000 scientific articles published worldwide (World Intellectual Property

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ISSN 1464-9888 print/ISSN 1469-9516 online/03/010095-28 © 2002 United Nations Development Programme
DOI: 10.1080/14649880120105399

Organization, 2000; World Bank, 2001). Of all royalties and license fees earned worldwide in 1999, 54% went to the US and 12% to Japan (World Bank, 2001). Despite rapid expansion of the Internet in developing countries, the digital divide is still huge. Internet users made up over one-half of the US population and nearly one-third of the rest of OECD countries, but still 3% or less in Latin America and East Asia, and 1% or less in South Asia, Sub-Saharan Africa and the Arab States (Nua, 2001).

Even old technologies that have been in existence for over a century have stalled — in sub-Saharan Africa, per-capita electricity consumption has not risen for the past decade and, since 1970, tractor use rate declined from 1.8 to 1.5 per 1000 hectares cultivated (Food and Agriculture Organization, 2000). Telephones are similarly out of reach for much of the developing world — contrast the lines per capita: 594 per 1000 people in the high-income OECD countries, and 69 per 1000 people in developing countries on average (International Telecommunication Union, 2001b). Although wireless phones have spread rapidly in poor countries, they have done so even more rapidly in the rich countries — widening the communications gap.

The gaps in technological advances can further widen developmental divides in the twenty-first century, as rapid technological transformations drive the historic shift from the industrial to the network age (Sagasti, 2000). The breakthroughs in biotechnology and in information and communications technology (ICT) are extending the frontiers of medicine, food production, communications, and many other activities that make possible major gains in human development. The technology sector is also the fastest growing sector of the global economy (Lall, 2000b).

The challenge of rethinking development policies goes beyond considering these incremental changes. Technological advances are now more rapid (e.g. a doubling of computing power every 18 months), more fundamental (e.g. breakthroughs in genetic engineering), and more dramatic in terms of cost (e.g. the decline in cost of transmitting trillion bits of information from US$150 000 to just 12 cents over the past three decades). The developments in biotechnology and information technology codify, store, process and communicate information and knowledge. These advances are pervasive 'inputs' into almost all human activities, and so have impacts throughout society. Production, research, and many other activities are restructured into 'networks' of individuals and organizations specialized into niches of expertise, with the costs of communications driven down to zero and geographical boundaries falling.

The network age is changing the way (by whom and where) technological innovation is created and diffused. Global research and development activities are increasingly privatized and networked. Corporations have resources and the ownership (patents) to finance R&D and to take products to market. They take cutting-edge innovations and carry them across the globe through direct foreign investments and licenses. Entrepreneurs with start-up companies take higher risk technological innovations to the market, financed by venture capital (Lall, 2001). Global markets and global rules of intellectual property shape incentives and diffusion.

A new map of technology creation and diffusion is emerging. Centres of global technology innovation are the 'hubs' that spin in the synergy of four inputs needed for technology development: knowledge, market opportunities, finance, and incentives. Top scientists from around the world congregate in these hubs, as do foreign direct investment, technology stocks and venture capital. In a global network, working collaboratively, migrating from one global laboratory or incubator to the next, the hubs and their actors circumnavigate the globe.

Developing technological capacity

Not all countries need to be on the cutting age of global technological advance, but every country needs the capacity to understand and adapt global technologies for local needs. It is often mistakenly assumed that technology transfer and diffusion are relatively easy, that developing countries can simply import and apply knowledge from outside by obtaining equipment, seeds and pills. But for firms or farms to use a new technology — to identify its potential benefits, to learn it, and adapt it — requires new skills and the ability to learn and develop new skills with ease (Lall, 2000b). For example, a study from Thailand shows that 4 years of education triples the chance that a farmer will use fertilizer effectively (Lipton *et al.*, 2001). Furthermore, with today's rapidity of technological advance, the skill and knowledge required is the adaptability to master new technology continuously.

Beyond the capacity to use or adopt new techniques, developing countries also need capacity to invent and adapt new technologies. Global markets will not develop cures for malaria, cheap wireless computers, or pest-resistant cassava — products with huge gains for the well being of poor people but not much profit potential. Poor countries need to foster their own creativity to use both local and global knowledge and science to find technological solutions to their development problems. Centres of excellence in the 'South' can do much to produce technology tools for tackling poverty.

There is a long history of efforts to develop science and technology in developing countries. In the network age, nurturing technological creativity and access to global technologies requires flexible, competitive, dynamic economic environments, private and public sector institutions, and a minimum of physical infrastructure. Three kinds of capacity are particularly critical in this new environment. First, technological change dramatically raises the premium every country should place on investing in the education and training of its people. And in the network age, primary education will not suffice: the advanced science and engineering skills developed in secondary and tertiary schools, as well as vocational and on-the-job training, are increasingly important capacities. Second, the capacity to develop policies that manage technology such as intellectual property rights as well as the risks for socio-economic development, the environment and health. Third, the capacity to be connected to and participate in global technology development networks.

A number of developing countries, or parts of them, are well connected to global networks. Concentrated in North America, Western Europe and Japan, global hubs of innovation are emerging in developing countries such as those in Bangalore (India), El Ghazala (Tunisia), Sao Paolo (Brazil), and Gauteng (South Africa). Among the 46 top global hubs ranked by the Wired magazine ranking, nine are in Asia, two in South America, and two in Africa (Hillner, 2000). Developing countries are competitive in global markets for technology intensive products. Korea, Singapore, China, Mexico, Malaysia are among the top 15 exporters of high-technology products, and outpace Ireland, Canada, Sweden and other long industrialized countries. Private sector investments in research-based technology sectors are increasing (Chako, 2001). Migration creates diaspora, which in turn creates business networks. Take the strong link between Silicon Valley and Bangalore, built on the Indian diaspora. A global labour market is in the making in skill-intensive professions, and the diasporas strengthen the social ties in economic networks as they invest at home, but also facilitate contacts for market access (Kapur, 2001).

Most significantly, public and private sector efforts are producing breakthroughs in adaptations that meet the needs of human development, from the public initiative to develop a low-cost computer in Brazil to India's simputer, a $300 computer that is wireless and runs on batteries, to malaria treatment in Vietnam that combines traditional herbal knowledge with modern science (WHO, 2000; Simputer Trust, 2000; Kirkman, 2001).

Assessing national capacity: the Technology Achievement Index

Concept and features

When a country reviews its technology policies, a useful starting point is a realistic assessment of its current situation in technological progress. The TAI, a composite index of technological achievement, reflects the level of technological progress and thus the capacity of a country to participate in the network age. A composite index helps a country situate itself relative to others, especially those farther ahead. Many elements make up a country's technological achievement, but an overall assessment is more easily made based on a single composite measure than on dozens of different measures. Like other composite indices in *Human Development Reports* such as the Human Development Index (HDI), the TAI is intended to be used as a starting point to make an overall assessment, to be followed by examining different indicators in greater detail.

The index aims to capture technological achievements of a country in four dimensions:

- creating new technology;
- diffusing recent innovations;
- diffusing existing technologies that are still basic inputs to the industrial and the network age; and
- building a human skill base for technological creation and adoption.

The index focuses on outcomes and achievements rather than on effort or inputs such as numbers of scientists, R&D expenditures, or policy environments. This is because the causal relationship between these inputs and outcomes are not well known. For example, does a larger number of scientists lead to more output in technological advance? Do countries that spend more on R&D achieve more?

