Chapter 5

Knowledge Policy for Development

by

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This chapter presents a conceptual framework for innovation policy in developing countries, starting from a distinction between innovation systems in which actors are linked and a knowledge ecology in which the connections between actors are weak or absent. The approach distinguishes between the requirements of middle-income and least developed countries and considers the best ways to search for relevant areas of progress in science and technology, the means to advance the knowledge ecology, and the emergence of multiple innovation systems.

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Introduction

This chapter provides a conceptual framework for an empirically and analytically informed innovation policy for developing countries. The framework is based on the distinction between the knowledge ecology[1] and innovation systems. It emphasises the role of a particular model of innovation for growth in developing economies as well as the process of discovering what a country does best in terms of its science and technology specialisation.

The framework takes account of the heterogeneity of developing economies. On the one hand, there are the large and developing middle-income countries which are clearly catching up because of increasing exposure to foreign technologies through foreign direct investment (FDI) and trade and improved absorptive capacity. On the other, there are the low-income economies which have seen very little progress in science, technology and innovation over the last decade.

The chapter first takes stock of the most recent data on technological change and technology diffusion in developing countries in order to illustrate the difference between two classes of countries. Next, it argues that innovation in less developed economies has certain peculiarities. These countries must focus on research and development (R&D) and more informal learning activities to produce locally oriented innovations and to develop absorptive capacity. But, at the same time, locally generated spillovers from this R&D may diffuse away within the domestic economy. There are vast areas of economic activity which require innovation to serve local needs, where "local" may mean a large fraction of the world population. It is not true that innovating for global markets is the only game in town.

The chapter then turns to the framework for distinguishing between the knowledge ecology and innovation systems. It describes the process of discovery of the relevant domains for advancing science and technology in a given country, and derives the three main dimensions of responsibility for innovation and knowledge policy in developing countries. The final sections propose knowledge policy responses in these three dimensions:

- a search for the relevant areas for progress in science and technology;
- improvement of the knowledge ecology;
- the development of a suitable institutional framework (incentives) to facilitate the emergence and development of multiple innovation systems.

Different countries, different challenges for knowledge policy

This section examines the most recent data on technology diffusion and technology transfer (TT) to developing countries to see whether countries are using the various TT mechanisms (notably FDI, trade and licensing) effectively. It considers the extent to which these mechanisms act as engines for growth, and whether there is any need to reconsider the premise of the central role of FDI and trade as TT mechanisms in current policy. It draws on data from a recent World Bank report (2008) focused on technology diffusion.

The World Bank's current assessment

The World Bank puts at the centre of its framework of analysis two fundamental determinants of technology diffusion in less developed countries. The first involves the three main channels by which developing countries are exposed to external technologies: trade; FDI (and licensing, which can substitute for FDI); and a highly skilled diaspora. The second is the country's absorptive capacity, or technological adaptive capacity. This can be increased by policy interventions which lead to improvements in governance and the business climate, in human capital (increase in basic technology literacy), in the technological capacities of firms, and in access to credit on capital markets.

These two determinants are clearly related. They create mutual externalities and thus form a dynamic system with feedbacks. Such systems are well known and well studied in the literature on economic development. They generate multiple equilibria that are reached through virtuous (or vicious) circles (*e.g.* Stiglitz, 1991).

For example, as a country becomes more exposed to foreign technologies (through an increase in FDI) it may increase, up to a point, the returns to improvements in absorptive capacity. As absorptive capacity improves, the probability of spillovers spreading through the domestic economy increases. This in turn raises the economy's overall efficiency, and this positively influences decisions to locate more FDI in the country. As in any positive feedback system, there are virtuous circles which take the form just described, but vicious circles may also occur.

