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The Challenge of Technological Learning for Developing Countries

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October 2005

[1] This draft paper was prepared under the overall guidance of the WB Science and Technology Program Coordinator Alfred J. Watkins and with research support from Ursula Maria Casabone.

ABSTRACT

Given the widely acknowledged importance of science and technology (S&T) as the primary drivers of national capacity for development, many development agencies (including UNDP, UNIDO and UNCTAD) undertook to classify developing countries according to their S&T capacity levels. Thus the World Bank has a choice of previously developed indices of S&T capacity that should help it to identify groups of client countries facing similar S&T capacity shortages and development constraints. However, the WB Science and Technology Program suggests supplementing these index-based groupings by a more dynamic, forward-looking and more qualitative classification, based on different models of technological learning.

Unlike other classifications, this approach does not presume that all countries should necessarily follow the same path of technological learning with the only difference among them being in different stages achieved on this common path. For example, such sources of new S&T knowledge as FDI or R&D, licensing of foreign inventions or controlling them through funding R&D performed by foreign researchers, can be used in different proportions depending not only on unequal national S&T capabilities but also on different learning opportunities available to countries as a result of their governments' policy choices and concurrent international environment. Based on these differences, most countries can be characterized as gravitating towards one of the 6 models, including 5 models of relatively fast S&T learning -- Passive FDI-dependent, Active FDI-dependent, Autonomous, Creative-isolated, Creative-cooperative -- and the model of Traditionalist slow learning.

Each of these models can be illustrated by a certain shape of the so-called "crystals of technological learning" (see above), which can also be used as a graphical/statistical tool for initial, relatively fast diagnostics of technological learning processes happening in particular. The first attempts at the practical application of this diagnostic tool to 3 very different countries -- Mauritius, Malaysia, and Russia -- appeared to be encouraging, but the Science and Technology Program Team at HDNED continues to work on further calibrating this new methodology. The Team very much counts on active discussion and critical suggestions regarding further improvements to the proposed methodological approach as well as its practical application to concrete countries.

Contents

1. Developing Countries in the 'Global' Knowledge Revolution

The popular expression "global knowledge revolution" appears to be overoptimistic and misleading. Only a handful of developing and transition countries have truly benefited from the new opportunities spawned by the global knowledge revolution, but all of them are struggling with new economic challenges and risks generated by that revolution. In addition to the growing income gap between groups of developed and developing countries, the technology-, education-, and information gaps are growing wider too. The problem for most World Bank clients is not only that the greatest share of new scientific and technological knowledge is now created in high-income countries (where about 85 percent of global R&D expenditure is concentrated) but that many developing countries face enormous difficulties in tapping international flows of existing knowledge and adapting it to their goals of combating poverty, meeting the MDGs, and generating sustainable development. The following difficulties are well known and well documented:

- The capacity of most of these countries to acquire and adapt foreign knowledge is constrained by the relatively small number of scientists and engineers as well as by the generally low level of their populations' education. Consider that the average number of years of schooling received by adults in low- and middle-income countries is only about 5.5 years, compared with 10 years in high-income countries.
- Add to that the so-called *digital divide*—the fact that about 80 percent of the world's personal computers and almost 90 percent of its Internet users are also found in high-income countries.
- Acquiring foreign knowledge through foreign direct investment is a big challenge for most developing countries too. No more than one third of all FDI goes to developing countries--with about 90 percent of those concentrated in just a dozen of the most attractive of them—and not all of these FDI have equally positive effects on local science and technology (S&T) capacity.
- Trade in patents and licenses could be another possible avenue of knowledge transfer to developing countries. However statistics show that only about 20 percent of all royalty and license fees payments come from developing countries, and just 10 countries, most of them in East Asia, account for more than 85 percent of those.

Since the knowledge revolution is occurring primarily in developed countries, developing countries inevitably face intensified international competition and have to deal with new forms of competition. In addition, the existing S&T gap between developed and most developing countries tends to grow even wider due to the fact that it also causes an intensified outflow of intellectual and financial resources from developing countries, the so-called brain drain and capital flight.

Low wages, low status, and the lack of opportunities for professional self-realization drive the most qualified professionals to emigrate to more knowledge-based economies where they can feel more appreciated. As a result, according to some estimates, there are currently more African-educated doctors and engineers working in Europe and North America than in Africa itself. In addition, low innovation capacity of most developing countries leads to low total factor productivity (TFP) of their economies and relatively few opportunities for profitable investment. As a result, capital outflows from developing to developed countries (without even taking into account the considerable illegal outflows) are, by some estimates, at least no smaller than the much better-known inflows from developed to developing countries (see, for example, the so-called "balancing item" in Table 1, Net Capital Flows to Developing Countries, in the Global Development Finance - 2004, World Bank, 2004).[2] Thus the knowledge and technology gap becomes self-propelling, threatening to marginalize a large number of developing countries.

Helping World Bank clients maximize their benefits from the current knowledge revolution must start with the recognition that building national science, technology, and innovation (STI) capacity is not a luxury activity appropriate for only the richest countries. On the contrary, it is now a major pre-requisite for sustainable economic and human development. Thus, STI learning and domestic capacity building are crucial tasks for all developing and transition countries.

Judged from the perspective of the overriding goal of Poverty Reduction, STI progress can be beneficial in at least 3 ways:

- For increased technical productivity (an absolute concept, in terms of physical units--important for fighting absolute poverty, hunger, and diseases),
- For increased international competitiveness (a relative concept, higher productivity in value added terms--important for higher incomes), and
- For increased social and environmental sustainability of economic development.

Note that these **3 ways of linking STI advancement to poverty reduction** do not always coincide with each other or even with the (most popular among many governments) goal of economic growth. For example, increased technical productivity in agricultural production of food for family consumption (rather than selling in the market) will directly contribute to hunger- and poverty-reduction, but may not get reflected in any macroeconomic indicators at all. Moreover, even if basic consumer goods are sold in the market but increased technical productivity is accompanied by lower market prices for these goods, this development will not show as faster economic growth although it will contribute directly to improving access of the poor to basic necessities and reducing absolute poverty (as deprivation of well-being). Such technological improvements may be desirable for developing countries even if these do not result in improved international competitiveness and economic growth.

This being said, accelerated economic growth--including through improved international competitiveness--still remains the main weapon for fighting poverty in developing countries, provided that the final goal of poverty reduction is not sacrificed in exchange for the intermediate goal of growth. It is broadly agreed that short-term growth achieved at the expense of increased poverty, higher inequality, or disproportional environmental damage is unsustainable and should be avoided.

[2] This is not to say that S&T backwardness, low innovation capacity, and low TFP are the only causes of capital flight from developing countries. We do however mean to say that these factors are important for explaining the redistribution of capital, as well as intellectual, resources in favor of more knowledge-based economies.

2. Classifying Countries by Measures of Endogenous S&T Capacity

It would be unrealistic to expect that all developing countries can or should follow the same path of technological advancement. In the first place, where countries start--i.e. their current S&T capacities–will have a major impact on their current priorities, strategic choices available, and choices out of reach. For example, transition countries like Russia and Ukraine, with high levels of math and technical literacy and substantial R&D capacity, evidently face different challenges and have different options available to them than countries where initial technological capacities are much lower, so that basic literacy and skill development are among the most pressing issues. For many less developed countries, the immediate task is to build the capacities required for maximizing their economic benefits from absorbing and adapting existing S&T knowledge. At the other extreme, some developing and transition countries have a realistic hope of joining the group of technological leaders/world-class innovators in the discernible future.

Quite a number of international organizations and individual researchers have already suggested different ways to measure and rank S&T capacities of countries through calculating various composite indices. Each such index has its own strengths and weaknesses as it inevitably reflects only some aspects of this very complex phenomenon. Moreover, each of them has a special focus, so that ranking of countries based on these indices can be very different (see Table 2.1).

Table 2.1.

Sample Country Ranks Based on Various Composite Indices of National Technological Capacity.

	By UNCTAD Index (of 117 countries)	**By UNIDO index** (of 87 countries)	**By UNDP Index** (of 72 countries)
China	72	37	45
Russia	23	44	-
Malaysia	67	22	30
Mexico	59	23	32
Philippines	60	25	44
Singapore	30	1	10
Sweden	1	7	3

To begin with, some composite S&T indices are based largely on statistical indicators of "inputs" into national S&T advancement, such as numbers of scientists and engineers, R&D expenditure, or R&D personnel, while others focus on 'outputs'-- the indicators of 'technological performance' such as the shares of high-tech industries in exports and in manufacturing value added (MVA). That explains the particularly striking differences in the ranks assigned to such countries as Russia or Mexico depending on whether they were judged based on inputs (by UNCTAD) or by outputs (by UNIDO). Obviously, input-focused approaches suffer from the lack of attention to the quality of these inputs and efficiency of their use, both of which can vary significantly across countries. At the same time output-focused approaches can be misleading too, because S&T performance indicators can be more easily affected by the (possibly temporary) presence of foreign TNCs, not necessarily linked to the rest of national economy.[3]

For example, the recently introduced by **UNCTAD Index of Innovation Capability** (UNCTAD, 2005) consists of two sub-indices – Index of Human Capital (calculated as a weighted average of tertiary and secondary school enrolment rates and literacy rate) and Technological Activity Index (calculated as an unweighted average of 3 indicators -- R&D personnel, US patents granted, and scientific publications, all per million population). None of these indicators show whether the underlying capacity for innovation identified in a country is actually used for improving the technological level of its production and exports. As a result, Russia is ranking relatively high on this index and Singapore, for example, relatively low (see Table 2.1). By contrast, when ranked on the **UNIDO's Index of Competitive Industrial Performance** (UNIDO, 2002), Singapore moves to the first place in the world, while Russia finds itself only 44th. That is because UNIDO's index is focused on the revealed (rather than underlying) technological capacity of countries, output indicators rather than input indicators. It consists of 4 'output'components – MVA per capita, manufactured exports per capita, share of medium- and high-tech activities in MVA, and share of medium- and high-tech products in manufactured exports.

Indices reflecting both inputs into national innovation process and outputs/returns from their economic use appear to reflect the actual levels of countries' S&T capacities more realistically. See for example **UNDP's Technology Achievement Index (TAI**), which in addition to "human skills" (mean years of schooling and tertiary enrolment in science, math and engineering) takes into account "diffusion of old innovations" (electricity consumption per capita and telephones per capita), "diffusion of recent innovations" (internet hosts per capita and high- and medium-tech exports as a share of all exports), and "creation of technology" as reflected by the number of patents granted and receipts of royalty and license fees from abroad (all per capita). Another advantage of TAI compared to UNIDO's index is its broader coverage – across national economies, rather than their industrial sectors only. The apparent shortcoming of TAI from our perspective is that it does not directly account for cross-country differences in institutions and policies essential for acquiring or creating, adapting and disseminating new technologies (see our definition of National technological capacity below, in section 5**).** Although it can probably be claimed that these are indirectly reflected in the levels of national technological achievement.

By contrast, the **National Innovative Capacity Index** suggested by Michael Porter and Scott Stern (2004) focuses mostly on institutional environment and government- and firm-level policies required for successful innovation. In addition to proportion of scientists and engineers, it is based on the following four sub-indices:

- Innovation policy
- Cluster innovation environment
- Innovation linkages
- Operations and strategy

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[3] The latter factor also explains why technological performance indicators tend to be more dynamic (relatively fast changing over time) than those of underlying technological capacity.

One of the shortcomings of this approach, from our perspective, is that the same "ideal" policies and institutions are searched for in very different countries, in many of which these can actually be quite irrelevant and out of sync with real needs. In addition, the Index's focus on institutions and policies makes it practically impossible to rely on any relatively "hard" statistical data. As for the outcomes of any surveys, these are not only affected by subjective perceptions of respondents, but also become hard to judge if the "degree of within-country consensus" is low (see WEF, 2003-2004, p.115).

S&T Capacity Index suggested by Francisco Sagasti (2003) is founded on an attractive conceptual model—indicators of Science, Technology, and Production are first averaged with respect to a country's "internal capacity" and then with respect to its "external linkages". Finally, the simple average of the internal and external sub-indices is calculated. In our opinion, this could be a fine index, provided that it could better reflect a country's capacity for learning from foreign sources. Unfortunately, the indicators used for calculating "external linkages" sub-index are much better in reflecting a country's input into global store of knowledge (number of scientific publications and number of patent applications filed) then its ability to absorb and benefit from foreign-produced knowledge. Only the "Infrastructure, communications and technology index" (making one third of "external linkages" sub-index) can to some, very limited extent, make up for this shortcoming.

In addition to these index-based classifications that draw purely conventional divides between groups of countries ranked on their S&T capacities, there exist at least three concept-based classifications of countries:

- Into two groups—countries innovating at the global S&T frontier (called "core innovators") and countries adopting foreign-produced technologies (called non-core innovators". This classification roughly coincides with classification of countries into developed and developing. (See Jennifer Blanke et al. in Global Competitiveness Report 2003-2004, p.5),
- Into four groups—a variation of the above innovators vs. adopters approach that divides countries into leaders, potential leaders, dynamic adopters, and marginalized countries (see UNDP, 2001), and
- Into three groups—countries with factor-driven, investment-driven, and innovation-driven economies. This classification roughly coincides with classification of countries into low-, middle-, and high-income.[4] (See Michael Porter in Global Competitiveness Report 2003-2004, p.34).

Without arguing against any of these classifications, we suggest to pay a particular attention to the speed of technological advancement of countries rather than the levels of technological development achieved by these countries. We will also attempt to be more specific about the qualitative differences in S&T learning capacities, policy choices, and resulting technological learning opportunities of various developing countries. For example, such sources of new

[4] The following formulation of the problem seems convincing enough: "A finding of low innovation indicators ... may simply be restating that the country is relatively poor. Put differently, it raises the question of whether a country's perceived innovation shortfall results from problems common to accumulation overall, or whether in fact the activity of innovation itself is somehow especially impeded". (Malloney, W.F. 2005)

technological knowledge as FDI or R&D, licensing of foreign inventions or controlling them through funding R&D performed by foreign researchers, can be used to a different extent and in different proportions depending on a country's pre-existing capacity to learn and on the learning opportunities available to this country as a result of its government's policies and concurrent international environment. Based on these differences, countries can be divided into 6 groups—5 groups of relatively fast S&T learners and a group of "traditionalist slow learners", still relying predominantly on traditional knowledge and remaining largely isolated from international knowledge flows, whether because of adverse political and economic circumstances or because of the lack of leadership for change. Our hope is that grouping countries by these national S&T learning models can help to identify developing countries facing similar risks and challenges and suffering from similar capacity shortages and development constraints.

3. Classifying Countries by National S&T Learning Models

National S&T learning is the term that we hereby use to denote **the learning process happening at all levels of national economies from the level of individual residents to the level of firms, industries, sectors, and governments, by which countries absorb and disseminate existing S&T knowledge as well as generate and process new S&T knowledge at the global technological frontier.** Note that by S&T knowledge we mean not only scientific and engineering knowledge, but also economic, managerial, and institutional knowledge that is required for successful use of more technical knowledge in the interests of national socio-economic development.