These approaches differ from some other indexes of technological advance that have been developed. The Technology Index published in the Harvard Competitiveness Reports focuses on the enabling policy environment for technological innovation and diffusion.[2] The Index of Technological Progress developed by Rodriguez and Wilson focuses only on information telecommunications technologies.[3]

The TAI is not a measure of which country is leading in global technology development, but focuses on how well the country as a whole is participating in creating and using technology. Take the US (a global technology powerhouse) and Finland. The US has far more inventions and Internet hosts in total than does Finland, but it does not rank as highly in the index because in Finland the Internet is more widely diffused and more is being done to develop a technological skill base throughout the population.

Two particular concerns influenced the design of this index.

- First, the concern to make it as relevant as possible for the broad range of the world's countries, especially developing countries with low levels of technological advance, and to be able to distinguish amongst these countries. Large proportions of people in these countries still do not have access to 'older' technologies such as the telephone, electricity, agricultural machines, or motorized transport. It was important to include a broad range of 'new' and 'old' technologies.
- Second, the concern to be of direct policy relevance to the challenges faced by a wide range of countries.

Components of the index

The TAI focuses on four dimensions of technological capacity that are important to reap the benefits of the network age. These indicators relate to important technology policy objectives for all countries, regardless of their level of development.

- *Creation of technology.* Not all countries need to be at the leading edge of global technological development, but the capacity to innovate is relevant for all countries and constitutes the highest level of technological capacity. The global economy gives big rewards to the leaders and owners of technological innovation. All countries need to have the capacity to innovate because the ability to innovate in the use of technology cannot be fully developed without the capacity to create, especially to adapt products and processes to local conditions. Innovation occurs throughout society, in formal and informal settings, although the current trend is towards increasing commercialization and formalization of the process of innovation. In the absence of perfect indicators and data series, the TAI uses two indicators to capture the level of innovation in a society. The first is the number of patents granted per capita, to reflect the current level of invention activity. The second is receipt of royalty and license fees from abroad per capita, to reflect the stock of successful past innovations that are still useful and hence have market value.

- *Diffusion of recent innovations.* All countries must adopt innovations to benefit from the opportunities of the network age. This is measured by diffusion of the Internet, indispensable to participation, and by exports of high-technology and medium-technology products as a share of all exports. Higher technology goods present important opportunities to developing countries. Many high-technology sectors are among the most dynamic in the global economy. Upgrading the technology content of the manufacturing sector diversifies the economy and creates opportunities in new markets. The Internet is far more than a tool for rich countries. By dramatically increasing the access to information while decreasing the cost, the Internet has vast potential to aid political participation, to increase people's incomes, and to improve healthcare.
- *Diffusion of old innovations.* Participation in the network age requires diffusion of many old innovations. Although leapfrogging is sometimes possible, technological advancement is a cumulative process, and widespread diffusion of older innovations is necessary for adoption of later innovations. Two indicators used here (telephones and electricity) are especially important because they are needed to use newer technologies and are also pervasive inputs to a multitude of human activities. Both indicators are expressed as logarithms. However, they are capped at the average OECD level because they are important at the earlier stages of technological advance but not at the most advanced stages. Thus, while it is important for India to focus on diffusing electricity and telephones so that all its people can participate in the technological revolution, Japan and Sweden have passed that stage. Expressing the measure in logarithms ensures that, as the level increases, it contributes less to the index.
- *Human skills.* A critical mass of skills is indispensable to technological dynamism. Both creators and users of new technology need skills. Today's technology requires adaptability — skills to master the constant flow of new innovation. The foundations of such ability are basic education to develop cognitive skills and skills in science and mathematics. Cognitive skills are hard to define and measure. There have been some limited attempts of cross-country comparisons of skills, such as the International Adult Literacy Survey and the Trends in Mathematics and Science Study. They are, however, very limited in their coverage, particularly when it comes to developing countries. Instead, the mean years of schooling is used as a proxy. This measure gives a good indication of the overall level of basic educational skills in the population, notwithstanding the fact that education quality varies from country to country. The second indicator used to gauge human skills is the enrolment in tertiary education in science, mathematics and engineering. This measure gives an idea of the

current effort in developing advanced skills in science and mathematics. Every country needs this skill base to be able to adapt and innovate new technologies. Although it would be desirable to include indicators of vocational training, these data are not available.

Weighting and aggregation

The methodology used to calculate the TAI is similar to the HDI: a simple average of the dimensions of the index, which in turn is calculated based on the selected indicators. The TAI has eight indicators, two in each of the four dimensions.

- Technology creation, measured by the number of patents granted to residents per capita and by receipts of royalties and license fees from abroad per capita.
- Diffusion of recent innovations, measured by the number of Internet hosts per capita and the share of high-technology and medium-technology exports in total goods exports.
- Diffusion of old innovations, measured by telephones (mainline and cellular) per capita and electricity consumption per capita.
- Human skills, measured by the mean years of schooling in the population aged 15 and older, and the gross tertiary science enrolment ratio.

Two of the indicators, telephones per capita and electricity per capita, are also expressed as logarithms and capped at OECD average levels, as already discussed. Just as in the HDI, the values of the different indicators are normalized to a scale from 0 to 1 using goalposts, such that an indicator value that is equal to the upper goalpost will be normalized to 1 and a value equal to the lower goalpost will be normalized to 0, according to the formula:

$$\text{Indicator index} = \frac{\text{actual value} - \text{observed minimum value}}{\text{observed maximum value} - \text{observed minimum value}}$$

However, in the HDI, these goalposts are set to reflect a desirable standard. For example, the upper goalpost for life expectancy is set to 85 years — a society with this life expectancy can be said to have succeeded in providing a long and healthy life for its citizens. In contrast, there are no such desirable levels for the indicators in the TAI: they have in common the property that higher levels are better, but it is impossible to set a ‘desirable’ level of patenting activity or of high-technology and medium-technology exports. For this reason, the goalposts used in calculating the index are simply the observed minima and maxima of the indicators: for each indicator, the best-performing country is assigned a value of 1 and the worst a value of 0 for the index calculation. The obvious drawback of this approach is that it complicates trend analysis: when values change over time, goalposts also change, making the indices of two different time points incomparable. However, the TAI was not designed to measure change over time.

A second important issue is that of weighting of different indicators and dimensions. In the TAI, the four dimensions each contain two indicators. The index for each dimension is calculated as the simple average of the indicator indices in that dimension. The TAI, in turn, is the simple average of these four dimension indices. The indicators in each dimension are given equal weight, and the dimensions are given equal (one-quarter) weight in the final index. This means that diffusion of technology is, effectively, given more weight since two of the four dimensions deal with this. (For an example on how the index is calculated, see Appendix 1: Calculating the TAI.)

TAI values and rankings

TAI estimates have been prepared for 72 countries for which data are available and of acceptable quality, and are presented in Table 1. For other countries, data were missing or unsatisfactory for one or more indicators so the TAI could not be estimated. For a number of countries in the developing world, data on patents and royalties are missing. Because a lack of data generally indicates that little formal innovation is occurring, a value of zero for the missing indicator was used in these cases.

Global patterns

The results show great disparities among countries as well as diversity and dynamism in technological progress among developing countries. As can be seen in Table 1 there are four groups of countries, with TAI values ranging from 0.744 for Finland to 0.066 for Mozambique. These countries can be considered leaders, potential leaders, dynamic adopters or marginalized.