Virtuous circles

The basic message of the World Bank report is that many developing countries – notably the middle-income countries – have engaged in a virtuous circle, in which the basic components of the feedback system described above mutually improve each other. The increasing exposure to foreign technology (through FDI and trade) is co-evolving with increased dissemination and spillovers of these technologies within the domestic economy. As a result, by many measures, these countries have made outstanding progress in innovation and in technology adoption and deployment. The main indicators of such trends are:

- R&D and other innovation-related activities becoming significant drivers of productivity;
- a rising share of high-technology and capital goods imports;
- the expansion of exports of technological goods;
- an increase in FDI as a percentage of gross domestic product (GDP) and as a percentage of fixed capital formation;
- increased exposure to external technologies.

For these countries, trade and FDI therefore seem to be the main channels for accessing foreign technologies. TTs as a joint products[2] work quite well when absorptive capacity is sufficient to allow spillovers from the transferred technology to the rest of the economy. Good policies and governance remain of course essential in order to maintain FDI and trade at a high level and to continuously improve absorptive capacity.

The situation described above is consistent with the evidence on the positive relation between the reform of intellectual property rights (IPR) and the stimulation of TTs in middle-income countries. Indeed, Park and Lippoldt (2008) find that stronger patent systems tend to be positively associated with inward FDI and trade and that a strong patent system is positively and significantly associated with TT (*i.e.* inflows of high-technology products, such as pharmaceutical goods, chemicals, aerospace, computer services, information, and office and telecom equipment). It is also consistent with the empirical evidence of Branstetter *et al*. (2007) suggesting that, owing to IPR reform, increased multinational activity in developing countries is sufficient to offset potential declines in imitative activity, resulting in an overall enhancement of industrial development in the South.

Vicious (or no virtuous) circles: The case of low-income countries

This is not the case in low-income countries, where the empirical evidence suggests that the various channels by which countries are exposed to foreign technologies are far less effective:

- FDI remains at a very low level (less than 1% of GDP) and the share of FDI in capital formation is also low.
- The ratio of high-technology product imports to GDP is very low and the role in the world market for high-technology goods is marginal.
- A licensing-based strategy for acquiring technology to complement or substitute FDI may not be very efficient because of a lack of technological and legal capabilities and because markets for technology are less efficient when the transactions are between very heterogeneous players.

These countries have not been very successful in improving their absorptive capacity, so that the potential of foreign technologies to improve the domestic economy is not fully realised. Their use of foreign technologies is described in terms of a "passive approach and limited effort to leverage the technology imported by foreign firms operating on their soil" (World Bank, 2008).

Not only have FDI and trade not greatly raised these economies' exposure to foreign technology, the extent to which they have benefited from this exposure has been limited by weak capabilities. As a result the gap between middle-income and low-income countries is widening (in terms, for instance, of the share of capital goods in GDP). What works in middle-income countries – foreign technologies are massively adopted through FDI and trade and spill over to the rest of the economy – does not work well in lower-income countries.

This leads to what is the main message of this chapter: different countries have different challenges in terms of innovation and knowledge policy. In an emerging, developing country context, the challenge appears directed towards the traditional "backing winners" industrial science and technology policy, and it draws attention to the importance of engineering and design skills and of accumulating "experience". In a least developed country (LDC)[3] context, characterised by "disarticulated" knowledge systems, the policy challenge is much more complex (Soete, 2009).

The need for technology transfer as a principal objective

A second, more precise, issue is the kind of technology transfer that should be supported and promoted in these countries. FDI as a valuable vehicle for technology transfer and spillovers in middle-income countries (Blomström and Kokko, 1998) exhibits some shortcomings that are likely to be amplified in low-income economies.