Compared to the better-known notion of national 'S&T capacity building', national 'S&T learning' refers to actions performed by learners themselves, rather than by their teachers, consultants, or advisors. Countries are seen as subjects of change rather than objects. And, unlike capacity building process, the learning process can be expected to occur not only as a result of deliberate effort, but also as a natural result of enabling learning environment. For example, S&T learning can take place as one of the natural outcomes of economic competition or as a natural consequence of practical experience accumulation (learning by doing).

The five major models of fast national S&T learning identified in the course of this study are as follows:

- Passive FDI-dependent,
- Active FDI-dependent,
- Autonomous,
- Creative-isolated, and
- Creative-cooperative learning.

Below, we will attempt to summarize the most characteristic features of each of these five S&T learning models as opposed to the sixth model of 'slow-learning traditionalism'. See also Fig. 3.2 and Fig. 3.3 for statistical illustrations of these models.

These illustrations are based on the new methodology that we hereby propose for initial, relatively fast diagnostics of technological learning processes underway in particular countries. This diagnostics focuses on selected statistical indicators reflecting a country's S&T learning capabilities as well as the S&T learning opportunities available to this country. We call these radar charts 'Crystals of national S&T learning' not only because of their visual resemblance, but also because, like real crystals, they have a propensity to grow in size as a country progresses in its technological and socio-economic development thereby further expanding the S&T learning opportunities open to it and rooted in its continuously increasing learning capabilities.

Our "crystals of national S&T learning" showcase selected statistical indicators measuring 5 major aspects of national learning:

- Human capital accumulated / human capability for S&T learning (see indicators 11, 12, 1);
- The most accessible opportunities for learning from foreign sources created by capital goods imports and FDI (indicators 9, 10);
- The more demanding opportunities for learning from domestic and foreign sources through domestic R&D (indicators 2, 3),
- The most demanding opportunities for learning through mutually beneficial exchange of disembodied knowledge and international S&T cooperation (indicators 4, 5, 6), and
- Success in using S&T knowledge for improving technological structures of a country's manufacturing value added (MVA) and of its manufactured exports (indicators 7, 8).

Note that important learning opportunities received by many developing countries due to their participation in global value chains ('vertical' learning from more advanced suppliers and/or industrial customers) are not forgotten here, but reflected by combinations of indicators rather than a single indicator (to the best of our knowledge, not yet available).

See Annex 1 for a more detailed discussion of this proposed methodology and each of the twelve indicators currently selected for our 'crystals'. Here we would only like to point out that, in order to convert all twelve different indicators to the same scale, they were first 'normalized' with respect to the range of variation of each indicator across all the countries for which data are available. Countries with the highest value of an indicator were assigned the 100% score (shown as 1 in our 'crystal' charts) and those with the lowest value the 0% score. The scores of all other countries were calculated as percentages of the range between the maximum and the minimum values using the following formula: **X normalized = (X – X min) / (X max – X min).** Some countries with indicators differing too sharply from all other countries were treated as outliers not included in the range calculation. Thus the normalized scores for these countries are more than 100% and in country-specific 'crystals' these scores are shown as peaks extending beyond the symmetrical 1 by 1 'crystal'. [5]

[5] See for example indicators #4 in crystals of Ireland and Singapore in Fig. 3.3.

Note also that the placement of indicators around the radar chart was selected in such a way as to allow our ‘crystals’ to grow more or less gradually clockwise, from 9 a.m. to 6 p.m. This growth is normally expected to begin from the ‘morning’ indicators 9 and 10 that reflect the most accessible learning opportunities, requiring minimal accumulation of human capital (importing foreign-produced machinery and attracting some, at least labor-intensive/low-value-added FDI), go through ‘around noon’ indicators 11, 12, and 1 that reflect 3 different aspects of national human capital accumulation, and then lead to ‘afternoon’ indicators 2 – 6 that reflect increasingly demanding learning opportunities, requiring progressively higher stocks of national human capital, from learning to perform some domestic R&D to cooperative participation in international research activities at the global technological frontier. Indicators 7 and 8, measuring two interrelated aspects of using S&T knowledge for socio-economic development, are placed so as to ‘happen after hours’. We hope that such intuitive placement of indicators will contribute to their easier interpretation.

Not surprisingly, the ‘learning crystals’ for the most developed and the fastest learning countries tend to be the largest, the most rounded, and the most bottom-heavy (with indicators 5, 6, and 7 reflecting some characteristic features of ‘creative-cooperative’ model of learning). See for example Sweden’s ‘crystal’ in Fig. 3.1. By contrast, ‘crystals’ of countries falling in the group of ‘traditionalist slow learners’ are barely visible (see Fig. 3.1 and 3.2), because most indicators (other than imports of machinery and equipment) are very close to zero[6], reflecting extremely low capabilities for national S&T learning and the extreme lack of learning opportunities open to these countries. It seems evident that it takes a certain minimal level of human capital for a developing country to engage in successful technological learning and upgrading. Below this level national S&T learning process and reducing a country’s technological gap with developed countries may prove impossible unless deliberate external aid is provided aimed at building these country’s learning capacity. All the least developed countries (LDCs) including most countries in Sub-Saharan Africa find themselves in this position, lagging further and further behind the technological frontier. The capacity-building needs of these ‘slow learning countries’ have to be addressed by international community most urgently.

Next, for countries that have reached a certain minimal level of learning capacity, the most accessible ways of technological learning and upgrading would probably be through importing foreign-produced capital goods and attracting some FDI, usually carrying some new, foreign-produced knowledge and skills with them. The problem is that attracting FDI tends to be a big challenge for the poorest countries and their governments are often in no position to influence the direction or the characteristics of FDI that do enter their economies. Thus this initial model of FDI-dependent learning is called ‘passive FDI-dependent’ (the term coined by Sanjaja Lall).

In poor countries, the major attraction for FDI is the opportunity for cost minimization stemming from the abundance of low-cost, low-skill labor. So most FDI will naturally focus

[6] These indicators are very small either in absolute terms or at least when normalized with respect to all the countries in the world. Quite often, many indicators for these countries are just not available from any international sources, but they can be estimated to be very low anyway, e.g. the number of researchers in R&D per million population or the share of high- and medium-tech industries in MVA and in exports.

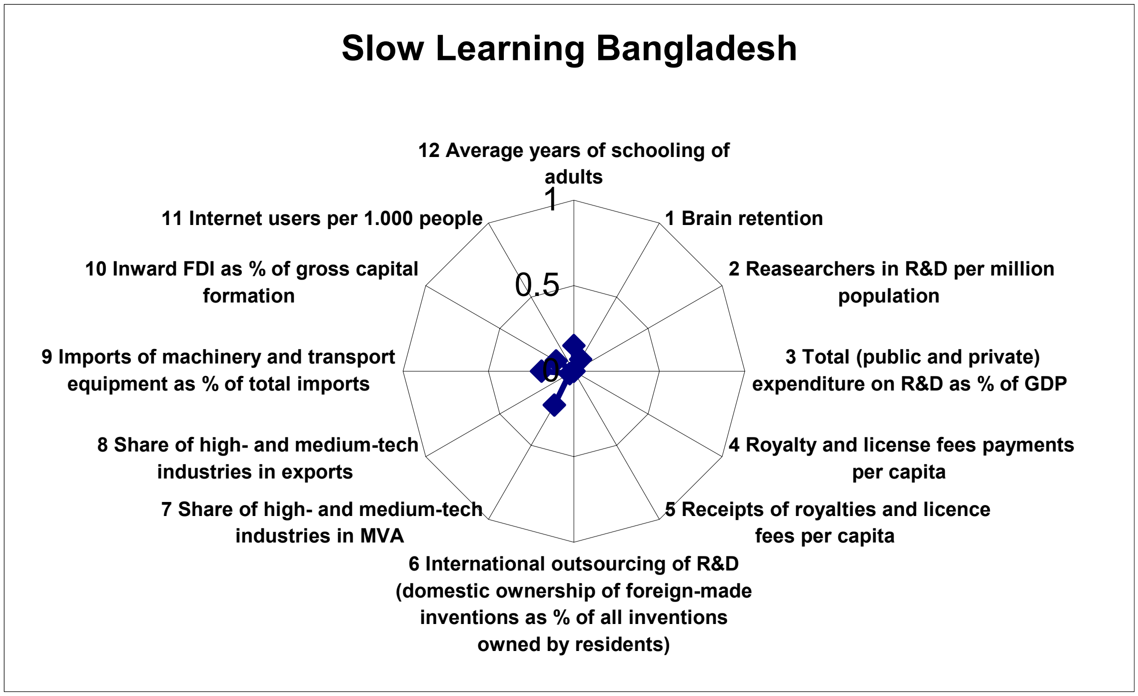
on the most labor-intensive, low-value-added industries and industrial operations such as textiles or manual assembling of medium to high-tech goods (from automobiles to PCs). However assembling these goods of imported components and exporting them through TNCs networks does not require any considerable capacity building in participating developing countries. In our 'crystals' this situation is reflected by 'unexpectedly' high shares of high- and medium tech industries in passive FDI-dependent countries' exports, visibly contrasting with the much lower shares of the same kind of industries in their MVA (see arrows from 8 to 7 in Mexico's and Philippines' crystals in Fig. 3.3).

Note that, even if relations of a developing country's government with foreign investors have to remain relatively passive, the same government's policies can still be active in facilitating maximal technological learning by domestic firms from all the opportunities created by the presence of FDI. Then the initial growth of FDI can be expected to lead to further increase in the stock of national human capital, including due to an increased demand for it from domestic firms. Thus the predominantly left-sided crystal will start to grow its top (indicators of human capital).

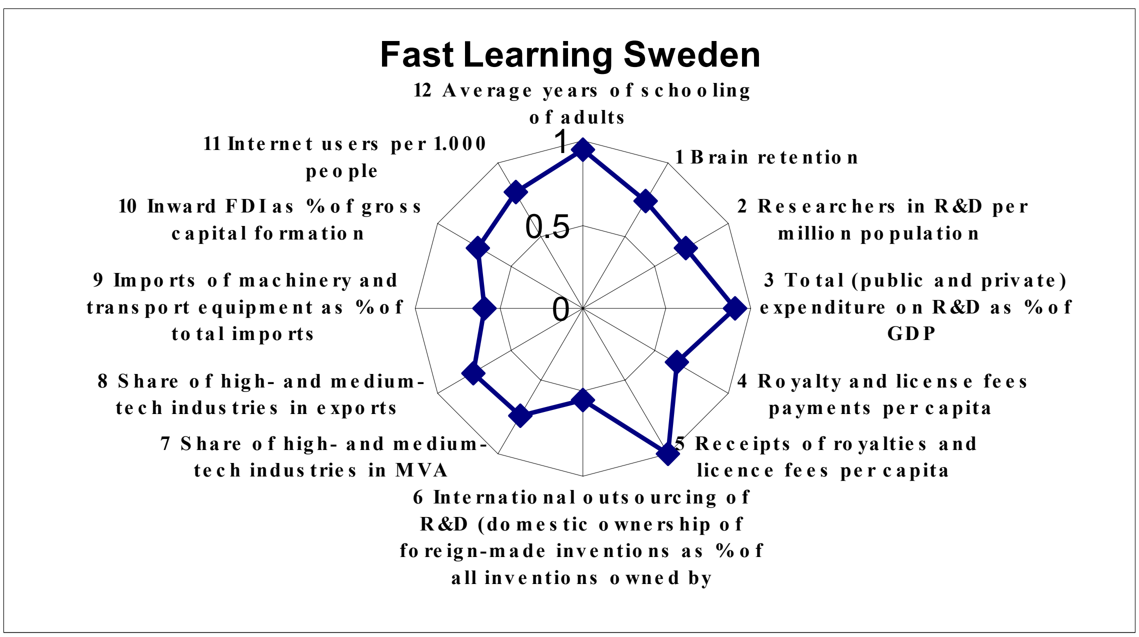
As a country's human capital continues to grow, this country acquires additional opportunities for learning by investing in domestic R&D for adapting available foreign knowledge to domestic needs as well as for new knowledge generation. A country at this point may have a wider choice of learning opportunities from foreign sources too – through more active relationships with foreign investors, who may be encouraged to invest in higher-skill operations including local R&D, or through more autonomous learning by imitating and, if necessary, licensing foreign technologies while limiting the country's reliance on FDI. Thus two different learning strategies/models – '<u>active FDI-dependent</u>' and '<u>autonomous'</u> learning – may be found in different countries with comparable learning capabilities (e.g. compare human capital indicators in Ireland and Korea or in Singapore and Japan as shown in Figure 3.3).

To summarize, the term "**passive FDI-dependent learners**" will refer to countries with low or medium technological learning capabilities, for whom the way out of non-learning traditionalism has been open thanks to their exposure to foreign direct investment. However, these countries do not undertake significant efforts to facilitate local absorption and dissemination of foreign S&T knowledge, e.g. by upgrading local workers' capabilities or by targeting the kind of FDI most relevant to the country's long-term technological learning interests. Note that even this learning model may not be available to countries with very low endogenous capabilities and/or low attractiveness for foreign investors.

Fig. 3.1.