- *Leaders (TAI> 0.5)*. Topped by Finland, the US, Sweden and Japan. This group is at the cutting edge of technological innovation. Technological innovation is self-sustaining, and these countries have high achievements in technology creation, diffusion and skills. Coming fifth is the Republic of Korea, and eighth is Singapore — two countries that have advanced rapidly in technology in recent decades. This group is set apart from the rest by its higher invention index, with a marked gap between Israel in this group and Spain in the next.
- *Potential leaders (TAI = 0.35–0.49)*. Most of these countries have invested in high levels of human skills and have diffused old technologies widely. However, they innovate little. Each tends to rank low in one or two dimensions, such as diffusion of recent innovations or of old inventions. Most countries in this group have skill levels comparable with those in the top group.
- *Dynamic adopters (TAI = 0.20–0.34)*. These countries are dynamic in the use of new technology. Most are developing countries with significantly higher human skills than the fourth group. They include Brazil, China, India, Indonesia, South Africa and Tunisia. Many of these countries have important high-technology industries and technology hubs, but the diffusion of old inventions is slow and incomplete.

TABLE 1. The Technology Achievement Index

TAI rank	Country	TAI value	Technology creation: Patents granted to residents (per million people), 1998[a]	Technology creation: Receipts of royalty and license fees (US$ per 1000 people), 1999[b]	Diffusion of recent innovations: Internet hosts (per 1000 people), 2000	Diffusion of recent innovations: High- and medium-technology exports (as % of total goods exports), 1999	Diffusion of old innovations: Telephones (mainlines and cellular, per 1000 people), 1999	Diffusion of old innovations: Electricity consumption (kW h per capita), 1998	Human skills: Mean years of schooling (age 15 and older), 2000	Human skills: Gross tertiary science enrolment ratio (%), 1995–1997[c]
Leaders										
1	Finland	0.744	187	125.6	200.2	50.7	1 203[d]	14 129[e]	10.0	27.4
2	US	0.733	289	130.0	179.1	66.2	993[d]	11 832[e]	12.1	13.9[f]
3	Sweden	0.703	271	156.6	125.8	59.7	1 247[d]	13 955[e]	11.4	15.3
4	Japan	0.698	994	64.6	49.0	80.8	1 007[d]	7 322[e]	9.5	10.0[g]
5	Korea, Republic of	0.666	779	9.8	4.8	66.7	938[d]	4 497	10.8	23.2
6	Netherlands	0.630	189	151.2	136.0	50.9	1 042[d]	5 908	9.4	9.5
7	UK	0.606	82	134.0	57.4	61.9	1 037[d]	5 327	9.4	14.9
8	Singapore	0.591	8	14.6[b,i]	72.3	74.9	901	6 771	7.1	24.2[b]
9	Canada	0.589	31	38.6	108.0	48.7	881	15 071[e]	11.6	14.2[f]
10	Australia	0.587	75	18.2	125.9	16.2	862	8 717[e]	10.9	25.3
11	Germany	0.583	235	36.8	41.2	64.2	874	5 681	10.2	14.4
12	Norway	0.579	103	20.2[i]	193.6	19.0	1 329[d]	24 607[e]	11.9	11.2
13	Ireland	0.566	106	110.3	48.6	53.6	924[d]	4 760	9.4	12.3
14	Belgium	0.553	72	73.9	58.9	47.6	817	7 249[e]	9.3	13.6[f]
15	New Zealand	0.548	103	13.0	146.7	15.4	720	8 215[e]	11.7	13.1
16	Austria	0.544	165	14.8	84.2	50.3	987[d]	6 175	8.4	13.6
17	France	0.535	205	33.6	36.4	58.9	943[d]	6 287	7.9	12.6
18	Israel	0.514	74	43.6	43.2	45.0	918[d]	5 475	9.6	11.0[f]
Potential leaders										
19	Spain	0.481	42	8.6	21.0	53.4	730	4 195	7.3	15.6
20	Italy	0.471	13	9.8	30.4	51.0	991[d]	4 431	7.2	13.0
21	Czech Republic	0.465	28	4.2	25.0	51.7	560	4 748	9.5	8.2

Table 1. *Continued*

TAI rank	Country	TAI value	Technology creation		Diffusion of recent innovations		Diffusion of old innovations		Human skills	
			Patents granted to residents (per million people), 1998[a]	Receipts of royalty and license fees (US$ per 1000 people), 1999[b]	Internet hosts (per 1000 people), 2000	High- and medium-technology exports (as % of total goods exports), 1999	Telephones (mainlines and cellular, per 1000 people), 1999	Electricity consumption (kW h per capita), 1998	Mean years of schooling (age 15 and older), 2000	Gross tertiary science enrolment ratio (%), 1995–1997[c]
Leaders										
22	Hungary	0.464	26	6.2	21.6	63.5	533	2 888	9.1	7.7
23	Slovenia	0.458	105	4.0	20.3	49.5	687	5 096	7.1	10.6
24	Hong Kong, China (SAR)	0.455	6	. .	33.6	33.6	1 212[d]	5 244	9.4	9.8[f,g]
25	Slovakia	0.447	24	2.7	10.2	48.7	478	3 899	9.3	9.5
26	Greece	0.437	(.)	0.0[j]	16.4	17.9	839	3 739	8.7	17.2[f]
27	Portugal	0.419	6	2.7	17.7	40.7	892	3 396	5.9	12.0
28	Bulgaria	0.411	23	. .	3.7	30.0[i]	397	3 166	9.5	10.3
29	Poland	0.407	30	0.6	11.4	36.2	365	2 458	9.8	6.6[f]
30	Malaysia	0.396	. .	0.0	2.4	67.4	340	2 554	6.8	3.3[f]
31	Croatia	0.391	9	. .	6.7	41.7	431	2 463	6.3	10.6
32	Mexico	0.389	1	0.4	9.2	66.3	192	1 513	7.2	5.0
33	Cyprus	0.386	. .	. .	16.9	23.0	735	3 468	9.2	4.0
34	Argentina	0.381	8	0.5	8.7	19.0	322	1 891	8.8	12.0[g]
35	Romania	0.371	71	0.2	2.7	25.3	227	1 626	9.5	7.2
36	Costa Rica	0.358	. .	0.3	4.1	52.6	239	1 450	6.1	5.7[g]
37	Chile	0.357	. .	6.6	6.2	6.1	358	2 082	7.6	13.2
Dynamic adopters										
38	Uruguay	0.343	2	0.0[j]	19.6	13.3	366	1 788	7.6	7.3
39	South Africa	0.340	. .	1.7	8.4	30.2[k]	270	3 832	6.1	3.4
40	Thailand	0.337	1	0.3	1.6	48.9	124	1 345	6.5	4.6
41	Trinidad and Tobago	0.328	. .	0.0[i]	7.7	14.2	246	3 478	7.8	3.3
42	Panama	0.321	. .	0.0	1.9	5.1	251	1 211	8.6	8.5