The issue is whether the incentives of the foreign investor and the importing country are really aligned when the latter is a low-income economy (alignment of incentives is the advantage most frequently advanced when the TT is a joint product of another economic operation). Foreign investors primarily want to succeed in putting a plant into operation and keeping it running for a certain period of time. If incentives are not properly balanced between the need to make the industrial facilities operate efficiently and the need to transfer learning and knowledge to local workers and engineers, the foreign investor is likely to devote insufficient resources and time to the learning process. The foreign investor is also likely to do most of its R&D in its home country, thereby preventing the development of core technologies in the host country.[4]

The nationals of the importing country need to absorb the whole range of capacities and capabilities (including tacit knowledge). But what matters most for the foreign investor is the success of the industrial operation, not of the transfer in itself. For example, Choii *et al*. (1994) argue that foreign investors have little incentive to take the initiative in shifting responsibility for technological adaptations to local suppliers or staff. If the replacement of expatriates is unnecessarily delayed, however, this prevents the learning process from fully taking place. This is a clear case of unbalanced incentives between the need to make the investment operational in the short term and the need to transfer the technology. In this case, TT becomes more a by-product than a joint product.

For low-income countries, the number, scale and sectors of technology transfer cannot be allowed to depend *only* on general economic operations such as FDI or infrastructure construction; neither can they take the form of market transactions alone (*e.g.* licences). In such cases, the circumstances and conditions prevailing in low-income countries imply a suboptimal level of technology transfer in relation to these countries' needs.

What model of innovation for the least developed countries? The importance of local innovation and local spillovers[5]

In LDCs it is important to support certain types of innovation as engines for growth. Otherwise, local needs and local markets may not necessarily be well served and more effective government incentives may be required.

In terms of their innovation capacities LDCs are characterised by two features: they are small countries (in terms not of the size of GDP but of the relative size of the relevant sectors of the economy, those that would potentially benefit from technological spillovers from innovation) and they have weak absorptive capacity. This entails both a difficulty and a risk: the difficulty of integrating spillovers that originate elsewhere; and the risk that the export-oriented R&D they do will spill out of the country and benefit external firms and consumers rather than the local economy. For the LDC, the balance of knowledge and information spill-in and spill-out may therefore be negative.

Therefore, even if an LDC may benefit from "plugging" some of its activities into the global market, this should not preclude support for locally oriented innovation, which can be critical for growth and social well-being. The development of capacities to produce locally oriented innovations allows the country to develop absorptive capacity, but at the same time locally generated spillovers from those efforts may diffuse away from the local economy.

Innovation should take place over the whole spectrum of economic activity, across sectors (not just in high technology) and types of innovations (not just formal R&D). In LDCs it is incremental, cumulative and mostly informal (without R&D), mainly in "traditional" sectors or in services that do not qualify as "high technology". Although these innovations mostly take place in low-technology activities, they generate local spillovers and will ultimately affect the productivity of a wide range of sectors in the local economy.

Given that information and communication technology (ICT) is considered the major general purpose technology (GPT) of our time, ever broader segments of a less developed country's economy should adopt ICT and "invent" new applications for ICT that increase their productivity. A GPT fosters economy-wide growth not simply and not mainly through innovation in the GPT itself; rather, growth will occur when a wide range of sectors adopt the GPT and improve their own technology. The key issue, therefore, in "secondary countries" (those not at the GPT frontier) is how to allocate R&D and other innovative inputs so as to leverage the growth potential of the prevalent GPT. The key point is not that ICT in and of itself causes growth, but rather that "innovation complementarities" in adopting sectors need to materialise for economy-wide growth to take place. These innovation complementarities (adoption, local innovations in traditional sectors) may be seen as less innovative and therefore may not be deemed as worthy of support or encouragement. Yet they ultimately constitute the key to economic growth.

In LDCs, innovation policy should pay attention to these issues. It should not aim just at increasing total R&D, but do so in a way that encourages local innovation and local spillovers rather than global R&D and external leakages, that develops absorptive capacity, and that ultimately affects the productivity of a wide range of sectors in the local economy.

A new framework

David and Metcalfe (2008) distinguish between the knowledge ecology and innovation systems. On the basis of this distinction they find that the innovation policy response has two related branches which can be used to explore problems relating to innovation in developing economies. To this framework a third dimension is added here which involves the search for the areas in which a country should try to position itself in the knowledge economy.