Slow Learning Bangladesh
12 Average years of schooling of adults
1 Brain retention
2 Reasearchers in R&D per million population
3 Total (public and private) expenditure on R&D as % of GDP
4 Royalty and license fees payments per capita
5 Receipts of royalties and licence fees per capita
6 International outsourcing of R&D (domestic ownership of foreign-made inventions as % of all inventions owned by residents)
7 Share of high- and medium-tech industries in MVA
8 Share of high- and medium-tech industries in exports
9 Imports of machinery and transport equipment as % of total imports
10 Inward FDI as % of gross capital formation
11 Internet users per 1.000 people
1
0.5
0



Fast Learning Sweden
12 Average years of schooling of adults
1 Brain retention
2 Researchers in R&D per million population
3 Total (public and private) expenditure on R&D as % of GDP
4 Royalty and license fees payments per capita
5 Receipts of royalties and licence fees per capita
6 International outsourcing of R&D (domestic ownership of foreign-made inventions as % of all inventions owned by
7 Share of high- and medium-tech industries in MVA
8 Share of high- and medium-tech industries in exports
9 Imports of machinery and transport equipment as % of total imports
10 Inward FDI as % of gross capital formation
11 Internet users per 1.000 people
1
0.5
0

Fig. 3.2 "Crystals" of National S&T Learning for Sample Slow-Learning Countries

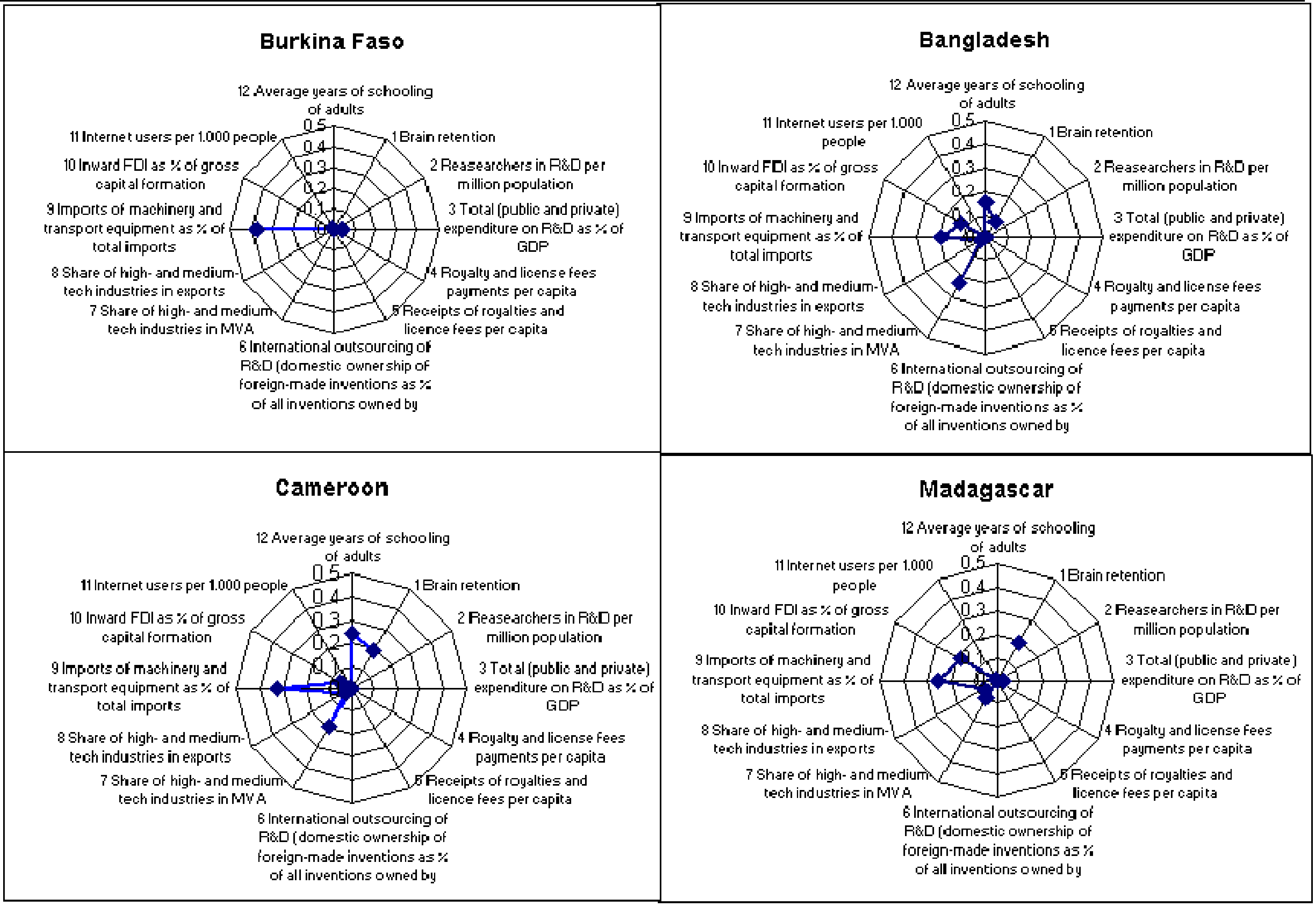
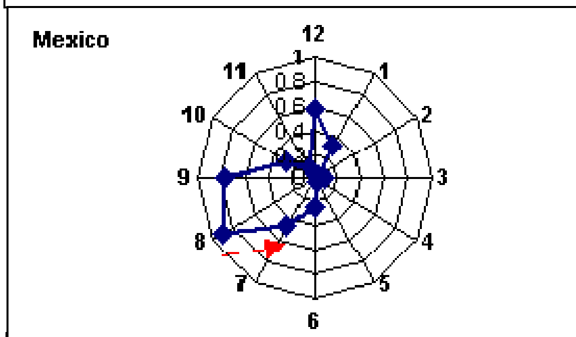
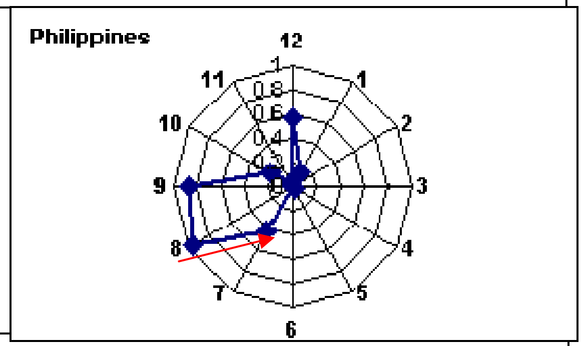


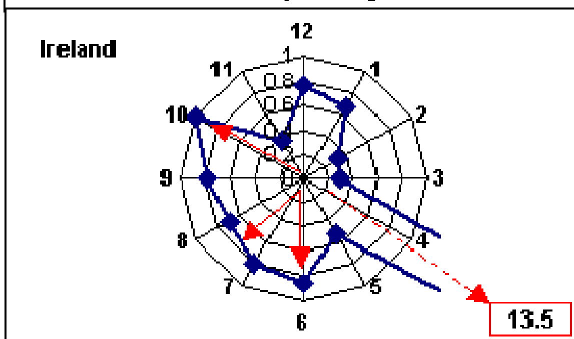
Fig. 3.3 Taxonomy of National S&T Learning Models

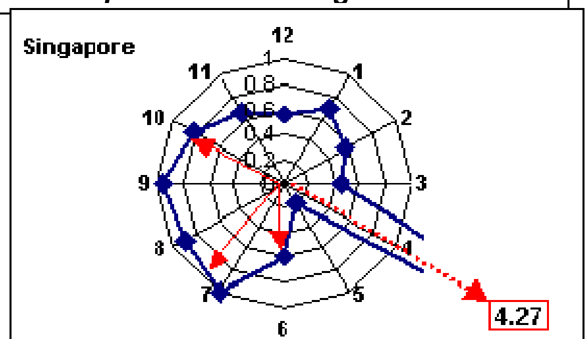
Sample Crystals of Passive FDI-Dependent Learning



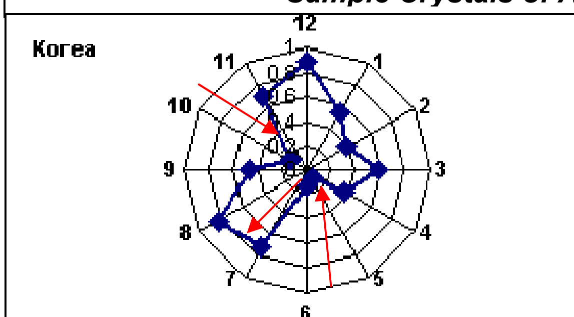


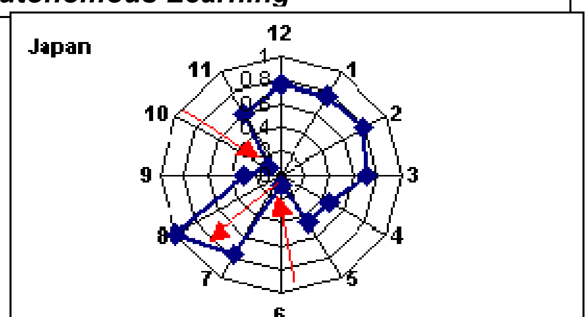
Sample Crystals of Active FDI-Dependent Learning



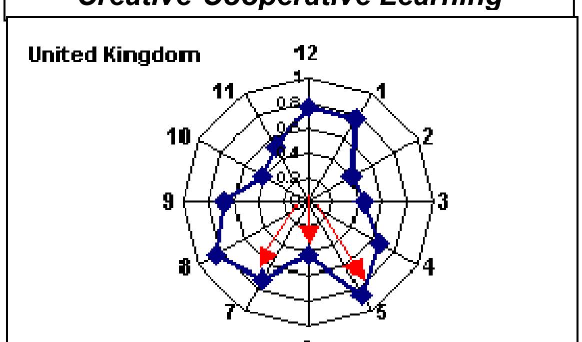


Sample Crystals of Autonomous Learning

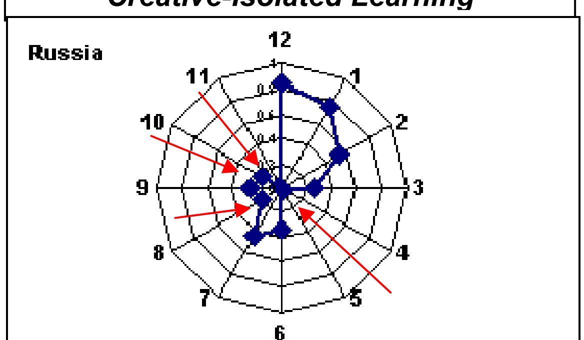




Creative-Cooperative Learning



Creative-Isolated Learning



9. Capital imports as % of all imports
10. Inward FDI as % of gross capital formation
11. Internet users per 1,000 people
12. Average years of schooling of adults
1. Brain retention
2. Researchers in R&D per million population
3. Total R&D expenditure as % of GDP
4. Royalty and license fees payments per capita
5. Royalty and license fees receipts per capita
6. International outsourcing of R&D
7. % of high- & medium-tech industries in MVA
8. % of high- & medium-tech industries in manufactured exports

By contrast, the group of "**active FDI-dependent learners**" consists of countries that are capable of and have succeeded in actively facilitating and promoting national S&T learning from various opportunities provided by FDI. Some of the relevant policies do require the recipient country's ability to rely on relatively favorable negotiating positions, e.g. on its being sufficiently attractive for foreign investors. However, some other "activist" policies, such as government support for basic literacy and science education, can be chosen by any country with strategically thinking leadership.

Note that our criterion for placing countries in the group of 'active FDI-dependent' learners is their *proven ability* to actively facilitate and promote technological learning from FDI, rather than government's expressed interest in this policy or even an approved government strategy reflecting these goals (although this might be the necessary first step). The 'learning crystals' of these countries will differ from those of 'passive' FDI-dependent learners not only by the higher human capital and R&D indicators (see indicators 11 – 3) but also by the much higher shares of high- and medium-tech industries in their MVA (indicator 7), more balanced with the share of these industries in exports (8). In addition, examples of Ireland and Singapore appear to suggest one more, and the most recognizable feature of this learning model—the unusually high score for Royalty and license fees payments, many times higher than the scores of any other countries (see indicator 4 in Fig. 3.3). One of the possible explanations to this aberration appears to be that these extremely high payments are boosted by intra-firm transfer pricing practices, since it is well known that most of these payments are made by TNCs operating in these countries.

The group of "**autonomous learners**" includes countries that have succeeded in active learning from foreign sources without heavily relying on FDI. Some policy instruments for such learning include active learning from open-source S&T publications, hiring foreign consultants and managers, acquiring foreign patents and licenses, learning through contract manufacturing as well as from foreign equipment suppliers and highly demanding foreign customers, incl. by copying and re-engineering high-quality foreign goods.

Note that relying on autonomous learning model requires relatively advanced levels of endogenous S&T capacity. In addition, opportunities for autonomous, as well as active FDI-dependent, learning are currently more limited than before due to the recent proliferation of international free trade and IPR agreements explicitly prohibiting many of previously proven practices (e.g. re-engineering or local content requirements to foreign investors).

Our 'crystals' help to see some of the main differences between active FDI-dependent and autonomous learners. The most obvious differences are to be found in the level of their reliance on FDI (see indicator 10) and payments for foreign patents and licenses (even though autonomous learners compare quite favorably on indicator 4 to the most developed, creative-cooperative learners). Next, such autonomous learners as Korea and Japan tend to invest higher shares of their GDP in R&D (indicator 3), and these investments are made mostly by domestic firms and government institutions rather than by affiliates of foreign TNCs. However autonomous learners appear to lag behind in international outsourcing of R&D (indicator 6) and (as shown by other indicators, not included in our ‘crystals’) also in other forms of international S&T cooperation.

“**Creative-isolated learners**” is the name by which we have chosen to call countries with relatively high (at least medium-high) S&T capabilities that attempt to produce most of the needed S&T knowledge domestically, with minimal reliance on international knowledge flows and S&T cooperation. This is the model that used to be characteristic of most countries of the Soviet block during the Cold War period (although there was in fact some S&T cooperation going on within this block). In today’s globalized world it may still be used by some politically isolated countries (e.g. North Korea), but it may also survive in some transitional countries that are no longer compelled to remain technologically isolated by political circumstances but continue to keep true to the old model mostly as a result of political inertia.

This is what seems to be observed in today’s Russia, where one of the highest stocks of human capital obviously fails to compensate for the country’s continuing lack of ability to absorb foreign technological knowledge. In Russia’s ‘learning crystal’ see low indicators of capital goods imports (9), FDI (10), and royalty and license fees payments (4) as well as extremely low share of high- and medium-tech industries in Russia’s exports (8) contrasting with considerably higher share of these industries in Russia’s MVA (7). The latter contrast – directly opposite to that in passive FDI-dependent countries--reflects low international competitiveness often characteristic of Russia’s surviving high- and medium-tech industries. It seems evident that isolated technological learning has historically proven its limited potential and is becoming less and less effective in the age of globalizing knowledge economies.

Finally among “**creative-cooperative learners**” are the countries with the highest levels of accumulated human capital that play the role of technological leaders in at least some niches of the global economy. These countries find themselves in the most opportune position for further technological learning from both, new knowledge generation by domestic R&D and from international S&T cooperation as the most effective way of acquiring foreign-produced knowledge e.g. through international outsourcing of selected R&D tasks, joint R&D projects, or strategic business partnerships. Creative-cooperative learners make the highest investments in domestic R&D (see indicators 2 and 3), engage in the most balanced, two-way exchange of patents and licenses (indicators 4 and 5), and in addition invest in foreign-performed R&D activities so as to become legitimate owners of resulting inventions (6). One more way of maximizing national S&T learning available predominantly to the most developed countries is attracting the inflows of highly qualified immigrants from other countries, the so-called “brain gain” (not yet reflected in our “crystals” for the lack of comparable data across developed and developing countries).

Our presumption is that even the most technologically advanced economies must continue to learn from not only domestic but also foreign sources. To be successful, they have to be able to both, create new, cutting-edge technologies and adopt cutting-edge technologies created by other countries. We thus disagree with those WEF authors who think that technological adoption has "zero weight for core innovators" (Global Competitiveness Report 2003-2004, p.6). In the modern world with enormous R&D expenditures, countries can't afford to be technologically independent. Their best option is to become technologically inter-dependent (as an alternative to being technologically dependent). The advantage that technological leaders really have is their much higher capacity for learning from domestic sources and their ability to learn from foreign sources in autonomous and cooperative fashions.

Our "Taxonomy of national S&T learning models" may help to classify a country of interest as belonging to a certain "type of learners" and thus point to some pertinent foreign experiences in dealing with similar risks and challenges. Many countries however will fall somewhere between the typical models, whether because several routes of technological learning are simultaneously experimented with in different sectors and/or different regions of their economies or because these countries currently happen to be in transition from one prevailing model of technological learning to another. This is particularly characteristic of the largest and the fastest developing countries such as China, India, and Brazil[7].

Anyway, 'stamping' every country as belonging to a certain model of technological learning is neither necessary nor particularly useful. What examining a country's 'crystal of technological learning' can actually help with is answering the following type of questions:

(a) Is the country's national S&T learning likely to be fast enough compared to that of its major competitors? (Look at the overall size of the 'crystal" and compare it to those of selected other countries.)