43	Brazil	0.311	2	0.8	7.2	32.9	238	1 793	4.9	3.4
44	Philippines	0.300	(.)	0.1	0.4	32.8	77	451	8.2	5.2[f]
45	China	0.299	1	0.1	0.1	39.0	120	746	6.4	3.2
46	Bolivia	0.277	. .	0.2	0.3	26.0	113	409	5.6	7.7[f,g]
47	Colombia	0.274	1	0.2	1.9	13.7	236	866	5.3	5.2
48	Peru	0.271	. .	0.2	0.7	2.9	107	642	7.6	7.5[f]
49	Jamaica	0.261	. .	2.4	0.4	1.5[i]	255	2 252	5.3	1.6
50	Iran, Islamic Republic of	0.260	1	0.0[i]	(.)	2.0	133	1 343	5.3	6.5
51	Tunisia	0.255	. .	1.1	(.)	19.7	96	824	5.0	3.8
52	Paraguay	0.254	. .	35.3	0.5	2.0	137	756	6.2	2.2
53	Ecuador	0.253	. .	. .	0.3	3.2	122	625	6.4	6.0[f,g]
54	El Salvador	0.253	. .	0.2	0.3	19.2	138	559	5.2	3.6
55	Dominican Republic	0.244	. .	. .	1.7	5.7[i]	148	627	4.9	5.7
56	Syrian Arab Republic	0.240	. .	. .	0.0	1.2	102	838	5.8	4.6[g]
57	Egypt	0.236	(.)	0.7	0.1	8.8	77	861	5.5	2.9
58	Algeria	0.221	. .	. .	(.)	1.0	54	563	5.4	6.0
59	Zimbabwe	0.220	(.)	. .	0.5	12.0	36	896	5.4	1.6
60	Indonesia	0.211	. .	. .	0.2	17.9	40	320	5.0	3.1
61	Honduras	0.208	. .	0.0	(.)	8.2	57	446	4.8	3.0[g]
62	Sri Lanka	0.203	. .	. .	0.2	5.2	49	244	6.9	1.4
63	India	0.201	1	(.)	0.1	16.6[i]	28	384	5.1	1.7
Marginalized										
64	Nicaragua	0.185	. .	. .	0.4	3.6	39	281	4.6	3.8
65	Pakistan	0.167	. .	(.)[j]	0.1	7.9	24	337	3.9	1.4[f,g]
66	Senegal	0.158	. .	0.0[j]	0.2	28.5	27	111	2.6	0.5[f,g]
67	Ghana	0.139	(.)	. .	(.)	4.1	12	289	3.9	0.4[f,g]
68	Kenya	0.129	(.)	(.)	0.2	7.2	11	129	4.2	0.3[f]
69	Nepal	0.081	. .	0.0	0.1	1.9[i]	12	47	2.4	0.7
70	Tanzania, United Republic of	0.080	. .	(.)	(.)	6.7	6	54	2.7	0.2
71	Sudan	0.071	. .	0.0	0.0	0.4[i]	9	47	2.1	0.7[f,g]
72	Mozambique	0.066	. .	. .	(.)	12.2[i]	5	54	1.1	0.2

TABLE 1. *Continued*

TAI rank	Country	TAI value	Technology creation		Diffusion of recent innovations		Diffusion of old innovations		Human skills	
			Patents granted to residents (per million people), 1998[a]	Receipts of royalty and license fees (US$ per 1000 people), 1999[b]	Internet hosts (per 1000 people), 2000	High- and medium-technology exports (as % of total goods exports), 1999	Telephones (mainlines and cellular, per 1000 people), 1999	Electricity consumption (kW h per capita), 1998	Mean years of schooling (age 15 and older), 2000	Gross tertiary science enrolment ratio (%), 1995–1997[c]
Others										
	Afghanistan	.	. .	. .	0.0	. .	1	. .	1.7	. .
	Albania	.	. .	. .	0.1	4.2[i]	39	678	. .	2.7
	American Samoa	.	. .	. .	. .	. .	248	. .	. .	. .
	Andorra	.	. .	. .	23.2	. .	722	. .	. .	. .
	Angola	.	. .	. .	(.)	. .	10	60	. .	. .
	Anguilla	.	. .	. .	. .	. .	. .	. .	. .	. .
	Antigua and Barbuda	.	. .	. .	6.6	. .	602	. .	. .	. .
	Armenia	.	8	. .	0.9	11.7	158	930	. .	4.0
	Aruba	.	. .	. .	5.0	53.5[i]	494	. .	. .	. .
	Azerbaijan	.	. .	. .	0.1	6.3	118	1 584	. .	7.3[f]
	Bahamas	.	. .	. .	. .	. .	422	. .	. .	..
	Bahrain	.	. .	. .	3.6	5.7[i]	453	7 645	6.1	6.7[f]
	Bangladesh	.	(.)	(.)	0.0	2.9[i]	5	81	2.6	. .
	Barbados	.	. .	0.8	0.5	31.3	538	. .	8.7	6.1
	Belarus	.	50	0.1	0.3	46.5	259	2 762	. .	14.4
	Belize	.	. .	0.0[i]	2.2	0.2[l]	182	. .	. .	. .
	Benin	.	. .	. .	(.)	. .	. .	46	2.3	0.5
	Bermuda	.	. .	. .	95.8	. .	. .	. .	. .	. .
	Bhutan	.	. .	. .	2.1	. .	18	. .	. .	. .
	Bosnia and Herzegovina	.	. .	. .	1.0	. .	110	539	. .	. .
	Botswana	.	1	(.)	2.7	. .	150	. .	6.3	1.6
	British Virgin Islands	.	. .	. .	. .	. .	. .	. .	. .	. .
	Brunei Darussalam	.	. .	. .	8.0	. .	451	7 676	. .	0.4

Burkina Faso	. .	. .	(.)	. .	5	. .	. .	0.2
Burundi	. .	0.0	0.0	. .	3	. .	. .	. .
Cambodia	. .	. .	(.)	. .	11	. .	. .	0.2
Cameroon	. .	. .	(.)	2.2[i]	. .	185	3.5	. .
Cape Verde	. .	(.)[i]	0.1	. .	131	. .	. .	. .
Cayman Islands	. .	. .	. .	. .	. .	. .	. .	. .
Central African Republic	. .	. .	(.)	13.6[i]	. .	. .	2.5	. .
Chad	. .	. .	(.)	. .	. .	. .	. .	0.1
Comoros	. .	. .	0.1	. .	10	. .	. .	. .
Congo	. .	0.0[j]	(.)	. .	. .	83	5.1	. .
Congo, Democratic Republic of the	. .	. .	(.)	. .	. .	110	3.0	. .
Cook Islands	. .	. .	. .	. .	. .	. .	. .	. .
Côte d'Ivoire	. .	. .	0.1	. .	33	. .	. .	. .
Cuba	. .	. .	0.1	. .	39	954	7.7	2.5
Denmark	52	. .	114.3	41.0	1 179	6 033	9.7	10.1
Djibouti	. .	. .	0.1	. .	14	. .	. .	. .
Dominica	. .	0.0[i]	4.1	50.7[l]	. .	. .	. .	. .
East Timor	. .	. .	. .	. .	. .	. .	. .	. .
Equatorial Guinea	. .	. .	0.0	. .	. .	. .	. .	. .
Eritrea	. .	. .	(.)	. .	7	. .	. .	. .
Estonia	1	1.2	43.1	31.9	624	3 531	. .	13.4
Ethiopia	. .	. .	(.)	. .	3	22	. .	0.3
Faeroe Islands	. .	. .	52.5	3.9	798	. .	. .	. .
Falkland Islands (Malvinas)	. .	. .	. .	. .	. .	. .	. .	. .
Fiji	. .	. .	0.9	. .	130	. .	8.3	. .
French Guiana	. .	. .	1.4	. .	386	. .	. .	. .
French Polynesia	. .	. .	9.3	. .	321	. .	. .	. .
Gabon	. .	. .	(.)	0.9[i]	39	749	. .	. .
Gambia	1	. .	(.)	. .	27	. .	2.3	. .
Georgia	67	. .	0.4	. .	142	1 257	. .	20.2
Gibraltar	. .	. .	. .	. .	935[d]	. .	. .	. .
Greenland	. .	. .	70.8	0.6	698	. .	. .	. .
Grenada	. .	. .	0.1	1.7[l]	337	. .	. .	. .