Knowledge ecology

The knowledge ecology is defined as involving all kind of institutions and organisations dedicated to the production, dissemination and utilisation of new and "superior" knowledge. The knowledge ecology encompasses not only the activities of R&D institutions but also the more applied research activities of public and private firms, as well as programmes for educating and training the technical workforce. The knowledge ecology determines the conditions of existence of knowledge. However, it is not itself a system of innovation. The role of the knowledge ecology is to form the research capabilities and the knowledge base for innovation. It provides the basis on which particular innovation systems focused on particular problems can either self-organise or, failing this, be encouraged to form through specific policy interventions.

Systems of innovation

A system of innovation cannot be taken for granted. The defining characteristic of a system of innovation is that its components are connected. When they are not, there is an ecology but not a system. Therefore, systems of innovation emerge as the elements of the ecology interact to further the innovation process.[6]

The notion of a single, monolithic and highly durable innovation system is a deceptive intellectual construct. It is far better to recognise the many ways in which research organisations, entrepreneurs, firms, users and economic institutions interact to further the innovation process. In a healthy industry and service economy, there are countless numbers of specialised innovation systems generated at the micro level, systems that are born and decay as new innovation problems are raised and solved.

Discovering the relevant areas for advancing science and technology

Finally, countries need to develop a vision of where they want to be positioned in the knowledge economy and implement a strategy. Some years ago, Enos (1998) described the shift in many LDCs in the locus of decision making concerning the future direction of their economies from local authorities to foreign assistance bodies. As a consequence, the science and technology areas to be pursued are chosen primarily for the effects on developed countries. It is instead crucial for LDCs to decide for themselves which science and technology areas they should seek to develop. They need to engage in a search process, involving entrepreneurial trial and error as well as public policy to create incentives for entrepreneurs who take the risk of engaging in new activities. It may be that the most important innovations in LDCs evolve from the process of discovering what the country should do in terms of specialisation in industry and services (Hausman and Rodrik, 2002).

Knowledge policy

The aim of knowledge policy should be to improve the chances of forming innovation systems from the knowledge ecology. The problem is largely one of barriers and incentives to collaborate in solving problems in the area of innovation. Seen from this perspective knowledge policy has three dimensions:

- Responsibility for encouraging entrepreneurs and institutions to engage in a trial and error process to discover where to allocate resources to develop capacities.
- Responsibility for undertaking to ensure that the ecology of research organisations and knowledge is sufficiently rich and diverse to cover all areas of relevant knowledge by research expertise (at country or regional level).
- Responsibility for framing the institutional architecture and the structures of regulatory constraints and rewards available to present and future researchers, entrepreneurs, managers and other stakeholders so as to allow sufficient flexibility and mobility to stimulate and reinforce connections and transform the knowledge ecology into adaptive innovation systems.

While the second responsibility involves some top-down initiatives (creation of new disciplines, establishment of new institutions), the first and third deal with the creation of the conditions that can facilitate bottom-up and decentralised processes of discovery and innovative activities.

Discovering the relevant areas for science and technology capacity building

Determining the kind of knowledge base a particular region or country must build in order to define its growth strategy is a key issue but a difficult one. It must be emphasised that this should be based not on a bureaucratic logic of industrial planning but on a research process of the entrepreneurial type, one in which entrepreneurs play a central role. Decision makers should limit their interventions to three aspects of the process: helping entrepreneurs of a rather special type (see below); identifying complementary investments (human capital) and facilitating the co-ordination mechanisms which allow a regional system to switch collectively to the selected specialisations; and cutting investments which turn out to be inappropriate but were supported as a result of the search process.