(b) Is national technological learning constrained mostly by the lack of human capital/learning capabilities or by the lack of learning opportunities? (Compare the top of the "crystal' with its upper-left, upper-right, and lower-right segments.)

(c) Which additional learning opportunities might be available to the country but appear to remain relatively under-used? And

(d) How successful is this country in using its S&T capacity for its economic development? (Look at indicators 7 – 8 and their relationship.)

For example, Russia's crystal in Figure 3.3 evidently shows that this country's national S&T learning has recently been (a) too slow, (b) constrained mostly by the lack of

[7] Thus, data permitting, it could be quite illuminating to build 'dynamic crystals' of technological learning for consecutive periods in a country's history (e.g. with the interval of 10 or 20 years) along with 'regional' or 'sector-specific crystals' of technological learning prevailing in different regions or sectors of the national economy (e.g. extraction industries vs. manufacturing or export-oriented industries vs. domestic-oriented). Meanwhile, we were using statistical data from the UN specialized agencies averaged for the last 5 years available, usually for the period of 1997-2002.

opportunities for learning from foreign sources, (c) could potentially be accelerated by expanding these opportunities practically 'around the clock' – from importing more machinery and equipment to increasing investment in R&D (indicator 3 too low compared to indicator 2, the number of researchers in R&D) to buying and selling more patents and licenses. Not surprisingly, Russia's use of national S&T capacity for economic development is not sufficiently successful either, particularly in terms of technological structure of exports (indicator 8).

Here one can observe that classification of countries on the basis of their S&T learning models has some of the same advantages over existing classifications based on countries' current S&T capacities that a video clip has over a still photograph. Imagine a photograph of a car on the road. There is no way to understand whether it is standing or going, and if going, then at what speed. A video clip can answer these questions because it shows how the position of this car is changing relatively to immovable objects (e.g. lamp posts) and to other moving cars. Our 'crystals' of national S&T learning achieve the same effect by allowing to compare national economies on the size of their learning capabilities and opportunities (responsible for the speed of their technological progress) and even on "the type of their learning engines" (relatively simple, cheap, and slow vs. those that are more sophisticated and fast, but also more expensive and requiring more 'driving skills').

FYI: Fig.3.3 "Taxonomy of National S&T Learning Models" appears to demonstrate that countries from different geographical regions can be pursuing similar types of S&T learning strategies. For example, Mexico and Philippines, or Ireland and Singapore rely mostly on the same sources of technological learning and thus look very similar in our charts. On the other hand, countries from the same region can be pursuing different learning strategies. For example, 'crystals' of Korea, Philippines, and Singapore all appear very different. That shows that classifying national S&T learning strategies using regional models, such as East Asian vs. Latin American model, may be misleading. Another approach is needed that would be based on identifying different sources of S&T knowledge successfully exploited by different relatively fast-learning countries.

4. Major S&T Learning Paths

Underlying our classification is the particular importance of learning from foreign sources for all developing countries. This classification is indirectly relying on the differences in countries' endogenous S&T capabilities as well as the differences in their access to external sources of technological knowledge. However, it is presumed that--even within these hard internal and external constraints—most developing countries still have some freedom to choose among several available policies with respect to national S&T learning. Moreover, choosing the optimal S&T learning strategy can be critical for the rate and sustainability of a country's development. While applying lessons of experience from today's fast learning countries to their specific situations, countries can benefit from understanding the risks and benefits of each particular learning model.

Take for example the passive FDI-dependent model. The advantage of relative accessibility of this model for countries with an abundance of low-skilled labor and low labor costs is counterbalanced by the risk of conserving a country's low-tech structure of MVA as FDI will most likely flow to labor-intensive, low-skill operations and technological learning opportunities may turn out to be quite limited. See for example the large difference between both Mexico's and Philippines' scores on the shares of high- and medium-tech industries in exports, on the one hand, and in MVA, on the other. Note that in the more developed countries this difference is either small or runs in the opposite direction – i.e. the technological structure of MVA is either close to or higher than that of exports. Furthermore, if a country's temporary attractiveness for FDI is not fully used for increasing its total stock of human capital, this "window of opportunity" for learning from foreign sources may soon close as the flows of FDI change their direction in favor of other developing countries with similar skill levels but even lower labor costs. This is the nature of the challenge currently faced by Mexico as a result of China's competition.[8]

The risk of losing access to further inflows of FDI and foreign technologies as a result of competition from countries with lower labor costs also exists for active FDI-dependent countries like Ireland or Singapore. The advantage of their situation is that, owing to the high stocks of human capital accumulated in these countries, it is much more difficult for any low-income countries to compete with them for the same roles in international value chains. China however does present a serious competition even for this group of fast learners. Thus these countries may need to consider some further improvements to their national learning strategies akin to transitioning to the most advanced, albeit also the most challenging, creative-cooperative model of learning.

The autonomous model of national S&T learning that was successfully used by Japan after the WWII and by Republic of Korea beginning in the 1960s appears to show its limitations in today's globalized economic environment. Both Japan and Korea seem to suffer from their traditionally low participation in international S&T cooperation, only partially caused by higher language and cultural barriers and longer physical distances between them and Europe or USA.[9] Both are probably quite ready for transitioning to the most advantageous creative-cooperative model of learning, although this may not yet be widely seen as one of their development priorities.

Next, it seems rather obvious that the higher a country's S&T capacity, the wider the range of learning models available to it. In addition, the specifics of a country's relationships with other countries can play a big role in opening or closing some of the national learning opportunities.

For example, oil-rich developing countries (like Dubai) can use their high export revenues for purchasing lots of ready-made foreign technologies – by stimulating and

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[8] See for example: Dian Farrell, Antonio Puron, and Jaana K. Remes. Beyond cheep labor: Lessons for developing economies. McKinsey Quarterly, 2005 Number 1.

[9] See for example OECD's STI Scoreboard 2003, where Japan and Korea consistently hold the bottom places in the lists of OECD countries ranked by percentage of patents with foreign co-inventors, by cross-border ownership of inventions, or by the share of foreign PhD students.

subsidizing not only rapid FDI inflow, but also mass immigration of skilled and educated human resources ("brain inflow"). Obviously, availability of lavish public funding creates some unique opportunities for accelerated FDI-dependent learning with active government leadership. However it remains to be seen to what extent purchasing foreign knowledge can substitute for or contribute to the necessarily much slower process of endogenous S&T learning.

On the other hand, in the case of mostly traditionalist Burkina Faso, not only its S&T capabilities, but also its overall attractiveness for foreign trading partners or foreign investors are quite low. Thus its government will hardly be in a position to actively negotiate the conditions of national learning from private foreign sources. At this initial stage, attracting any FDI allowing for some inflow of relatively advanced technological knowledge and skills--passive FDI-dependent learning--might be the most realistic goal. In addition, official development assistance (ODA) could play a particularly important role in opening additional S&T learning opportunities for Burkina Faso and other countries under similar constraints.

By contrast, countries like Republic of Korea or Israel, with their high S&T capabilities and experience in mostly autonomous learning, have practically no learning options unavailable to them. The main challenge for them appears to be in transitioning from mostly autonomous to mostly creative-cooperative model as the most effective one in today's globalizing knowledge economy, albeit also the most demanding to both S&T and institutional capacities of these countries.

Clearly, different developing countries face different challenges depending on (1) their unequal S&T learning capacities, and (2) their unequal access to sources of foreign knowledge and skills, e.g. a certain country's ability to rely on FDI, on buying licenses, or on political alliances with technological leaders. Faced by these constraints, countries exercise their political choice among available S&T learning models or (as it happens with most LDCs) find themselves unable to break out of the group of traditionalist slow learners.

Proceeding from the proposed classification of countries by their prevailing learning models, we will now examine some generic S&T learning paths that are available and desirable to countries at different starting points:

1. From slow-learning traditionalism to passive and active FDI-dependent learning,
2. From passive FDI-dependent to more active FDI-dependent or autonomous,
3. From active FDI-dependent to autonomous and creative-cooperative,
4. From autonomous to creative-cooperative, and
5. From creative-isolated to autonomous and creative-cooperative learning.

Some other, less than desirable learning paths that can sometimes be observed in real history, e.g. from isolated and autonomous to passive FDI- dependent learning or from active to passive FDI-dependent learning, will be hereby treated as risks to be avoided. Another kind of risk faced by many developing countries is the risk of failing to perform a timely transition to the next, higher technological learning model, leading to slower technological advancement and weakened international competitiveness.

In Tables 4.1, 4.2, and 4.3 we attempted to demonstrate the specifics of policy challenges faced by countries moving along 3 of the above-mentioned desirable S&T learning paths. Note that these 3 paths can also be seen as consecutive stages of the same country's long-term S&T learning.

In each of these tables priority policies are organized into Most Important, Important, and Less Important (Already or Not yet). Among the "most important" or "first priorities" we included those policies that address the most immediate and pressing needs, so that no S&T advancement can start without some success achieved in these areas, and some economic returns from these policies can be expected already in the short term. Among "important" and "less important" are those policies that can be expected to bring economic returns only in the medium- or in the long term, after the necessary prerequisites are created by "first-priority" policies. This certainly does not mean that "less important" policies can be ignored for the time being—in fact the earlier countries start planning for their long-term future the better, or else their future may never come. However prioritization means that the bulk of limited resources—including political and administrative resources—are allocated in a carefully sequenced manner, addressing the most immediate needs first, while laying down the foundations for next-generation policies (see for example how second-priority policies in Table 4.1 lead to first-priority policies in Table 4.2, and third-priority policies in Table 4.1 lead to second-priority policies in Table 4.2).

It is also worth noting that all three categories of policies in these tables pursue strategic goals—policies that could result in short-term benefits at the expense of future losses are not considered here.

Table 4.1

Prioritization Table of Policies for Transitioning from Non-learning Traditionalism to Passive/Active FDI-dependent S&T Learning

Most important/1st priorities (for short- as well as long-term returns)	**Important/2nd priorities (foundations for medium-term returns)**	**Not yet as important/3rd priorities (foundations for long-term returns)**
1. Human resources development: - Primary and secondary education (S&T literacy) - S&T tertiary education relevant to local needs - Measures to retain tertiary graduates - Measures to attract skilled expatriates - Promoting S&T awareness among government officials and business leaders	**1. Preparing to build national S&T institutional infrastructure**: - Public-private dialog to begin defining national S&T priorities and plans - Developing mechanisms for local funding of S&T activities of local relevance - Helping establishment of local S&T institutions - Learning to scan international environment for available technologies relevant to local needs	**1. Fiscal and credit measures to stimulate innovation at firm level**
2. Creating stable macroeconomic environment	**2. Trade openness**	**2. Intellectual property rights protection**
3. Encouraging trust and building social capital	**3. Competition policies**	**3. Reducing bureaucratic impediments**
4. Providing physical infrastructure for S&T advancement: - Reliable energy provision - Transportation - Modern communications incl. ICT	**4. Control for safety and ethical application of new technologies**	
5. Linking up to foreign sources of S&T knowledge: - Promoting FDI (reliance on diasporas) - Facilitating technological spillovers from FDI - Linking up to global value chains for vertical capabilities transfer - Encouraging import of machinery and equipment - Facilitating technical ODA - Exploring opportunities for regional S&T cooperation		
6. **Promoting diffusion of modern technologies**		
7. Commercializing and protecting traditional		

knowledge for export purposes **8. Negotiating international agreements beneficial for S&T learning incl. on IPR**		

Table 4.2

Prioritization Table of Policies for Transitioning from Passive- to Active FDI-dependent S&T Learning

Most important/1st priorities (for short- as well as long-term returns)	**Important/2nd priorities (foundations for medium-term returns)**	**Not yet as important/3rd priorities (foundations for long-term returns)**
1. Building national institutional infrastructure for S&T: - Defining national S&T priorities and plans - Domestic and foreign funding of S&T activities in accordance with national S&T priorities and plans - Creating networks of local S&T institutions for scanning available foreign technologies and broad dissemination of findings (access to information and training opportunities)	**1. Establishing S&T forecasting centers**	**1. Purchasing of foreign technologies and technological services**
2. Human resources development: - Continuing to improve S&T literacy and tertiary education - Upgrading skills of national workforce - Adding post-graduate stage of S&T education relevant to local needs - Continuing with policies to retain high-level professionals and attract skilled expatriates - Improving S&T awareness among government officials and business leaders	**2. Fiscal and credit measures to stimulate innovation at firm level**	**2. Cluster-related policies to link technology and production**
3. Maximizing technological learning from FDI and other foreign sources: - Targeted FDI promotion focused on meeting national S&T priorities and on creating higher-skill/ higher-wage jobs (moving up the global value chains) - Stimulating foreign funding of local R&D - Facilitating technological spillovers, incl. horizontal capabilities transfer e.g. through local spin-offs - Control for safety and ethical application of new technologies - Using technical ODA for	**3. Trade openness**	

national S&T priorities - Joining regional S&T cooperation - Improving access to international S&T information, - Technology scanning and search + broad dissemination		
4. Using purchasing power of the state to promote demand for knowledge-intensive goods and services	**4. Competition policies**	
5. **Building trade marks for unique exports based on commercialized and protected traditional knowledge**	**5. Reducing bureaucratic impediments**	
6. Maintaining stable macroeconomic environment	**6. Engineering design and consulting services**	
7. Building social capital and freedom of initiative	**7. Intellectual property rights protection**	
8. Improving physical infrastructure for S&T: - Improving reliability of public services (energy, water, sanitation) - Lowering the costs of public services, transportation, and communications incl. ICT	**8. S&T parks and technology incubators**	
9. Pressing for more beneficial international agreements, incl. on IPR		

Table 4.3

Prioritization Table of Policies for Transitioning from Active FDI-dependent to Autonomous and Creative-Cooperative S&T Learning

Most important/1st priorities (for short- as well as long-term returns)	**Important/2nd priorities (foundations for medium-term returns)**	**Already less important/ 3rd priorities**
1. Perfecting national institutional infrastructure for S&T: - Regular revising of national S&T priorities and plans based on technological forecasting - Increasing national funding of S&T activities for cutting-edge innovations incl. through public-private partnerships - Further developing networks of local S&T institutions and linking them to global S&T networks	**1. Trade openness**	**1. Using technical ODA for national S&T priorities**
2. Human resources development: - Continuing to improve S&T literacy, tertiary S&T education, and technical skills of national workforce - Emphasizing post-graduate S&T education and attraction of high-level foreign specialists relevant to national competitiveness goals - Establishing regular information channels and consultations between government and business leaders and S&T community	**2. Cluster-related policies to link technology and production**	**2. Using purchasing power of the state to promote demand for knowledge-intensive goods and services**
3. Promoting autonomous learning from foreign sources: - Improving access to international S&T information, incl. through Internet connectivity and international S&T collaboration - Foreign technology scanning and search - Direct learning from foreign equipment suppliers and from highly demanding foreign buyers - Purchasing of foreign technologies and technological services (patents, licenses, services of foreign consulting firms) - Hiring foreign experts, incl. in R&D and management	**3. Pressing for more beneficial international agreements, incl. on IPR**	**3. Building trade marks for unique exports based on commercialized and protected traditional knowledge**
4. Promoting world-class product innovations to achieve technological leadership in selected global market niches: - S&T parks and technology incubators		

- Measures to link public R&D and private enterprise sectors - Intellectual property rights protection - Engineering design and consulting services - Fiscal and credit measures to stimulate innovation at firm level - Competition policies - Reducing bureaucratic impediments - Reducing risks of innovation - Building local and trans-national production chains based on domestic R&D **5. Continuing policies for maximizing technological learning from FDI:** - Targeted FDI promotion focused on meeting national S&T priorities and creating higher-skill/ higher-wage jobs (moving up the global value chains) - Stimulating foreign funding of local R&D - Facilitating technological spillovers incl. horizontal capabilities transfer e.g. through local spin-offs - Control for safety and ethical application of new technologies **6. Promoting cooperative learning** - Outsourcing selected R&D tasks - Joint R&D projects with technological leaders in other niches - Strategic business partnerships with foreign technological leaders - Leading in regional S&T cooperation **7. Maintaining stable macroeconomic environment** **8. Building social capital and freedom of initiative** **9. Improving physical infrastructure for S&T:** - Improving reliability of public services (energy, water, sanitation) - Lowering the costs of public services, transportation, and communications incl. ICT		

One could notice that some first-priority policies first named in Table 4.1--such as those dealing with macroeconomic stability, social capital, or physical infrastructure--remain among the first priorities in all the other tables (reflecting further stages of S&T learning) even though they tend to move down the list as the list becomes longer and more complex. That means that these policies continue to play the role of critical conditions of success although they may no longer drive the learning process.