TABLE 1. *Continued*

TAI rank	Country	TAI value	Technology creation: Patents granted to residents (per million people), 1998[a]	Technology creation: Receipts of royalty and license fees (US$ per 1000 people), 1999[b]	Diffusion of recent innovations: Internet hosts (per 1000 people), 2000	Diffusion of recent innovations: High- and medium-technology exports (as % of total goods exports), 1999	Diffusion of old innovations: Telephones (mainlines and cellular, per 1000 people), 1999	Diffusion of old innovations: Electricity consumption (kW h per capita), 1998	Human skills: Mean years of schooling (age 15 and older), 2000	Human skills: Gross tertiary science enrolment ratio (%), 1995–1997[c]
	Guadeloupe	.	. .	. .	2.3	. .	643	. .	. .	. .
	Guam	.	. .	. .	1.5	. .	. .	. .	. .	. .
	Guatemala	.	(.)	. .	0.5	16.0	86	322	3.5	. .
	Guinea	.	. .	. .	(.)	. .	9	. .	. .	0.4
	Guinea-Bissau	.	. .	. .	(.)	. .	. .	. .	0.8	. .
	Guyana	.	. .	. .	0.1	. .	78	. .	6.3	2.7
	Haiti	.	. .	. .	0.0	3.2[i]	12	33	2.8	. .
	Holy See	.	. .	. .	. .	. .	. .	. .	. .	. .
	Iceland	.	15	. .	232.4	9.8	1 297	20 150	8.8	7.4
	Îles Turques et Caïques	.	. .	. .	. .	. .	. .	. .	. .	. .
	Îles Wallis et Futuna	.	. .	. .	. .	. .	. .	. .	. .	. .
	Iraq	.	. .	. .	0.0	. .	30	1 359	4.0	. .
	Isle of Man	.	. .	. .	. .	. .	. .	. .	. .	. .
	Jordan	.	. .	. .	0.2	. .	105	1 205	6.9	. .
	Kazakhstan	.	55	. .	0.6	15.0	111	2 399	. .	13.7
	Kiribati	.	. .	. .	1.0	. .	45	. .	. .	. .
	Korea, Democratic Republic	.	. .	. .	. .	. .	46	. .	. .	. .
	Kuwait	.	. .	. .	4.4	6.8	398	13 800	6.2	4.4
	Kyrgyzstan	.	14	. .	1.1	10.9	77	1 431	. .	3.3[f]
	Lao People's Democratic Republic	.	. .	. .	0.0	. .	8	. .	. .	. .
	Latvia	.	71	4.3	13.4	12.4	412	1 879	. .	9.5
	Lebanon	.	. .	. .	2.3	. .	. .	1 820	. .	4.5

Lesotho	. .	6.5	0.1	. .	. .	. .	4.2	0.3
Liberia	. .	. .	(.)	. .	. .	. .	2.5	. .
Libyan Arab Jamahiriya	. .	. .	(.)	1.8[i]	. .	3 677	. .	. .
Liechtenstein	. .	. .	. .	. .	902[d]	. .	. .	. .
Lithuania	27	(.)	7.5	29.2	401	1 909	. .	11.7
Luxembourg	202	272.6	49.5	34.0	1 211	12 400	. .	. .
Macau	. .	. .	0.7	3.7	610	. .	. .	2.7
Macedonia, TFYR	19	1.1	1.9	23.8 [i]	258	. .	. .	7.6
Madagascar	. .	(.)[i]	0.1	3.0	. .	. .	. .	0.4
Malawi	. .	. .	0.0	. .	6	. .	3.2	. .
Maldives	. .	0.0[j]	1.7	. .	90	. .	. .	. .
Mali	. .	. .	(.)	. .	. .	. .	0.9	. .
Malta	18	0.0	19.5	72.0	609	3 719	. .	3.9
Marshall Islands	. .	. .	0.1	. .	. .	. .	. .	. .
Martinique	. .	. .	1.6	. .	698	. .	. .	. .
Mauritania	. .	0.0[i]	(.)	. .	6	. .	. .	. .
Mauritius	. .	0.0	5.2	4.3	312	. .	6.0	1.0
Micronesia, Federal States of	. .	. .	6.2	. .	. .	. .	. .	. .
Moldova, Republic of	42	(.)	0.7	6.2	131	689	. .	12.0
Monaco	641	. .	. .	. .	. .	. .	. .	. .
Mongolia	56	0.4	0.1	3.2[i]	53	. .	. .	4.2
Montserrat	. .	. .	. .	. .	. .	. .	. .	. .
Morocco	3	0.2	0.1	12.4[i]	66	443	. .	3.2
Myanmar	. .	(.)	0.0	. .	6	64	2.8	2.3
Namibia	. .	3.5[i]	3.7	. .	82	. .	. .	0.4
Nauru	. .	. .	. .	. .	. .	. .	. .	. .
Netherlands Antilles	. .	. .	0.9	. .	. .	4 118	. .	. .
New Caledonia	. .	. .	2.3	. .	362	. .	. .	. .
Niger	. .	. .	(.)	. .	. .	. .	1.0	. .
Nigeria	. .	. .	(.)	0.4	. .	85	. .	1.8
Niue	. .	. .	. .	. .	. .	. .	. .	. .
Norfolk Island	. .	. .	. .	. .	. .	. .	. .	. .
Northern Mariana Islands	. .	. .	0.5	. .	526	. .	. .	. .
Occupied Palestinian Territory	. .	. .	. .	. .	. .	. .	. .	. .

Table 1. *Continued*

			Technology creation		Diffusion of recent innovations		Diffusion of old innovations		Human skills	
TAI rank	Country	TAI value	Patents granted to residents (per million people), 1998[a]	Receipts of royalty and license fees (US$ per 1000 people), 1999[b]	Internet hosts (per 1000 people), 2000	High- and medium-technology exports (as % of total goods exports), 1999	Telephones (mainlines and cellular, per 1000 people), 1999	Electricity consumption (kW h per capita), 1998	Mean years of schooling (age 15 and older), 2000	Gross tertiary science enrolment ratio (%), 1995–1997[c]
	Oman	.	..	..	1.4	13.2	139	2 828	..	2.4
	Palau	.	..	..	..	..	..	..	..	..
	Papua New Guinea	.	..	..	0.1	..	14	..	2.9	..
	Pitcairn	.	..	..	..	..	..	..	..	..
	Puerto Rico	.	..	..	0.6	..	542	..	..	..
	Qatar	.	..	..	..	..	406	13 912	..	..
	Reunion	.	..	..	(.)	..	..	..	..	..
	Russian Federation	.	131	0.3	3.5	16.0	220	3 937	..	19.7[g]
	Rwanda	.	..	0.0	0.1	..	3	..	2.6	..
	Saint Helena	.	..	..	..	..	..	..	..	..
	Saint Kitts and Nevis	.	..	..	0.2	30.6[i]	536	..	..	..
	Saint Lucia	.	..	..	0.2	5.4[i]	..	..	..	..
	Saint Pierre and Miquelon	.	..	..	..	1.2	..	..	..	..
	Saint Vincent and the Grenadines	.	..	..	(.)	2.0[i]	221	..	..	..
	Samoa (Western)	.	..	..	5.3	..	..	..	..	..
	San Marino	.	..	..	..	..	..	..	..	..
	Sao Tome and Principe	.	..	..	8.6	..	31	..	..	..
	Saudi Arabia	.	(.)	0.0	0.3	5.2[i]	170	4 692	..	2.8
	Seychelles	.	..	..	0.1	(.)[i]	..	..	..	..
	Sierra Leone	.	..	..	0.1	..	..	..	2.4	..
	Solomon Islands	.	..	0.1	1.4	..	21	..	..	..
	Somalia	.	..	..	0.0	..	..	..	..	..
	Suriname	.	..	0.0[i]	0.0	1.0[i]	213	..	..	..