The search for the right science and technology areas is an entrepreneurial process

This involves a particular learning process, which has not so far received very much attention from economists. It consists of discovering the areas of research and innovation in which a region can hope to excel. It depends primarily on the entrepreneurs who are best placed to discover these specialisations. This involves a process of discovery since the production functions of the different types of innovation and invention are not common knowledge.

According to Hausman and Rodrik (2002), a key role for entrepreneurs in LDCs is to learn what the country is good at producing. For an LDC, there is great social value in discovering this since this knowledge can orient the investments of other entrepreneurs.

This activity poses a problem for public policy. The discovery of pertinent areas of specialisation has high social value since this knowledge will define the direction of company investments and the projects of research organisations. But the entrepreneur who makes this discovery will only be able to capture a very limited part of his/her investment's social value since, by definition, other entrepreneurs will swiftly move into the area. There is consequently a risk that too few entrepreneurs will "invest" in the discovery process.

Insofar as the process of finding appropriate areas for a given region implies investment, and as the return on this investment cannot be completely appropriated by those who discover them, this raises an incentive problem, which apparently cannot be resolved by resorting to intellectual property. The basic discovery concerns a field of research or type of innovation in which the region could take the lead. This type of discovery is not normally subject to legal protection, whatever its social return. Public policies thus have an essential role to play in encouraging entrepreneurs who invest in this particular discovery process but will not be able to use the usual legal protection mechanisms to capture a large proportion of the social return on their investments.

Opportunities for everyone?

One key aspect of the scenario developed above is that it offers strategies for everybody. Certain advanced regions are well placed to try their luck in the area of general purpose technology production. Many others are in a good position to develop applications of these GPTs for economic activities which are important for the region in question: biotechnology applied to the exploitation of maritime resources; nanotechnology applied to wine quality control, fishing, cheese and olive oil industries.

Major innovations are the result of the invention of a GPT and of the ensuing successive technological generations but myriads of equally economically important innovations result from the "co-invention" of applications. A GPT is in fact distinguished by its horizontal propagation throughout the economy and the complementarity between the invention and the development of applications. These complementarities are fundamental. In the terms of the economist, the invention of the general technology extends the frontier of invention possibilities for the whole economy, while development of applications changes the production function of a particular sector. Application co-invention increases the size of the general technology market and improves the economic return on inventive activities relating to it. There are therefore dynamic feedback loops: inventions give rise to the co-invention of applications, which in turn increase the return on subsequent inventions. When the process evolves favourably, a long-term dynamic develops, consisting of large-scale investments in research and innovation which give rise to high levels of social and private marginal rates of return. This dynamic may be spatially distributed between regions specialised in the basic inventions and regions investing in specific areas of application.

Most of the recent productivity gains from information technologies thus result from applications in certain sectors but previously resulted from generic inventions. This goes to show that there are indeed strategies for everyone: some key regions will play a role in the production of these technologies, a role that will be all the more prominent as these regions will benefit from more powerful agglomeration effects. A great many other regions must develop their knowledge bases at the intersection of a GPT and one or several sectors of application.

These regions must however forge strong links with one of the regions that supply the generic knowledge, so that the application co-invention processes are permanently revitalised by the dynamic of the generic invention. These connections are in theory facilitated by the existence of externalities between the two regions, but additional incentives are also necessary.

"Beware of investing in things that can move"

The search for the right areas – if successful – is likely to help countries to manage the brain drain issue somewhat better. The knowledge resources produced by the region, thanks in particular to its higher education, professional training and research programmes, constitute "co-specialised assets" – in other words the regions and their assets have a mutual need of each other – which reduces the risk of seeing these resources go elsewhere. It is worth recalling the old maxim of the economics of development: "Beware of investing in things that can move!" They will more logically circulate among the small number of regions that seek to advance science and technology in the same areas.

The particularisation of regional and/or national knowledge bases will prevent the global market for the highly skilled from becoming a mechanism for "draining" certain territories and will instead encourage the emergence of a geographically distributed system of research capacities.