5. National S&T Capacity Building Needs

Although national S&T learning often occurs 'naturally', as a result of an enabling learning environment, this process can also be deliberately accelerated with the help of appropriate national strategy and, if necessary, with the help of ODA coming from international development community. The latter way of **ODA-enabled learning** is particularly critical for the least developed countries facing the gravest double challenge of minimal S&T learning capacities and minimal S&T learning opportunities. Thus the international community should be able to address this challenge by two-fold measures too--by direct 'teaching the learners' (e.g. through facilitating access to the most critically needed S&T knowledge and organizing international training events or consultation forums) and by creating additional opportunities for 'natural' S&T learning (e.g. through facilitating countries' access to international trade and foreign investment flows). Both kinds of measures can qualify for the name of 'capacity-building measures' even though in one case capacity is built more directly and in the other less directly but with the more active role of the 'learners' themselves.

This paper uses the following definition of country-level technological capacity***:*** ***National technological capacity*** **includes S&T knowledge and skills (*human capabilities* of individuals or groups of individuals, e.g. firms) as well as *institutions* and *policies* essential for acquiring or creating, adapting, and disseminating new technologies**. Note that since we are talking about "new technologies" (new for a given country, industry, or firm) all of the enumerated activities (acquiring or creating, adapting and disseminating) have to do with **S&T learning** at different levels – by members of the national workforce, by local production firms and public or private institutions (e.g. in education, health, finance, etc.), and by governments themselves. Deliberate capacity-building measures implemented by national governments in partnership with the international community should thus be aimed at creating the most enabling and stimulating environment for national learning.

Note that this learning can draw on either domestic sources, as in the case of domestically funded and domestically conducted R&D and its results' dissemination among domestic firms, or on foreign sources, as in various cases of learning from foreign firms, universities, or international development agencies. It is also critical that national learning is happening at all appropriate levels—from top government officials to enterprise managers, engineers, farmers, scientists, doctors, teachers, students, and industrial workers. Identifying the optimal S&T learning path for each developing country in need of assistance and adapting capacity-building programs to specific needs of each country is a prominent challenge for international development agencies.

For all developing countries, S&T learning from foreign sources—absorbing foreign-produced knowledge and adapting it to domestic needs-- is particularly important, because most scientific knowledge that they need for their immediate development is already created in other countries although it is not always freely available or easily accessible. Developing countries need to be able to scan internationally available sources of knowledge from the point of view of their usability for meeting national development needs and then be able to "absorb" this knowledge, which often requires certain adaptation to local conditions. Improving their **absorptive capacities (**as a major component of broader technological capacities) is the main tool that developing countries can use to reduce their technological and economic gap with developed countries. Accelerated absorption of existing technologies as an alternative to a much slower and costlier process of domestic development of similar technologies is what is often referred to as "a latecomer's advantage" and what is expected--at least to some extent—to counterbalance the many 'latecomer's disadvantages', e.g. those caused by 'increased returns to scale' in R&D and knowledge-intensive industries.

This is not to say that **creative capacities** (meaning countries' ability to create cutting-edge innovations at the global S&T frontier) do not matter for developing countries. However, in our opinion, these become particularly useful for middle-income countries striving to become high-income. See Table 5.1 below that can possibly be used for analyzing a concrete country's capacity-building needs in terms of its absorptive vs. creative capacities.

As illustrated by Tables 4.1 – 4.3, capacity-building needs of different countries that find themselves at different stages of S&T learning —with unequal levels of S&T capacity and opting for different learning models—cannot be the same. In particular, the importance of producing new, world-class S&T knowledge as opposed to absorbing and adapting foreign-produced knowledge tends to increase as countries move to higher levels of technological capacity and more advanced learning models. Both, absorptive and creative capacities remain important for all countries, albeit in different proportions. Table 5.1 provides a tentative logical framework for a concrete country analyses by dividing the capacities in question along these lines and also by subjects of learning--national workforce, firms, and governments.

Table 5.1

Logical Framework for National S&T Capacity Building Needs Analysis

	Capacity to absorb and adapt foreign S&T knowledge	Capacity to create new, world-class S&T knowledge
Capacity of national workforce	- S&T literacy for all (primary/secondary/tertiary) - Availability of national and foreign funding for local R&D - National networks of local S&T institutions	
	- Retaining and attracting sufficient number of specialists with tertiary and postgraduate S&T education - S&T institutions for scanning, assessing, selecting available foreign technologies and adapting them for local use, incl. opportunities and incentives for learning from foreign sources	- Critical mass of world-class researchers and other knowledge workers - S&T institutions for basic and applied research, incl. incentives for producing and transferring to industry cutting-edge innovations (IPR protection, public-private partnerships, subsidies, other)
Capacity of domestic firms and local enterprises of TNCs	- Revealed and underlying capabilities to absorb and adapt foreign knowledge for producing more knowledge-intensive goods and services - Opportunities available to them for learning from foreign sources (trade, FDI, foreign partnerships, foreign consultants, patents, open sources, etc.) - Economic and institutional incentives for absorbing foreign technologies (competitive environment, quality of domestic demand, incentives for learning to export, etc.)	- Revealed and underlying capabilities for producing cutting-edge innovative, globally competitive goods and services - Levels of and incentives for funding local R&D activities by domestic firms and local enterprises of TNCs - Incentives for implementing cutting-edge innovations counterbalancing increased business risks.
	- Participation in international division of labor and in global value chains - Participation in regional and global S&T collaboration	
Capacity of governments (national, sub-national, local)	- Capacity to receive and make effective use of information and expert advice from national and international S&T community - Capacity to develop enabling and stimulating S&T and economic policies - Administrative capacity	
	- Capacity for facilitating national S&T learning from foreign sources	- Capacity for identifying national S&T priorities and developing targeted programs, incl. effective funding mechanisms

Note that in each of the six major segments of Table 5.1 we tried to consistently look at three groups of phenomena that together make up the notion of 'national technological capacity':

- Individuals' or groups' science, technology and innovation (STI) capabilities,
- Institutions enabling further development and effective use of these capabilities, and

- Government policies aimed at strategic STI goals.

Consistently differentiating between the notion of 'human capabilities' and the wider notion of 'national capacity' has more than purely linguistic significance—it can help to focus attention of researchers and practical policy makers on those exact components of national capacity that happen to constitute the most binding constraints to further technological learning. For example, in many transitional countries of Europe human S&T capabilities are relatively high but the absence of enabling and stimulating institutions and policies often prevents these capabilities from materializing in industrial innovations and further technological learning.

Next, the notion of 'capability' itself appears to deserve some discussion, including for clarifying some terms used in Table 5.1.

In business management, the notion of 'capabilities' is probably best known with respect to capabilities of firms (see for example John Sutton, 2005). The latter notion is helpfully divided into 'revealed capability' measured by the perceived value of the firm's product per unit of its production costs (u/c) and 'underlying capability' that consists of 'know-how' and working practices (knowledge and skills) held collectively by the group of individuals comprising the firm. It is clear that both 'process innovations', i.e. finding new methods of production to lower the unit costs, and 'product innovations', i.e. new product development to increase consumer's perceived value of the firm's products, can contribute to increasing a firm's revealed capability which practically shows as an increase in the firm's competitiveness. As for the underlying capabilities, these are evidently harder to measure, although not impossible to analyze. It is important to keep in mind that the underlying (potential) capabilities of firms may fail to 'reveal themselves' in these firms' increased competitiveness, for example if business opportunities are limited by excessive government control or in the absence of proper economic and institutional incentives. It seems to us that these twinned notions of 'underlying' and 'revealed capabilities' can well be applied not only to firms but also to other large groups of actors at different levels of national economies.

With respect to labor force, capabilities are better known as 'competencies', subdivided into basic competencies (literacy) and advanced competencies, and then also by fields of knowledge, e.g. competencies in math, science, engineering, ICT, languages, etc. and by modes of thinking, e.g. competencies in critical thinking, problem solving, constructive discussion, or consensus building. Obviously, different sets of competencies are required for countries to learn from foreign sources and to create pioneering S&T knowledge, and the failure to make timely adjustments to national labor force development policies can have very negative and hard-to-correct implications for the overall economic development. As an example, we would venture to suggest that current economic difficulties of Japan are to some extent caused by its past lack of attention to science education as opposed to engineering education.[10] Meanwhile, the task of successfully competing in the global markets of high-tech products increasingly requires the country to excel in product innovation based on unique basic research.

[10] According to OECD data, Japan annually produces more engineering graduates than even USA, but almost 6 times fewer science graduates (OECD STI Outlook, 2004).

Finally, government capabilities are most often criticized from the point of view of corruption and administrative incompetence. Seen from STI policy perspective, government capabilities should also include appropriate levels of awareness and understanding of modern S&T problems at least sufficient for effective consultations with research and education communities.

Another helpful concept that could be borrowed from business management theory is the concept of the 'window of capability'. This concept is ordinarily applied to firms to indicate that, in order to enter the market and remain there, firms have to fit in a certain space between the highest (achieved by the industry leader) and the lowest acceptable, threshold levels of revealed capability. If the firm's costs are too high or the product quality is too low, the firm is just not viable. Applying the same concept to entire national economies competing in building capabilities of their labor forces, firms, and even governments, we can say that *developing countries need to fit into certain 'global capability window' at the risk of being excluded not only from the global market, but also from the global technological learning process*.

To assist developing countries with the most urgent capacity building needs in maximizing their benefits from the global technological learning process, international development agencies could start with assessing past development aid projects from the point of view of new S&T capacities directly created at different levels of national economy and new learning opportunities open to national learning agents. Such assessment could allow for developing 'best practice' guidelines for screening all new aid projects. For example, the following questions could be asked to determine national technological learning consequences/value of the past (as well as future) development projects:

1. How valuable was this project from the viewpoint of national S&T learning? (In the long run, this learning may prove more important for national socio-economic development than short-term economic growth.)
2. How flexible/widely applicable was this learning?
3. Has this learning contributed to alleviating any of the aspects of absolute poverty in the country (e.g. extreme deprivation of food, shelter, health, education, etc.)?
4. Has this learning contributed to improving environmental and social sustainability of national development?
5. Has this learning created a 'retainable' competitive advantage for local firms (see Ralph Gomory and William Baumol, 2000)?
6. Can this learning lead to producing more knowledge-intensive products with higher value added or to creating a unique, trademarked product to be marketed at premium prices?
7. Can this learning help local firms to link to and move up the international value chains, enter new markets, and/or compete with higher-wage producers? Or will it involve local firms in 'immiserizing' price competition with lower-wage producers (e.g. China)?

In addition, international development agencies could use their negotiating powers (e.g. with the WTO) to push for modifying those international regulations that currently stand in the way of accelerated technological learning of the poorest developing countries. For example, some of the following changes in existing regulations appear to deserve discussion by the international development community:

- A modified IPR regime for countries in urgent need of the most technologically advanced solutions to their absolute poverty problems (e.g. problems of infectious diseases, maternal health, or children malnourishment),
- The use of local-content requirements to foreign direct investors by low-income countries with the necessary threshold level of S&T learning capacity but extreme lack of technological learning opportunities,
- The use of government subsidies to high- and middle-tech industries by developing countries suffering from significant brain drain and striving to build their stock of human capital through creating decent employment opportunities for their secondary and tertiary graduates,
- ?

Annex A.

'Crystals' of National Technological Learning:
Selection of Indicators and their Interpretation

The so-called "crystals" are a graphical/statistical tool designed for initial, relatively fast diagnostics of technological learning processes happening in particular countries (see Sample Applications in Annex 3). The Science and Technology Program Team at HDNED continues to work on improving this tool by trying different statistical indicators and different sources of data. The number of indicators used for these crystals can be increased or reduced; composite indices can be used instead of relatively simple indicators; different indicators can be selected depending on the group of countries in focus. However, for the tool to preserve its illustrative and persuasive power, it seems preferable to keep the number of indicators limited to 12 and group them in such a way as to allow for easy comparison of the most inter-related indicators. Note that no twelve or even twenty-four statistical indicators will give us a clear and complete picture of a country's condition, so the results of this initial diagnostics have to be interpreted with a lot of caution and preferably by country experts.

To be sure, each particular country can use more than one of these learning models in different sectors or regions, but in most cases it should be possible to identify the model that is used most widely, enjoys the greatest support from the government, and thus tends to prevail in this or that country.[11] The idea was to help diagnose the current learning capabilities and learning opportunities of different countries by relying mostly on broad cross-country comparisons. Thus all the indicators used in 'crystals' were first "normalized" with respect to the range of variation of each indicator from Min. to Max[12].

For some purposes, it might make sense to calculate the averages of all 12 normalized scores for each country and rank the countries in accordance with their average Technological Learning Scores—the larger the 'crystal', the higher the country's average score, reflecting its higher capacity and wider opportunities for further technological learning. However the advantage of 'crystals' methodology is in identifying qualitative, rather than just quantitative differences among prevailing national models of technological learning, so taking the average of different and often competing methods of learning (e.g. through FDI and through investing in domestic R&D) is not really advisable.

We will now proceed with discussing some advantages and disadvantages of each of the twelve indicators that were included in our 'crystals' in order to reflect the following 5 aspects of national technological learning:

- Human capital accumulated / human capability for S&T learning (see 'around noon' indicators 11, 12, 1);
- The most accessible opportunities for learning from foreign sources created by capital goods imports and FDI ('morning' indicators 9 and 10);

[11] In other cases we will classify countries as those with "mixed or transitional" learning models. This seems to be often the case with larger countries, with considerable differences among sub-national regions.
[12] Some countries were sometimes treated as 'outliers' not included in the range calculation.