Svalbard and Jan Mayen Islands	.	. .	. .	. .	. .	. .	. .	. .	. .
Swaziland	.	. .	0.2	1.4	. .	45	. .	6.0	1.3
Switzerland	.	183	. .	82.7	63.6	1 109	6 981	10.5	10.3
Taiwan Province of China	.	. .	. .	74.3	61.3[i]	1 068[d]	6 287	8.8	. .
Tajikistan	.	2	. .	0.1	. .	35	2 046	. .	4.7
Togo	.	. .	. .	0.1	0.4	12	. .	3.3	0.4
Tokelau	.	. .	. .	. .	. .	. .	. .	. .	. .
Tonga	.	. .	. .	82.6	. .	94	. .	. .	. .
Turkey	.	(.)	. .	2.5	26.7	384	1 353	5.3	4.7
Turkmenistan	.	10	. .	0.3	. .	83	859	. .	. .
Tuvalu	.	. .	. .	. .	. .	. .	. .	. .	. .
Uganda	.	. .	0.0[j]	(.)	2.2	5	. .	3.5	0.3
Ukraine	.	84	. .	1.2	. .	203	2 350	. .	. .
United Arab Emirates	.	. .	. .	20.9	. .	754	9 892	. .	3.2
Uzbekistan	.	25	. .	(.)	. .	68	1 618	. .	. .
Vanuatu	.	. .	. .	1.6	. .	. .	. .	. .	. .
Venezuela	.	. .	0.0	1.2	6.2	253	2 566	6.6	. .
Viet Nam	.	. .	. .	(.)	. .	31	232	. .	. .
Virgin Islands (US)	.	. .	. .	9.2	. .	. .	. .	. .	. .
Western Sahara	.	. .	. .	. .	. .	. .	. .	. .	. .
Yemen	.	. .	. .	(.)	. .	18	96	. .	0.2
Yugoslavia	.	19	. .	2.4	23.4[i]	271	. .	. .	9.0
Zambia	.	(.)	. .	0.2	. .	12	539	5.5	. .

[a] For purposes of calculating the TAI, a value of zero was used for countries for which no data were available. [b] For purposes of calculating the TAI, a value of zero was used for non-OECD countries for which no data were available. [c] Data refer to the most recent year available during the period specified. [d] For purposes of calculating the TAI, the weighted average value for OECD countries (901) was used. [e] For purposes of calculating the TAI, the weighted average value for OECD countries (6969) was used. [f] Data refer to the most recent year available during the period 1989–1994. [g] Data are based on preliminary UNESCO estimates of the tertiary gross enrolment ratio. [h] Data from national sources. [i] Data refer to 1998. [j] Data refer to 1997. [k] Data refer to the South African Customs Union which comprises Botswana, Lesotho, Namibia, South Africa and Swaziland. [l] Data refer to medium-technology exports only.

Source: Column 1, calculated on the basis of data in columns 2–9; column 2, World Intellectual Property Organization (2000); column 3 (unless otherwise noted), World Bank (2001); column 4, International Telecommunication Union (2001a); column 5, calculated on the basis of data on exports from Lall (2001) and United Nations (2001); column 6, International Telecommunication Union (2001b); column 7, World Bank (2001); column 8, Barro and Lee (2000); column 9, calculated on the basis of data on gross tertiary enrolment ratios and tertiary science enrolment from UNESCO (1998a, 1999, 2001).

- *Marginalized (TAI< 0.20).* Technology diffusion and skill building have a long way to go in these countries. Large parts of the population have not benefited from the diffusion of old technology.

These rankings do not shadow income rankings and show considerable dynamism in several countries with rising technological achievement. For example, Korea ranks above the UK, Canada and other established industrial economies. Ireland ranks above Austria and France. Large developing countries (Brazil, China, India) do less well than one might expect because this is not a ranking of 'technological might' of a country. Finally, technology hubs have a limited effect on the index because of disparities within countries. If the TAI were estimated only for the hubs, such countries would undoubtedly rank as leaders or potential leaders.

Policy priorities for countries

A look at a country's TAI ranking and composition can reveal areas of strengths and weaknesses. This can be illustrated by the cases of Brazil, Mexico and India.

Brazil. Brazil is one of the most dynamic countries in Latin America, having two world-class technology hubs in Sao Paolo and Rio de Janeiro, and being in the forefront of policy initiatives in global fora in areas such as the management of intellectual property. Yet the country ranks relatively poorly in the TAI at 43rd place, behind a number of other developing countries such as Malaysia, Mexico, Argentina, Costa Rica, Chile, Uruguay, Thailand, and South Africa. Why?

First, the diffusion of old inventions (telephones and electricity) has been slow. Brazil lags far behind such countries as Malaysia, Argentina, and Chile. The likelihood is that these basic technologies that have been around for a century have still not reached rural communities and poorer families. And these two technologies are fundamental building blocks to being fully linked to the new technologies driving progress in the twenty-first century.

Second, Brazil lags behind in training people with skills. For example, enrolment of Brazilian students in science and mathematics in post-secondary education is only 3.2% of the age group, far less than the 13.2% in Chile or 7.3 % in Uruguay. Developing countries that have made the most rapid progress in technological achievements (Korea and Singapore) have invested heavily in education. Gross enrolment rates are over 20%. Mean years of schooling in Brazil is 4.9 years, compared with 6.8 years in Malaysia, 8.8 years in Argentina, 7.2 years in Mexico and 6.1 years in South Africa. The proportion of students in universities and other tertiary level institutions enrolled in science and mathematics is only 3.2% of the age group in contrast to over 10% in Argentina, Chile, and the OECD average.

Technological advance is more rapid and more fundamental than it has ever been before in any historical era. Workers have to adapt to new technologies all the time, and that means that basic education is a necessity.

Does Brazil's education system need to be re-thought so as to meet the challenges of the network age?

Third, Brazil is doing better than Argentina and Chile in entering the high-technology export markets. But is this leading to linkages to dynamic development of the rest of the economy? Are employers providing training for workers? Countries that have successfully used technology for sustained economic growth and for equitable development show high levels of commitment to diffusing technology widely through the population, and to the development of human skills. Countries as diverse as Finland, Korea, and Singapore all adopted very pro-active policies for increasing the quantity and quality of education in science and mathematics, scoring well not only in enrolment levels, but also in international performance tests. They also provided many incentives for businesses to train their workers and have invested heavily in the diffusion of technology.

While Brazil is participating in the network age with its world-class hubs and pioneering policies to make new technologies work for human development, it still has a long way to go in spreading technological progress throughout the country, to all its people.

Mexico. In contrast to Brazil, Mexico does well in the index, ranking number 32 out of 72 countries, higher than any other developing country except for the four Asian Tigers and cubs (Korea, Singapore, Hong Kong and Malaysia) and outranks Argentina, Costa Rica, Chile, Uruguay, and Brazil.

Mexico's high score is due, first and foremost, to its success in one measure: 66% of export earnings come from high-technology and medium-technology products. This is one of the highest levels in the world. The only other countries that have over 60% are the US, Japan, Korea, the UK, Germany, Hungary, and Malaysia. This clearly shows Mexico's extraordinary success in using new technologies. It shows that the country has responded very positively to the niche opportunities that are being created in the global market.

Yet other indicators show that Mexico has a long way to go in developing its technological capacity, and in translating that for the purposes of sustainable development for all its citizens.

First, the diffusion of old inventions (telephones and electricity) has been slow. Mexico lags far behind such countries as Malaysia, Argentina, and Chile. The likelihood is that these basic technologies, which have been around for a century, still have not reached rural communities and poorer families. And these two technologies are fundamental building blocks to being fully linked to the new technologies driving progress in the twenty-first century. The question for policy-makers is: How can this technological divide be bridged?