Improving the knowledge ecology

The fundamental policy question here is whether the knowledge ecology is sufficiently rich and diverse to cover all relevant areas of knowledge (given the areas of specialisation) and to ensure that the processes that are critical for advancing knowledge (codification and cumulativeness) can develop.

The four functions of the knowledge ecology

The knowledge ecology encompasses the set of institutions that enable access, production, transmission/use and measurement of knowledge for learning and innovation. This section briefly presents the main issues for each of the functionalities of a knowledge ecology in a developing economy.

Access to new knowledge, once it has been produced, has a particular meaning in a developing economy context. New knowledge that is essential in both the developed and developing worlds is produced for rich markets but is not accessible to LDCs as very few people (firms) can afford to pay the price for patented knowledge. Typically this is the case of the GPT-related knowledge that forms the building blocks for further development of applications. The crux of the issue is that this knowledge must be sold in the developed world at a price that provides a return to R&D, while being made available at or near marginal cost in poor countries. The first issue is, therefore, the question of efficient distribution (optimal use) of existing knowledge, given its economic nature as a semi-public good. Since the marginal cost of its reproduction is negligible, prices should be negligible. However the production of knowledge often entails very high fixed costs which need to be recovered; otherwise nobody would commit the necessary resources and effort. The obvious solution here is "Ramsey prices" – a price discrimination scheme that maximises allocative efficiency in situations where some properties of the good considered (here the knowledge) make "price equal to marginal costs" unprofitable (Doyle, 1997). Other mechanisms are also possible. This issue of access is affected by the central role of IPRs in the current economics of technology transfer. Because patents allow inventors "above marginal cost pricing" and the system of intellectual property protection imposes its rules everywhere, new mechanisms and institutions are needed to maintain access to essential knowledge both for passive consumption and for learning and innovation.

The production of the knowledge and technologies which are needed in developing countries but have no market in the developed world raises a second issue. In this case, differentiated pricing will not work, because there is no rich country market in which to recover the cost of R&D. Pricing in developing countries at levels that would recoup such costs is not feasible because incomes are too low to generate adequate demand. In such cases, incentive mechanisms other than intellectual property may be needed. These include mechanisms and instruments to encourage governments and firms to develop research capacities and to create conditions for low-cost research activities within the country. While IPRs are a not a central issue here, the creation and development of a legal framework to create an "information commons" and to promote open source projects (an

IP-free zone in which knowledge and information are freely available and easily accessible) are of critical importance.

Transmission and use of knowledge is the third function. At this point, it is perhaps necessary to recall that "knowledge" as such – and the institutional framework devised to "optimise production and access" are almost useless in the absence of some other critical resources. As Machlup (1983) wrote: "the use of knowledge always complements the use of other resources, such as labor, material or, at least, user's capabilities and time. One cannot use knowledge without something else, and the complementary input may be scarce and valuable.... We have the knowledge to carry out irrigation projects in developing countries, but each of these programs would require additional scarce resources." In other words, the proposition "knowledge is available at zero marginal cost" does not imply anything about the cost of using the knowledge. Very often knowledge is usable together with resources available only at positive, and often very high, cost. For example, to be used effectively, knowledge needs educated people. Efficient processes and mechanisms for accessing knowledge cannot do the job alone. Resources such as human capital, physical infrastructure, the rule of law and service delivery infrastructures are also essential.

For instance, the building blocks of ICT technologies that are made available through various access mechanisms can lead to the co-invention of new applications in ways that increase productivity in traditional sectors. However this will only happen if infrastructures and enabling conditions for entrepreneurial activities (including human capital) are available in the developing economy. Knowledge that already exists in the country itself – traditional knowledge and know-how, natural substances – requires legal infrastructure and domestic entrepreneurial capabilities to be transformed into an economic asset that will contribute to growth and development.