- The more demanding opportunities for learning from domestic and foreign sources through domestic R&D (indicators 2, 3),
- The most demanding opportunities for learning through exchange of disembodied knowledge and international S&T cooperation (indicators 4, 5, 6), and
- Revealed capacity to use S&T knowledge for improving technological structures of a country's MVA and of its exports (indicators 7, 8).

First we look at 3 indicators of human capability for technological learning that we chose to place on top of our 'crystals':
(12) Average years of schooling of adults, measuring the stock of human capital created by all three levels of formal education, is an important indicator of a country's capacity not only to produce new technological knowledge, but also to absorb it from foreign and domestic sources, adapt, disseminate, and use productively. However data on the number of people with formal education does not cover a lot of people with similar knowledge and skills acquired through informal and non-formal learning. These alternative routes of acquiring highly specialized technological knowledge and skills are partially measured by the number of people with access to Internet (indicator 11)

(11) The number of **Internet users per 1.000 people** reflects computer literacy of a country's population and, to some extent, its capacity for life-long learning. It can be argued that, with sufficient motivation, much of the same access to information and knowledge can be obtained through Internet as through formal educational institutions. Moreover, tertiary students without access to Internet may actually be in less favorable learning environment than secondary students or working adults with access.

(1) Brain retention indicator is critical not only because we aim to reflect accumulation of human capital in the country rather than its 'production', but also because it allows us to some extent to reflect the quality of human capital remaining in the country. In this case we relied on the survey data collected by the World Economic Forum through questionnaires asking enterprise managers across the world to score their answer to the following question: "Do your country's talented people normally leave to pursue opportunities in other countries (=1) or almost always remain in the country (=7)?" Thus, a country's low score on brain retention here means that this country suffers from loosing lots of its most talented (rather than just educated) people.

Note that all of the indicators above reflect the stock of human capital accumulated in a country over several generations and it is that stock that really matters for determining the current national capability for technological learning. The more widely available indicators of **enrolment** in primary, secondary, and tertiary institutions cannot be used as substitutes, because they reflect the current flow, rather than the stock of human capital.

This top section of "crystal" could be potentially improved by the addition of an indicator reflecting not just individuals' but also national **firms' capacity** for technological learning. Theoretically, a special composite 'Index of national firms' learning capacity' could be calculated for this purpose. However, to the best of our knowledge, such index is not yet available. Some survey data can be obtained on the shares of firms providing formal training opportunities to their employees, but these are obviously different across different industries within each country and international comparisons based on these data appear to be too risky. Besides such surveys do not cover most countries of the world as needed for our purposes.

Next we turn to examining the indicators of S&T learning opportunities, from the most accessible (morning indicators) to the most demanding (afternoon indicators):

(9) Imports of machinery and transport equipment as a share of total imports. These data require particularly careful interpretation if they have to serve as an indicator of opportunities for technological learning from foreign sources. The indicator is affected by the size of economy and by the presence of FDI. To some extent, imports of machinery and equipment can compete with national technological effort. Besides, this avenue of technological learning tends to be more important in less developed countries where other learning opportunities may not be available. However data show that even for the most developed countries such as USA or UK--which are also among the most successful learners—the normalized score for the share of machinery and equipment in total imports tends to be over 0.6 (standing for over 40 percent of their import expenditures allocated for machinery and equipment). The even higher indicators, such as in Malaysia (maximal normalized score of 1.0 standing for over 60 percent of total imports) and in the Philippines (about 55 percent of all imports normalized to 0.87 score) probably reflect not only relatively wide learning opportunities through this particular avenue, but also relatively limited opportunities for learning through other means. In Singapore the high level of machinery imports is largely explained by the small size of the country, and in both Ireland and Singapore also by the high presence of foreign investors. In slow-learning countries such as Bangladesh and Madagascar the low share of imports of machinery and equipment is definitely a negative phenomenon limiting these country's opportunities for catching up with the global technological level. Meanwhile in Japan the reasons and the consequences of the relatively low level of the same indicator might be more debatable.

(10) Inward FDI as a share of gross capital formation. This indicator, along with the Imports of machinery and equipment, is supposed to reflect a poor country' most accessible opportunities for technological learning from foreign sources. These opportunities often become available before any others, in addition to opportunities that can possibly be created by foreign economic aid. That is where our 'crystals' usually begin to 'grow', from the top-left side.

Alternatively, **Inward FDI as a share of GDP** can be used, if the goal is to control for the differences in gross capital formation as a share of GDP. Another possible approach is to use **Inward FDI per capita**, if the goal is to look at the possible affects of FDI on individuals' learning opportunities.

In any case, technological learning from FDI does not happen automatically and proportionately to their size. A lot depends on human learning capabilities available in the country and on deliberate government policies aimed at facilitating technological spillovers to national companies. These factors largely account for the difference between Passive and Active FDI-dependent learning (see Fig. 3.3).

(2) Number of Researchers in R&D per million people reflects the opportunities available to a particular country for learning through new knowledge generation as well as through adaptation of high-level foreign-produced technological knowledge to domestic needs. This indicator depends not only on the stock of human capital available to the country but also on the use of this stock for relatively complex technological learning, because unemployed researchers or researchers working in other areas would not be covered by it. For example Russia, boasting the highest share of people with tertiary education in its labor force, moves as far as 11th place in the world on this indicator.

On the number of researchers working in R&D calculated per million of population, the leadership actually belongs to Finland (over six thousand researchers per million population, normalized to 100%) followed by Iceland and Japan. Note however that results in R&D often depend on the absolute numbers of researchers working in close collaboration, so larger countries with lower proportion of researchers in their populations may have an advantage over smaller countries with higher proportion of researchers. Or, to put it in a different way, smaller countries may need to "compensate" for their size by the higher proportion of researchers in their populations.

(3) Total (public and private) R&D expenditure as percentage of GDP is another indicator of opportunities available for learning through new knowledge generation and foreign knowledge adaptation. Because R&D expenditure is shown in percentage of GDP, it reflects intensity of national technological effort rather than its scale. Besides, this is one of the 'input' indicators of R&D, so the scale of actual R&D activities in the country would be proportional to R&D expenditures only if cost-efficiency of these expenditures were the same in all countries.

Unfortunately, these data are not available for many developing countries and data for public and private R&D expenditure calculated separately are even scarcer. Otherwise it might be useful to look at **public R&D expenditure vs. private** and compare their ratios across different models of technological learning.

Such a widely used indicator of new knowledge generation as "**the number of patents registered**" (or even US-registered) is known to be quite ineffective in reflecting the real scale of innovation in poorer developing countries with weak institutions. The problem is that scientists from these countries either don't see the need for applying for a patent (given the absence or persistent failure of legal mechanisms for IPR protection) or don't have enough money to pay for it or its protection (particularly abroad). In addition, when the patents are registered by national agencies, their quality can be very uneven across countries. The issue of uneven quality of patents is to some extent controlled for in indicator (7) Royalty and license fees receipts per capita, because insufficiently innovative inventions are not likely to generate any receipts.

(4) Royalty and license fees payments per capita. This is one of the 2 indicators that we have selected to reflect a country's participation in international exchange of disembodied S&T knowledge. Indicator (6) reflects an inflow of patented technological knowledge into the country, so it is particularly interesting to compare it to its neighboring indicator (7) Royalty and license fees receipts per capita that shows the reverse flow of patented knowledge from the same country to other countries.

Not surprisingly, the lowest scores on this indicator belong to Slow-learning countries, followed by Passive FDI-dependent and Creative-isolated learners. Autonomous and Creative-cooperative learners show comparable scores in the range of 30-65 percent. The obvious outliers are the two Active FDI-dependent countries, Ireland and Singapore, whose payments tend to be several times higher than those of the next leader on this indicator Netherlands (normalized to 100 % score). One of the possible explanations to this aberration (see Fig. 3.3) appears to be that these extremely high payments are boosted by intra-firm transfer pricing practices, since it is well known that most of these payments are made by TNCs operating in these countries.

(5) Royalty and license fees receipts per capita. The most knowledge-intensive Creative-cooperative economies have an obvious advantage on this indicator as they have more patented technological knowledge to sell. We treated Luxemburg as an outlier (due to its small size), which gives the leadership on this indicator to Sweden (normalized to 100 % score) closely followed by USA, UK, and Netherlands.

It appears important to note a large gap on this indicator between a few technological leaders, selling much of all patented knowledge, and all other countries. Even many of the high-income countries such as Italy, Spain, Australia and Austria find themselves in a completely different category, competing only with the most fast-learning developing countries. The absolute majority of countries are practically excluded from participation in this knowledge market as they have nothing to sell and there is very little they can afford to buy.

(6) Domestic ownership of inventions made abroad as percentage of all inventions owned by residents shows what share of all technological knowledge controlled by a country's residents was generated by foreign researchers, mainly as a result of transnational corporations' (TNCs') activities in other countries. By definition, this indicator refers mostly to countries that have developed their own TNCs and are thus in a position to benefit from funding R&D activities of researchers in their foreign affiliates. Because the inflow of foreign inventions is shown as a share of all inventions controlled by the country, the USA, being the largest owner of foreign inventions in absolute terms, is not a leader. If Luxemburg is treated as an outlier again, the leadership among OECD countries belongs to Switzerland. Some other countries realizing proportionately high additions to their portfolios of inventions are Netherlands, Canada, and Belgium, while "autonomous" Japan and Korea obviously under-use this avenue of technological learning. The relatively high scores of Ireland and Singapore probably need more careful interpretation again, taking into account unique roles played in their economies by foreign TNCs, which sometimes register their headquarters in these countries too.

In place of indicator (8), it would be preferable to put a composite Index of a country's technological learning through international S&T cooperation. Such index still remains to be developed. Meanwhile, there is one more indicator available from the same OECD Patent Database that we can work with. In addition to the one that we currently use (#8 above), this database also contains a 'partner' indicator—**Foreign ownership of domestic inventions as percentage of all domestic inventions**. Together these two indicators reflect a relatively new phenomenon of cross-border ownership of inventions, when an increasing share of technology is owned and controlled by firms of a country that is not the inventor's country of residence. In the late 1990s as in the mid-1990s, the average for all OECD countries was quite balanced—about 14% of all inventions made in OECD countries were owned or co-owned by a foreign resident and about the same 14% of all inventions owned by OECD residents were made abroad. However both of these indicators differ considerably for concrete countries and their balance for concrete countries can be either positive or negative. For example, it is highly negative for Russia and Mexico, meaning that the share of foreign inventions controlled by Russians and Mexicans is much lower than the share of Russian and Mexican inventions controlled by foreigners. Interestingly enough, this "balance of cross-border inventions' circulation" is also negative for United Kingdom, but it is positive for United States.[13]

Considered from the point of view of national technological learning, it would not be right to treat domestic inventions owned by foreign residents as a pure loss to their country of origin. Foreign funding of domestic R&D (e.g. about 60% of all R&D expenditure in Singapore and around 70% in Ireland) allows a country to build up its army of researchers working in R&D and thus increases its potential capacity for further technological learning from both domestic and foreign sources. Thus, instead of subtracting one share from another, we would suggest to add them up to acquire an **indicator of national participation in cross-border R&D**[14]. However, it can well be argued that the "outflow" of domestic inventions to their foreign owners often deprives their country of origin of the otherwise possible economic benefits from using these inventions for technological upgrading and international competitiveness. To deal with this consideration, we suggest assigning a higher weight to Domestic ownership of foreign-made inventions (e.g. multiply it by 0.7) than to Foreign ownership of domestic inventions (e.g. multiply it by 0.3).

This new indicator of National participation in cross-border R&D could then be used for 'crystals' diagnostics in place of indicator (8) Domestic ownership of inventions made abroad.

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[13] Note that in order to compare these two indicators, one of them has to be corrected so that both fractions have the same denominator, for instance both are shown as percentages of all inventions made by residents of the country.

[14] This indicator would be somewhat similar to the sum of exports and imports as a share of GDP used as an indicator of a country's participation in international trade.

Finally, **(7) Share of high- and medium-tech industries in manufacturing value added (MVA)** and **(8) Share of high- and medium-tech industries in manufactured exports** reflect two important aspects of a country's success in using its stock of technological knowledge and skills for its economic development. These two indicators are obviously interrelated, but--as shown by our 'crystals' diagnostics--can differ considerably and in both directions. In fact comparing these two indicators can often help diagnosing different models of national S&T learning (see Fig. 3.3).

For example, Philippines and Mexico -- passive FDI dependent learners--demonstrate a big gap between the two scores, with Mexico ranking 4th in the world by the share of medium- and high-tech products in its manufactured exports, but only 43rd by the same share in manufacturing value added. This is a sign that a country is integrated in the sections of the global value chains with the minimal value added, such as product assembling and testing. Such countries are bound to be most vulnerable to the erosion of their competitive advantages, wherever those advantages stem mostly from cheap semiskilled labor.

By contrast, creative isolated learners such as Russia and to some extent India tend to have an opposite misbalance—their technological structure of production looks more advanced than that of their exports. In these countries import substitution strategies have created diverse and complex industrial structures, but the insufficient quality of outputs made most of these industries internationally uncompetitive. For example, even though Russia ranks as low as 34th by technological structure of manufacturing value added, the technological structure of its manufactured exports is ranked even lower - only 41$^{st.}$

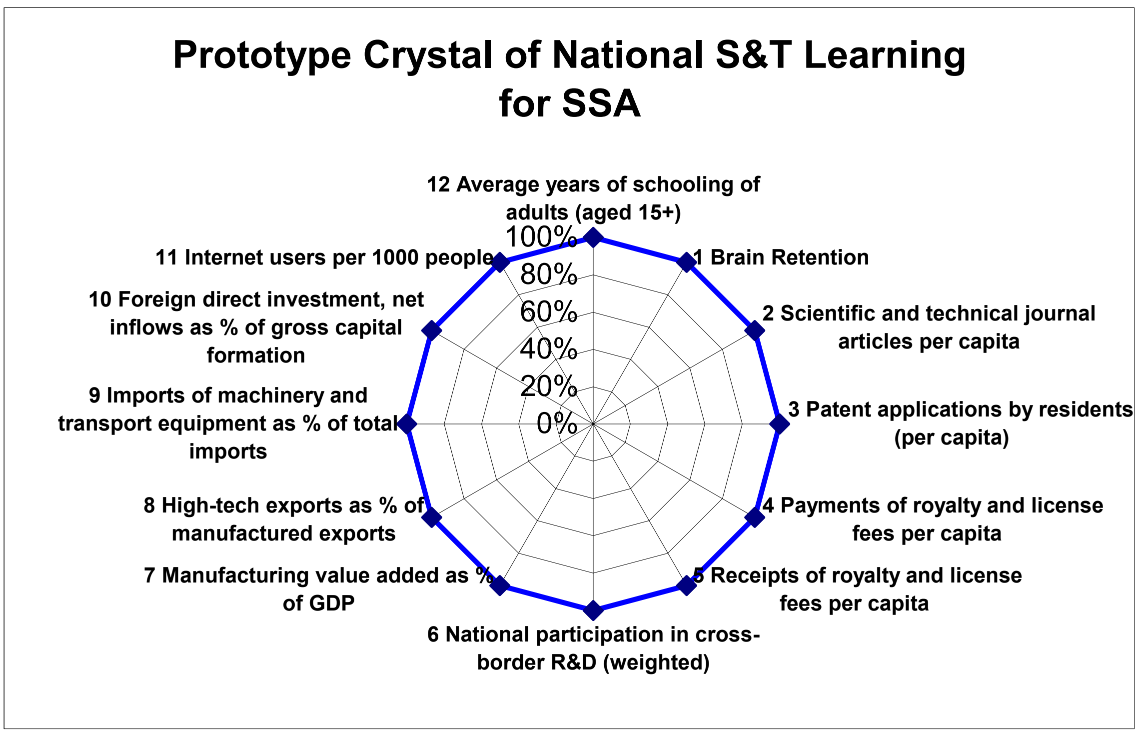
Countries with high R&D expenditures and relatively limited reliance on FDI (see Japan and Korea as autonomous learners and USA as a creative-cooperative learner) tend to have relatively balanced technological structures of production and exports. Singapore and Ireland, active FDI-dependent learners, lean toward the "balanced" group of countries too, largely thanks to their successful use of FDI for funding local R&D and other high-value-added production operations.