Second, the development of human skills is another fundamental building block of technological capacity. Here again, Mexico can do much more, especially in science and mathematics training. Mexico has made significant progress in improving overall education, achieving 7.2 years of schooling, a level comparable with Chile, Uruguay, Italy and Malaysia. Yet the proportion of students in universities and other tertiary level institutions enrolled in science and mathematics is only 5% of the age group in contrast to over 10% in Argentina, Chile, and the OECD average. In an age of rapid technological advance, workers have to adapt to new technologies all the time, and that means that basic education is a necessity. Is Mexico's education system adequate to meeting the challenges of the network age?

Third, much of the exports are from foreign direct investment. The same questions asked in regard to Brazil apply. Is this leading to linkages to dynamic development of the rest of the economy in Mexico? Are employers providing training for workers? Is Mexico able to climb up the skill ladder and move into more skill intensive segments of the high-technology and medium-technology industries?

Mexico's high rank in the TAI reflects the country's technological success in using advanced technology and the ability to compete successfully in the technology-based global marketplace. But there is a long way to go in diffusing technology — reaching poor people and empowering them to lift themselves out of poverty. The TAI for Mexico is a starting point for debates on national technology policies — not for technology, but for the use of technology in development that is dynamic and equitable.

India. India has achieved showcase success in exploiting the opportunities of the network age. The ICT industry exports rose from $150 million to nearly $4 billion in 1999. Bangalore is a world-class hub, and other centres of technological innovation are emerging and developing. Yet the country is only 63 out of 72 countries, at the bottom of the group of 'dynamic adopters'. Why?

First, while the country has considerable capacity in state-of-the-art technological innovation in new technologies, the TAI shows that these technological advances are not widespread. The country still only has 28 telephones per 1000 people, compared, for example, with 238 in Brazil, or 192 in Mexico. Mean years of schooling is only 5.1, whereas countries in the 'potential leaders' category have achieved more typically 8 or 9 years. It is also well known that rural electrification has a long way to go. The diffusion of technology has not been widespread, and the world-class capacity to innovate has not been translated into patents or royalties and licence earnings to any significant level.

Second, India is a large country with a very large population. This has tended to dilute the strengths of the country in world-class innovations.

Towards further developments

While this index provides interesting information for policy-makers, further work is needed to develop a more complete measure of technological achievements. To do so requires overcoming the limitations of both concept and data.

In concept, this index measures only technological achievements, not those that are relevant for human development. The technological achievements measured could be used as much for destructive purposes as for human well-being. The index does not indicate how well these achievements have been translated into human development. The index is also incomplete. A nation's technological achievements are larger and more complex than what this or any other index can capture. It is impossible to reflect the full range of technologies — from agriculture to medicine to manufacturing. Many aspects of technology creation, diffusion and human skills are hard to quantify. And even if they could be quantified, a lack of reliable data makes it impossible to fully reflect them. For example, important technological innovations occur in the informal sector and in indigenous knowledge systems. But these are not recorded and cannot be quantified. Thus, the TAI is constructed using indicators, not direct measures, of a country's achievements in four dimensions. It provides a rough summary, not a comprehensive measure, of a society's technological achievements.

The index is also incomplete in country coverage — limited in coverage to 72 out of the nearly 200 countries of the world. While this is broader than that achieved by some other indices, it is still far from ideal. The data used to construct the TAI are from international series that are the most widely used in analyses of technology trends, and so are considered the most reliable of available sets. The range of appropriate indicators is limited to those with reasonable coverage. Limitations in data series must be taken into account in interpreting TAI values and rankings. Some countries will have undervalued innovations because patent records and royalty payments are the only systematically collected data on technological innovation and leave out valuable but non-commercialized innovations such as those occurring in the informal sector and in indigenous knowledge systems. Moreover, national systems and traditions differ in scope and criteria. High numbers of patents may reflect liberal intellectual property systems. Diffusion of new technologies may be understated in many developing countries. Internet access is measured by Internet hosts because these data are more reliable and have better coverage than Internet user data at the country level. As technology policies gain prominence in development strategies, it is likely that progress will be made in overcoming both the data and conceptual limitations.

Notes

1. The index was developed for the *Human Development Report 2001*, Making New Technologies Work for Human Development, published by Oxford University Press for the United Nations Development Programme.
2. Andrew Warner developed an Economic Creativity Index, of which one component is the Technology Index, itself using either the Innovation Index or the Technology Transfer Index (World Economic Forum, 2000). The index is built in the context of competitiveness ranking countries by the 'economic creativity index'. The conceptual framework is stated as "nations can link themselves to the global technology engine by being centres of innovation themselves, or by facilitating technology transfer and rapid diffusion of innovation". But the index, which covers 61 countries, is focused on the enabling environment rather than on outcomes. There is a great deal of value judgement in the choice of indicators used. For example, Intellectual Property Rights is seen as an indicator of innovation. There is no indicator to show aggressive use of compulsory licensing or parallel imports of generic drugs as an indication of proactive policy to diffuse technology. The

innovation index is highly correlated with patents. The coverage is mostly OECD countries plus the transition economies and a handful of developing countries. It does not distinguish adequately among developing countries.

3. Rodriguez and Wilson (2000) developed an 'Index of Technological Progress'. It focuses on ICT, and combines televisions, fax machines, personal computers, Internet hosts and mobile phones. Consumption of technologically advanced commodities is not necessarily a good measure for the 'technological advance' of a country. Thus, for example, high-income/low-population countries like Kuwait and Qatar rank higher than Korea or Russia.

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Appendix 1. Calculating the technology achievement index: an example

Goalposts for calculating the TAI

Indicator	Observed maximum value	Observed minimum value
Patents granted to residents (per 1000 people)	994	0
Royalties and license fees received (US$ per 1000 people)	272.6	0
Internet hosts (per 1000 people)	232.4	0
High-technology and medium-technology exports (as % of total goods exports)	80.8	0
Telephones (mainline and cellular, per 1000 people)	901[a]	1
Electricity consumption (kwh per capita)	6969[a]	22
Mean years of schooling (aged 15 and above)	12.0	0.8
Gross tertiary science enrolment ratio (%)	27.4	0.1

[a] OECD average.

Calculating the TAI

This illustration of the calculation of the four dimensions of the TAI uses data for New Zealand for various years in 1997–2000.

1. Calculating the technology creation index. Patents and receipts of royalties and license fees are used to approximate the level of technology creation. Indices for the two indicators are calculated according to the general formulae.

Patent index $= (103 - 0)/(994 - 0) = 0.104$

Royalty and license fee index $= (13.0 - 0.0)/(272.6 - 0.0) = 0.048$

The technology creation index is the simple average of these two indices:

Technology creation index = (0.103 + 0.048)/2 = 0.076

2. Calculating the diffusion of recent innovations index. Using Internet hosts and the share of high-technology and medium-technology exports in total goods exports, the same formula is applied to calculate the diffusion of recent innovations index.

Internet host index = (146.7 − 0.0)/(232.4 − 0.0) = 0.631

High-technology and medium-technology export index = (15.4 − 0.0)/(80.8 − 0.0) = 0.191

Diffusion of recent innovations index = (0.631 + 0.190)/2 = 0.411

3. Calculating the diffusion of old innovations index. The two indicators used to represent the diffusion of old innovations are telephones (mainline and cellular) and electricity consumption per capita. For these, the indices are calculated using the logarithm of the value, and the upper goalpost is the OECD average.