Measurement is the final key ingredient of the knowledge ecology. Without measurement activities, the production of indicators and the regular collection of systematic data, the knowledge ecology is hardly visible and policy makers are unable to track progress, assess structural transformations and compare performance. They will therefore abandon the field. Data and science and technology indicators are necessary to make the knowledge ecology more visible to policy makers who can then design innovative policy responses for science and technology issues (Gault, 2008).

In sum, the four main functional objectives to be achieved for the knowledge ecology in a developing country context are:

- optimising access to existing knowledge and technologies;
- allocating global and local resources to research capacity building;
- developing human capital – in the form of sophisticated users, entrepreneurs and highly skilled workers – for effective use of the new opportunities offered;
- measuring inputs, outputs and outcomes.

Forming research capabilities and the knowledge base for innovation

The development of research capacities "at home" is of course a central issue for the development of the knowledge ecology. It raises both quantitative and qualitative challenges.

The building and expansion of a strong public research sector is an issue that must be addressed in ways appropriate to the stage of development. The arguments regarding the models of innovation to be supported in an LDC context can be used to stress the crucial role of public research organisations in the development of GPT applications: making generic knowledge locally applicable and "re-inventing" locally, to borrow from Stiglitz (2000), are crucial tasks. It is the local selection, assimilation and adaptation of knowledge that is central. Neither multinational corporations' affiliates nor local firms have the incentives and/or capabilities to do this.

In LDCs, the initial step is to build a research infrastructure through the creation and development of government laboratories in order to maintain some brains at home and support the specialisation of the entrepreneurial economy. The issue is different for catching-up countries, where the relative weight of government laboratories and research universities as R&D performers has to start shifting.[7] Table 5.1 shows, for example, the increasing percentage of scientific publications from universities as compared to other research institutions in South Africa.

Table 5.1. Distribution of scientific publications across institutions in South Africa, 1987-2003

Percentages

	1987	1991	1995	1999	2003
Universities	63.1	67.6	70.8	72.9	74.9
Institutes	12.1	12.4	11.0	9.9	9.3
Government	5.7	5.9	4.7	5.2	4.2
Hospitals	15.5	11.4	10.0	8.0	7.1
Business sector	2.4	2.0	2.4	3.2	3.1
	100.0	100.0	100.0	100.0	100.0

Source: Losego, P. and G. Goastellec (2008), "Nouvelle Afrique du Sud, nouvelle politique des sciences, nouvelles politique universitaire", *Les Cahiers de l'Observatoire*, No. 18, Université de Lausanne, based on SCI data.

Another fundamental issue for the improvement of the knowledge ecology in developing countries is the strong policy focus needed on allocating resources to the engineering sciences. Clearly, the willingness of firms to devote money to scientific research is very much influenced by the prospect of converting research findings into finished and marketable products. What matters for firms is that, whatever the specific research findings, an enlarged engineering capability will substantially increase the likelihood of being able to use them to bring improved or new products to the marketplace. Engineering sciences are also critical for ensuring that universities are responsive to the technological and scientific needs of industry.

Engineering sciences are a part of the knowledge ecology that will play a central role in animating innovation systems because their impact runs two ways. First, they create an impetus for engineers to systematically transform basic knowledge to improve products and processes. Second, the establishment of a new engineering discipline lays the basis for making scientific research profitable. Engineering disciplines involve not only fields related to the hard sciences (mechanical, electrical, computer, etc.) but also the social sciences – the so-called "service engineering" which deals with organisation and management practices.

As Henry Ergas[8] has shown, what really matters in innovation performance at country level is not the best shot but the weakest link. This is particularly true when the weakest link is engineering science.