Annex B.

Modified 'Crystals' for Sub-Saharan Africa

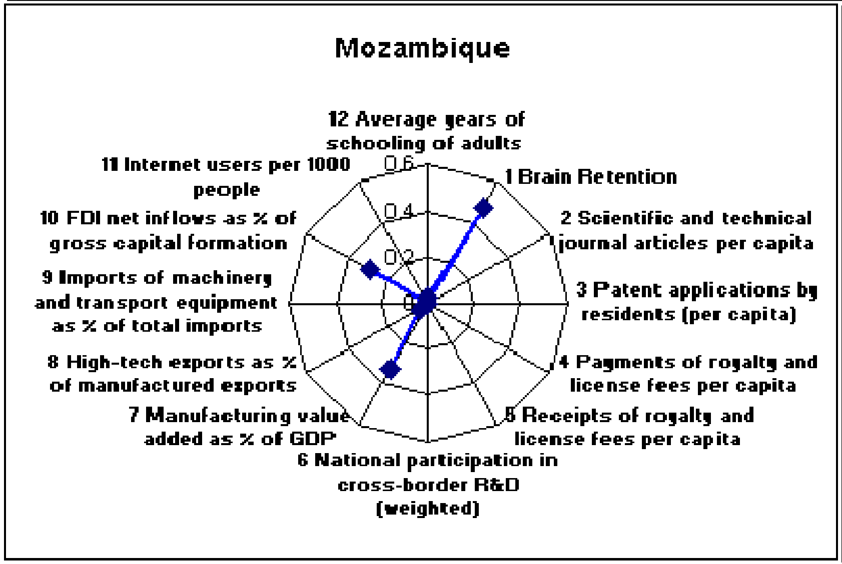
One of the problems with applying our diagnostic methodology to the poorest countries of the world, including most countries of SSA, is that the necessary data if often not available. To deal with this challenge, we have developed a temporary solution based on substitute indicators more often available for the least developed countries albeit somewhat less indicative of the S&T learning opportunities and results that they are supposed to reflect. In the prototype 'crystal of national learning for SSA" shown below, we have made the following substitutions:
(2) Instead of Researchers in R&D per million people – Scientific and technical journal articles per capita,
(3) Instead of Total R&D expenditure as a share of GDP – Patent applications by residents (per capita),
(7) Instead of Share of high- and medium-tech industries in MVA – Manufacturing value added as a share of GDP,
(8) Instead of Share of high- and medium-tech industries in exports – High-tech exports as a share of manufacturing exports.

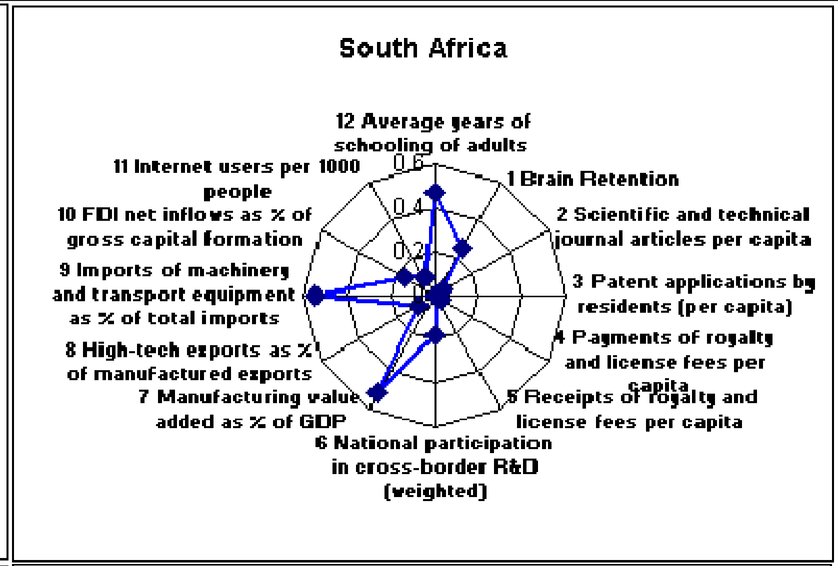
In addition we have piloted our new indicator of National participation in cross-border R&D as indicator (6) – see its description in Annex 1.

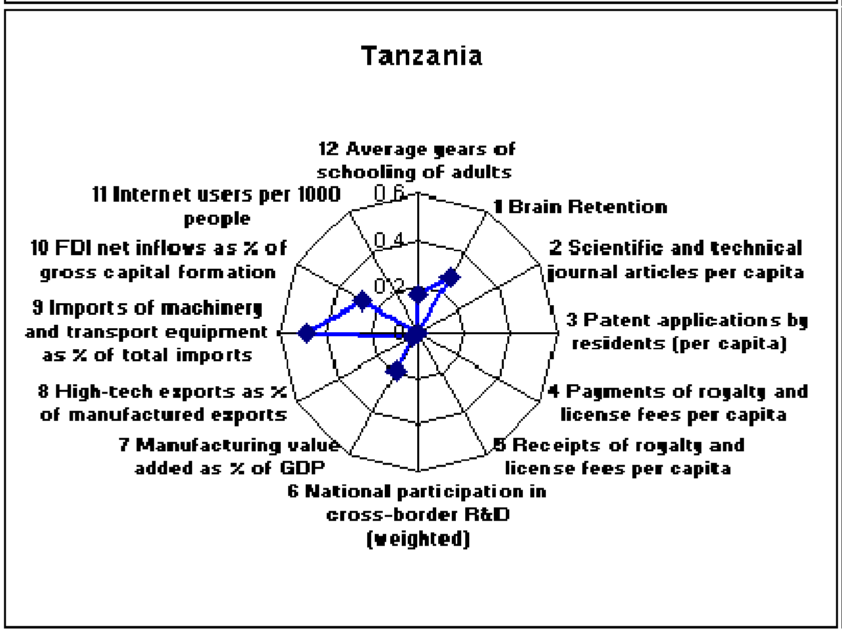


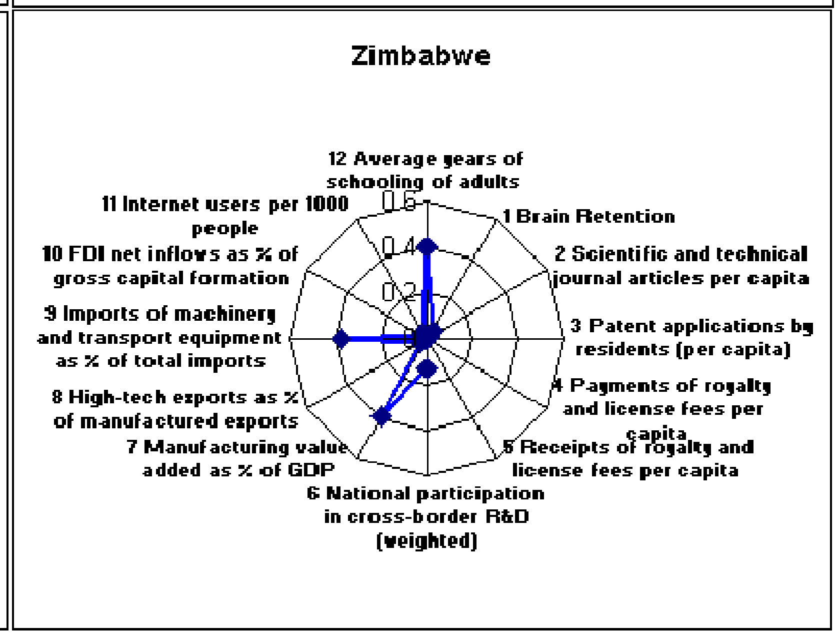
See next page for sample 'crystals of national S&T learning' of 4 neighboring SSA countries.

'Crystals' of National Technological Learning of Mozambique and its Neighbors







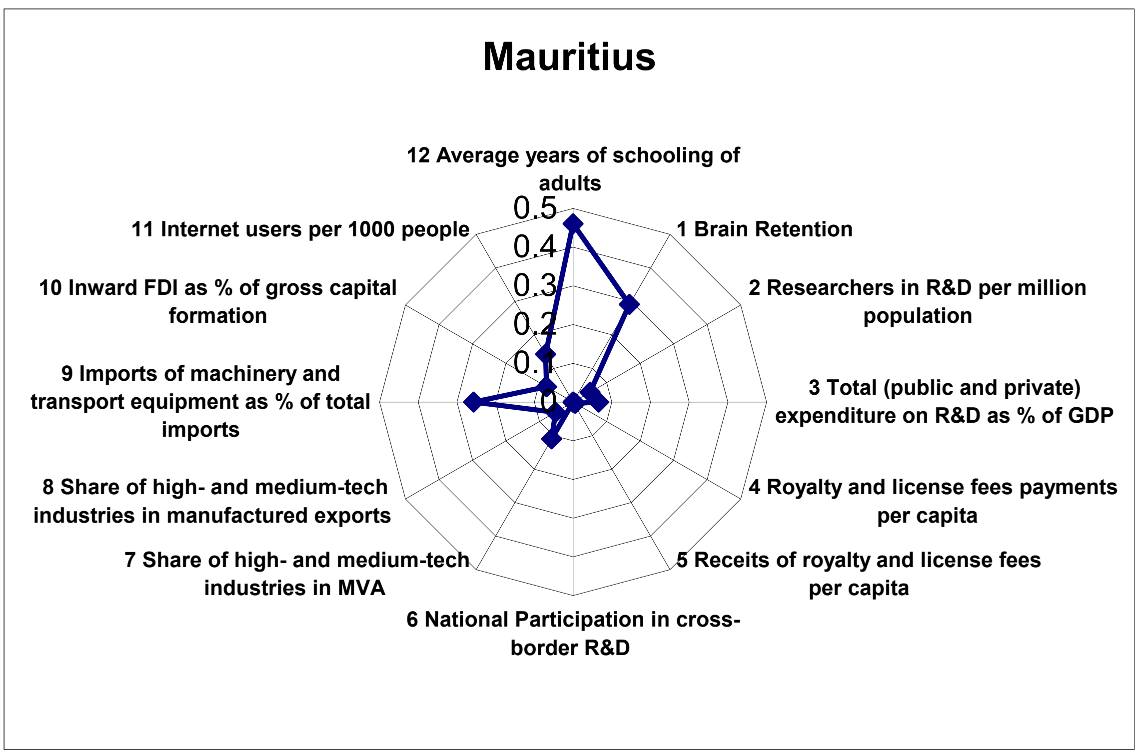


Annex C.

Sample applications of 'crystals method' for preliminary technological diagnostics of countries

1. Mauritius S&T Policy Challenges

Our method using Crystals of Technological Learning--'crystals method'-- is designed for preliminary assessment of a country's capacity for improving its technological structure. In addition to looking at the national level of human capabilities/human capital accumulation (see the top of the crystal, indicators 11,12, and 1), this method focuses on national technological learning opportunities that exist beyond the boundaries of education system (from the most accessible opportunities shown by indicators 9 and 10 to the more demanding, indicators 2-6) and on the country's revealed capacity to use technological knowledge for its economic development (indicators 7 and 8). Based on this approach, it seems clear that—in spite of all the government efforts—Mauritius still belongs to the group of 'slow learning' countries, with all the learning opportunities except for formal education scoring far below 50% of the world distribution (see the chart below). The country's achievements on macroeconomic and structural indicators as well as in raising the average education level of its population create good prerequisites for accelerating national technological learning including learning from foreign sources that is of particular importance to all developing countries. But this acceleration is not likely to happen automatically, without deliberate government strategies.



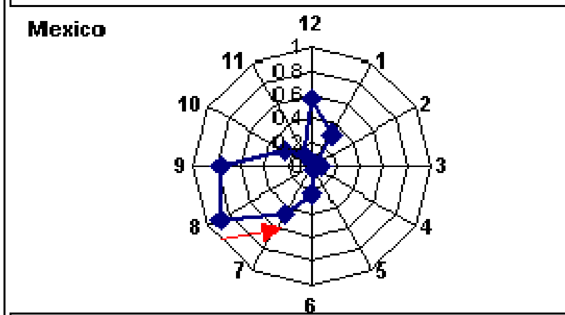
Our Taxonomy of National S&T Learning Models (see Fig. 3.3 above) might be of some help in discussing a new technological learning strategy for Mauritius. For example, any attempts to learn from the so-called 'East-Asian Model' would be confused without clear understanding of significant differences in policy choices that different East Asian countries made with respect to major sources and methods of their relatively fast technological learning--compare the model of Philippines as Passive FDI-dependent learner to those of Singapore as Active FDI-dependent learner and Korea as Autonomous learner. What would be the preferred model for Mauritius, given its specific strengths and limitations? Or would the country choose to rely on different models of technological learning in different sectors of its economy? Facing this kind of policy choices might be timely for Mauritius now.

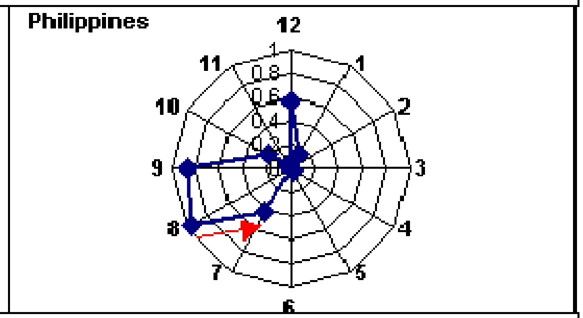
2. Malaysia's Mode of Technological Learning in Comparative Perspective

Our method of graphical analysis with the help of "crystals of technological learning" suggests that – despite the history of active government S&T policies – the prevailing mode of technological learning in Malaysia is still Passive FDI-Dependent (see figure 'Malaysia in Taxonomy...' below). Typically for this model, Malaysia's 'crystal' is strongly left-sided with all the right-side indicators (#2,3,4,and 5), reflecting active learning from foreign sources and domestic knowledge creation, below (in most cases far below) 15% of the world distribution (not unlike those for Mexico, Philippines, or Thailand). Also typically for this group of countries, the share of high- and medium-tech industries in Malaysia's manufactured exports (indicator # 8) is higher than the same share in its manufacturing value added (indicator #7), reflecting high dependence of its manufacturing sector on imports of technologically sophisticated components and relatively lower technological complexity of manufacturing operations performed domestically. Note however that the difference between indicators 7 and 8 for Malaysia is not as big as for Philippines, Thailand or Mexico. Malaysia also looks much better than these countries on the indicators of Internet Users and Brain Retention (the topside indicators #11 and #1) and slightly better on Royalty and License Fees Payments (right-side indicator #4).