Telephony index = (log 720 − log 1)/(log 901 − log 1) = 0.967

For electricity consumption, New Zealand's value is capped at 6914, since it exceeds the goalpost.

Electricity index = (log 6,969 − log 22)/(log 6,969 − log 22) = 1.000

Diffusion of old innovations index = (0.966 + 1.000)/2 = 0.984

4. Calculating the human skills index. The human skills index is calculated according to the general formula, using mean years of schooling and the gross tertiary science enrolment ratio.

Mean years of schooling index = (11.7 − 0.8)/(12.0 − 0.8) = 0.973

Gross tertiary science enrolment index = (13.1 − 0.1)/(27.3 − 0.1) = 0.474

Human skills index = (0.990 + 0.477)/2 = 0.725

5. Calculating the technology achievement index. A simple average of the four dimension indices gives us the technology achievement index.

TAI = (0.076 + 0.411 + 0.984 + 0.725)/4 = **0.549**

Note: Calculations based on data in the technical note may yield results that differ from those presented in Table 1 because of rounding.

Appendix 2. Statistics on technology

Technology creation

The capacity for technology creation is a complex and dynamic system that cannot be fully captured by any particular indicator. And, on a global scale, there is very little quantitative data on technology creation. For these reasons, it is impossible to give an accurate picture of technology creation capacity using only statistical evidence. Nonetheless, the data give a good indication of how technology creation capacity is distributed.

Patents

Patents are an often-used measure of innovation. Patents are clearly a very important indicator of innovative activity, as has been shown in numerous studies. What complicates the use of patent data is that patent regulations vary widely from country to country. Some countries allow patents on, for example, plant varieties or business methods, others do not. Also, many developing countries have weak national patent offices, and so residents of these countries might choose to apply for patents in other countries directly. Business practices in some countries produce a large number of patent applications that are not directly related to innovations. Also, industry structure has an impact: different industry sectors patent to varying degrees (Fleischer, 1999). There are two main patent indicators used to measure innovation: first-time patent applications filed by residents, and patents granted to residents. For the TAI, the number of patents granted was chosen, in order not to count applications that were not awarded patents. However, the time between application and grant is about 3 years, introducing an extra time lag in the index.

Receipts of royalties and license fees

Royalties and license fees are, effectively, payments for the use of the intellectual property. As such, this data gives valuable information on the stock of innovations — which countries are and have been successful in building capacity for technology creation. But like all other indicators, these data are not perfect. Widely available data includes only payments received from abroad, not domestic payments. This penalizes large countries, who are less internationally oriented. The second problem is that the data include payments not only for the use of innovations, but also other kinds of intellectual property, such as publishing rights (World Bank, 2001).

Publications of scientific articles

The production of scientific articles is an established measure of scientific activity. There are, however, serious problems with this measure (UNESCO, 1998b). Some of the most important are as follows.

- The selection of publications where articles are counted. Existing measures, such as the Institute for Scientific Information, suffer from a heavy Anglo-Saxon bias.
- Scientific articles are only one output of science. They do not directly measure such things as the quality of higher education or technical skills.
- The output of articles depends very much on the structure of R&D. In some disciplines, such as medicine, researchers publish many more articles per year than in other disciplines.

These reasons make this indicator unsuitable for the TAI.

Research and development expenditures (as a percentage of Gross National Product)

A country's expenditure on research and development, usually as a percentage of Gross National Product, is a widely used measure of a country's efforts in technology creation. The TAI focuses on achievements, not efforts, which is why this indicator in not included.

Diffusion of technology

Manufacturing. Using technology in manufacturing is on important aspect of technology diffusion. There are two different approaches to measuring technology content in manufacturing: sectoral and product-based. The sectoral approach tries to classify different industries according to their technology intensity. Recent work by OECD in this field highlights some major problems with this approach. On the conceptual level, it is not clear whether technology intensity means using technology or producing technology. Beyond this conceptual problem, there are several practical problems. The most serious one is of cross-country comparability. Any particular industry (e.g. textiles) could be low technology in one country but high technology in another. Especially when comparing developing countries with developed, this is highly problematic. The product-based approach escapes these problems by measuring technology intensity of products, not sectors. Products in the same category by definition have the same technology content.

Because of the constraints of available data, exports were used as a proxy for manufacturing — the structure of exports is closely related to the structure of manufacturing for most countries.

There are different classification methods for exports by technology content. The OECD has proposed one, based on product categories in the export classification system known as Standard Industry and Trade Classification (SITC) revision 3 (Hatzichronoglou, 1997). This is a very detailed classification system. However, the OECD proposal only studies high-technology exports. Many poor countries have very little or no high-technology exports. To distinguish between these, it is important to also study medium-technology exports. For this reason, a classification by Lall

(2000a) was used in the TAI. This classification is based on SITC revision 2, which is less detailed but enables trend analysis. The classification distuingishes between high-technology, medium-technology and low technology exports, as well as resource-based manufactures and primary products.

Internet/computing. There are many ways to measure Internet diffusion. Of primary interest is how many people have the possibility of using the Internet should they need to do so. However, as in many other cases, the availability of data for developing countries is a major constraint. For many developing countries, Internet user surveys are of very poor quality or non-existent. User data are very often estimates with no basis in observations. Measuring Internet hosts instead of users is an attempt to escape these problems. A host is, in essence, a computer connected to the Internet. This is straightforward to count. While the number of Internet-connected computers does not directly tell us how many users there are, it gives a good indication, and data are available for practically all countries.

Electricity. Electricity is an old technology that is still not diffused to large parts of the world. It is crucial to almost all forms of technological development. Therefore, it is of great importance when measuring technology diffusion. The problem in measurement is that no data is available on the national level on how many people have access to electricity. The closest proxy available is consumption — the more people have access to electricity, the higher the consumption. Of course, other factors, such as geography, also influence consumption.

Telephony/telefax. Telephones are another old technology where diffusion has stalled, and one that is important to many other aspects of technological development. Fortunately, telephony diffusion is also easy to measure. Data on the number of telephone subscribers, both of landlines and cellular telephones, are widely available.

Human skills. Human skills are vital to be able to adapt to new technological realities, and are thus included in the TAI. Two indicators are used: mean years of schooling, and the gross tertiary science enrolment ratio.

Mean years of schooling. The mean years of schooling is the average number of years of school completed in the population of age 15 and older. While this measure does not take into account differences in the quality of schooling, it gives an indication of the level of human skills in the population.

To create these estimates, a combination of survey data on school attainment and time-series data on enrolment was used. The survey data gives information on proportions of the population that have completed primary, secondary and tertiary education. This data is available for about 40% of data points. Where this data is not available, trend data on gross enrolment, adjusted for repeaters, is used to estimate the proportions of the population having attained primary, secondary and tertiary education (Barro and Lee, 1993, 2000).

In the second step, these attainment levels are multiplied by the duration of the respective level in different countries to produce an estimate on the average years of schooling. These estimates are produced for two different groups, the population age 15 and older, and the population age 25 and older. For the TAI, the prior was chosen since it corresponds more closely to the age of the workforce, particularly in developing countries.

Enrolment data. The mean years of schooling is an indicator that moves very slowly. To reflect present efforts in building a technology skill base, it is useful to study enrolment data. While primary and secondary education are important, tertiary science education is vital to have the capacity to adapt to new technologies. This indicator refers to the number of students enrolled in technical and scientific tertiary education, as a share of the population in the relevant age range (19–24 years for most countries). The indicator used in the TAI is the gross tertiary science enrolment ratio, which refers to the number of students enrolled in technical and scientific tertiary education, as a share of the population in the relevant age range (19–24 years for most countries).