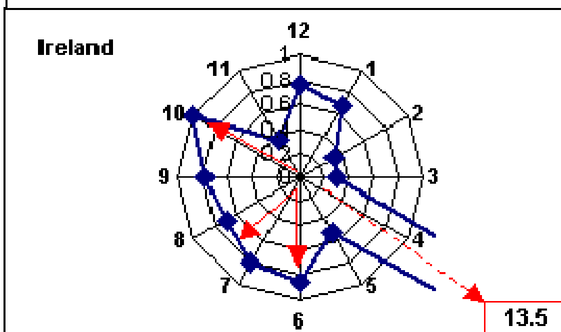
Malaysia in Taxonomy of National S&T Learning Models for Developing Countries

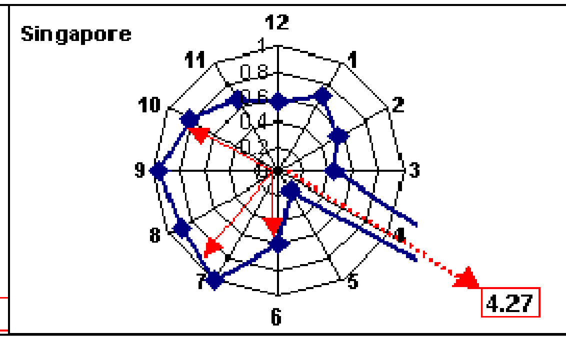
Sample Crystals of Passive FDI-Dependent Learning



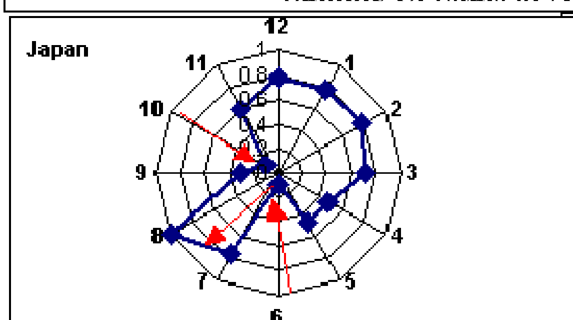


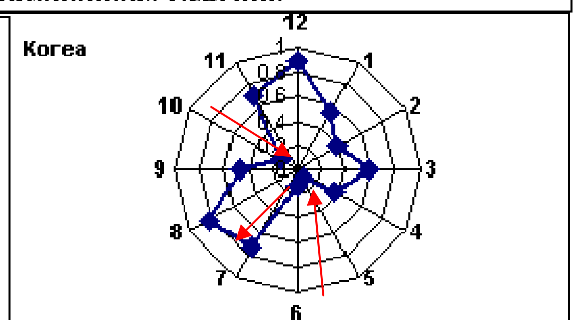
Sample Crystals of Active FDI-Dependent Learning



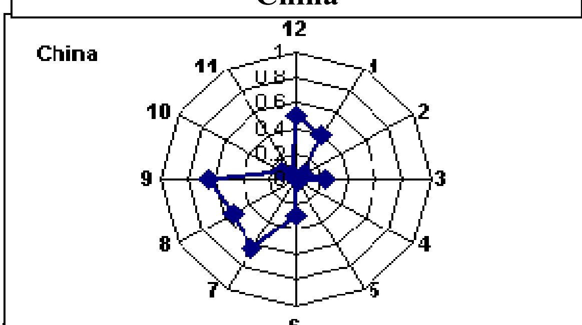


Sample Crystals of Autonomous Learning

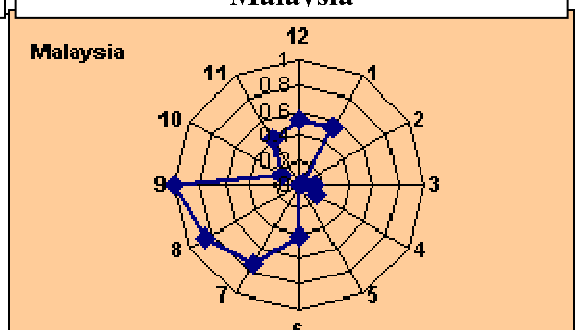




China



Malaysia



9. Capital imports as % of all imports
10. Inward FDI as % of gross capital formation
11. Internet users per 1,000 people
12. Average years of schooling of adults
1. Brain retention
2. Researchers in R&D per million population
3. Total R&D expenditure as % of GDP

4. Royalty and license fees payments per capita
5. Royalty and license fees receipts per capita
6. International outsourcing of R&D
7. % of high- & medium-tech industries in MVA
8. % of high- & medium-tech industries in manufactured exports

Still, as things stand now, the most characteristic features of Malaysia's mode of technological learning are found along the horizontal Axis 9-3 of our "crystal" – the highest in the world (!) share of capital goods in imports vs. one of the lowest share of R&D expenditure in GDP (12% of the world distribution, which is lower than in Uganda). For comparison, see Active FDI-dependent Singapore, where high capital goods imports are counterbalanced by relatively high R&D expenditure. Next, Malaysian indicator #2 - Researchers in R&D per million of population - is even lower relative to the rest of the world (just about 3% of the world distribution, comparable to Guinea). The good news is that both of these R&D indicators appear to have increased between 1998 and 2002 (the latest date that the data are available to me), but this happened after a period of negative trend between 1990 and 1997.[15] The recent improvement might be one of the outcomes of deliberate government policies, whereas the previous deterioration might result directly from the relative fall in FDI inflows and relocation of some high-tech foreign enterprises to lower-cost economies. (O*r are there any other explanations to this uneven dynamics?)* That shows the urgency of government policies to make the critical aspects of national technological learning less dependent on FDI dynamics – learning to acquire new technologies in a more Active mode (like Singapore) and/or more Autonomous mode (like Korea), while at the same time using this endogenous learning and innovation capacity for slowing the outflow of FDI and attracting more knowledge-intensive/higher value added FDI.

The urgency of this task is under lied primarily by the strong competition that Malaysia faces from China, both in trade (with about 50% of Malaysian exports to US markets overlapping with Chinese exports) and in attracting FDI. From the point of view of FDI, two of the critical factors are labor costs on the one hand and the quality of the labor force on the other. On these criteria, China looks preferable to Malaysia, because, with comparable levels of labor force education[16], the average manufacturing wage in China is 5-8 times lower than in Malaysia (Yusuf, Shahid 2003). In addition, China has higher own innovation potential due to the higher share of R&D researchers in population (633 per million in 2002) and greater absolute number of researchers, which is important for creating critical mass of research capacity in any given field. The same refers to China's R&D expenditure advantage over Malaysia – 1.2% of GDP vs. 0.5% as of 2002 with incomparable scale of GDPs. The conclusion seems to be that Malaysia might benefit by

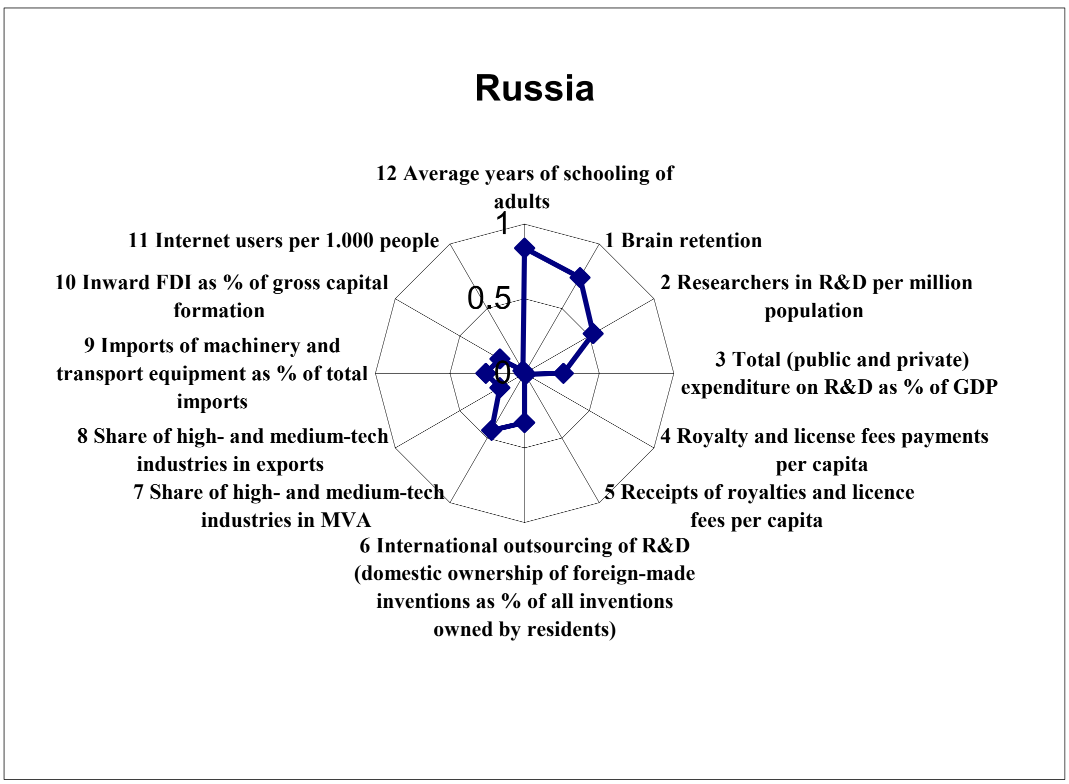
[15] The share of R&D in GDP also tended to decrease in other ASEAN-4 countries (in contrast to NIEs), but Malaysia was the only East Asian economy where even the number of researchers was going down -- from 208 per million in 1990 to only 93 per million in 1997. However by 2002 this number has increased to 294 per million (WDI – 2005).

[16] The average years of schooling of adults in 2000 were 6,4 in China and 6.8 in Malaysia, while the UNDP's Education Index (based on literacy and combined enrolment rates in 2002) is exactly the same for both countries (0.83).

learning from China's experience of combining continued reliance on FDI with gradual building of own innovation capacity, but it would have to move even faster than China because of the already existing wage- and other costs differential working against it. In other words, Malaysia will have to "justify" it's higher than China's per capita income by acquiring higher endogenous innovation capacity.

3. Russia in urgent need of changing its model of technological learning

Russia's 'crystal of technological learning' evidently shows that its national S&T learning has recently been (a) too slow (judging by the overall small size of the 'crystal', (b) constrained mostly by the lack of opportunities for learning from foreign sources (rather than by availability of human capital), and (c) could potentially be accelerated by expanding these opportunities practically 'around the clock' – from importing more machinery and equipment to increasing investment in R&D (indicator 3 is too low compared to indicator 2, the number of researchers in R&D) to buying and selling more patents and licenses. Not surprisingly, Russia's use of national S&T capacity for economic development is not successful at all, particularly in terms of technological structure of exports (indicator 8). To have only about 3 percent of high- and medium-tech exports in the total manufactured exports is an outrageous indicator for the country that prides itself on being a member of G-8 group.



Russia clearly demonstrates the weakness of Creative-isolated model of technological learning by the fact that even unusually high stock of human capital in Russia (unprecedented for its level of per capita income) fails to compensate for its continuing lack of ability to absorb foreign technologies. In Russia's 'learning crystal' see low indicators of capital goods imports (9), FDI (10), and royalty and license fees payments (4) as well as extremely low share of high- and medium-tech industries in Russia's exports (8) contrasting with considerably higher share of these industries in Russia's MVA (7). The latter contrast – directly opposite to that in passive FDI-dependent countries--reflects low international competitiveness often characteristic of Russia's surviving high- and medium-tech industries. It seems evident that isolated technological learning has historically proven its limited potential and is becoming less and less effective in the age of globalizing knowledge economies.

Russia's strategic goal should be to join the ranks of creative-cooperative learners involved in creating new knowledge at the global technological frontier and exchanging it with other technological leaders on an equal and mutually beneficial basis. This will require repairing Russia's national innovation system (NIS) while at the same time learning to actively use foreign sources for acquiring already existing technologies. Successful accomplishment of this double task should allow Russia to simultaneously achieve fast technological upgrading of all of its industries and targeted mobilization of domestic S&T potential for conquering technological leadership in selected niches of the global market.

So, which of the known and tried models of technological learning from foreign sources would be most beneficial for Russia? Experiences of which countries are most relevant to Russia's twin goals of fast technological upgrading across all industries combined with conquering technological leadership in some of them?

It is important that Russia's knowledge strategy focuses on redressing possibly the world's largest mismatch between the high quality of human innovation capabilities, on the one hand, and the inadequate institutions and policies needed for fast technological learning. This specific focus can be seen as both, a unique challenge (with practically no opportunities to learn from any other countries' experience of dealing with this problem) and a unique chance for success. After all, catching up on institutions for stimulating enterprises' drive for innovation is likely to be a matter of years, while radically improving on the quality of national human capital could take several generations.

In spite of the granted uniqueness of Russia's challenges in its transition to a knowledge-based economy, Russian decision-makers should make the most of learning from the past and present experiences of today's technological leaders as well as of those countries that currently appear to be in the process of successfully catching up with the leaders. Among the latter are such new entrants into the "global knowledge economy' as Republic of Korea, Finland, Ireland, Singapore, and to some extent China. Experiences of many other countries can also be instructive in a way, if only for understanding the range of choices available and the risks to be managed.

Take for example the passive FDI-dependent model of technological learning described above. This model appears to be by far outgrown by Russia, being most beneficial for countries with low endogenous S&T capacity and an abundance of low-skilled low-cost labor. With the current, relatively low level of wages and salaries in Russia, this model of technological learning is still possible for it too. But it should be understood that this model carries with it high risks of conserving or even deteriorating Russia's low-tech structure of MVA, even if the technological structure of exports will appear to improve. FDI attracted mostly by low labor costs will naturally flow to labor-intensive, low-skill operations, such as manual assembly of imported components, be that automobiles or computers. In this case technological learning opportunities may turn out to be quite limited.[17] Furthermore, this "window of opportunity" for learning from foreign sources with the help of cost-minimizing FDI may soon close as the flows of FDI change their direction in favor of other developing countries with even lower labor costs. This is the nature of the challenge currently faced by Mexico as a result of China's competition.[18]

In our opinion, Russia, with its remaining wealth of human capital, might attempt to perform a transition to the most advantageous model of technological learning used by the most advanced economies – the Creative-cooperative model – in those industries where it still possesses scientific potential for prospective global leadership (possibly, in some sectors of telecommunications, nuclear energy, bio-technology, etc.). In other industries Russia would have to rely on either Autonomous or Active FDI-dependent models. Note that in all three cases the role of the central government would have to become much more active and strategic than it is now.

[17] See for example the large difference between both Mexico's and Philippines' scores on the shares of high- and medium-tech industries in exports, on the one hand, and in MVA, on the other. Note that in the more developed countries this difference is either small or runs in the opposite direction – i.e. the technological structure of MVA is either close to or higher than that of exports.

[18] See for example: Diana Farrell, et al, 2005.

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