The development of capabilities and absorptive capacity in the business sector is another key issue for the knowledge ecology. Capabilities are a matter of some consequence to the less (and least) technologically advanced firms (Enos, 1996). The most technologically advanced firms can profitably absorb new technological knowledge and subsequent improvements and undertake development to adapt the technology to specific conditions. They employ the skilled persons needed to appreciate and assimilate advanced technologies, and can draw upon their previous experience in carrying out successive tasks. Less advanced firms lack these prerequisites for technological progress: even if they draw upon outside suppliers for planning, design, engineering, construction and initial operation, they are likely to find themselves unable to operate the plant so as to exploit its full potential, let alone to make the mundane day-to-day improvements that markedly increase its performance. It may take all the technical and managerial resources of the less advanced firms to master the transferred technology and implement the necessary adaptations and developments. Mastering improvements as they come along may prove too great a challenge. Building the capabilities to enhance innovative capacities is therefore crucial. It points towards economic models of development that emphasise the accumulation of skills and learning capacities, rather than fixed assets or capital, for facilitating innovation and technical change. This, in turn, calls for an explicit and proactive human capital policy.

Human capital for innovation is a focal point in any knowledge ecology policy. Widely available skills are of course necessary for any innovation-based growth strategy to succeed. Basic skills are necessary for innovative ideas to arise in the first place, would-be innovators need advanced skills to search for and absorb the necessary information, and inventors typically need even more sophisticated skills to be able to tackle the technological and business-related problems that arise along the way. Skills in this context thus mean a wide spectrum of capabilities to be acquired both through formal education and learning by doing (Trajtenberg, 2009). Two key competences – literacy and learning to learn – may be considered essential in any country which is challenged by the task of advancing science and technology in certain key areas.

Literacy is not only a precondition for using knowledge as consumption capital. It is also important for learning about advances in knowledge and innovation. This point was made initially by the 1964 Nobel prize-winning economist T. Schultz, who explored an apparent puzzle in developing economies. In some agricultural societies, persons who could read and calculate produced more crops per acre than persons who were illiterate. In other societies, literacy made little difference in how much persons grew per acre. Schulz solved the puzzle by explaining the importance of the pace of change. Where farming techniques had not changed for generations, techniques were passed down orally from generation to generation. In these traditional societies the economic payoff to literacy and math skills was extremely modest. In other societies, "the green revolution" in seeds and fertilisers was rapidly changing farming techniques. Here, reading was important to understand the directions that accompanied the new inputs, directions that were often very different from those for applying traditional inputs. The ability to measure accurately was important as well, since the payoff to the new techniques often depended on the spacing of seeds and the amounts of fertilisers applied at specified time.

Learning particular routines or skills is not the same thing as "learning to learn". As Enos (1996) observed, mastering a given state of the art is not enough; what is critical is to master a progressive state of the art. In the knowledge economy, the process is never-ending: no sooner have workers mastered one state of the art than they must begin to master its successor. Improvements may occur so rapidly that once workers have absorbed the current changes, the next set is already upon them. In a context of such rapid change, learning to learn or meta-learning provides workers with the capacity to transfer the skills acquired in formal education to a wider class of learning situations.

In this respect, policy requires a two-pronged strategy, consisting of the supply of the traditional public good type of education and skill formation, on the one hand, and ensuring the responsiveness of vocational and advanced skills supply, on the other. In particular, vocational schools, training programmes, colleges and universities should be made highly responsive to shifts in the demand for skills; policy has to ensure that "endogeneity kicks in" (Trajtenberg, 2009).

Building systems of innovation from the elements of the knowledge ecology: Barriers and incentives

To form a system of innovation the relevant organisations and individuals have to interact in ways that help to solve innovation problems. Systems depend on connections (interactions) and cannot be described or understood simply in terms of their components. So, the policy issue concerns the areas of the knowledge ecology in which connections have to be stimulated to transform the ecology into an adaptive innovation system and how to frame the institutional architecture and the structure of rewards so that interactions and the formation of multiple systems of innovation will occur. For reasons of space, the discussion is limited to two connection processes of particular relevance for innovative activities in an LDC.

Technology transfer and diffusion between the North and the South: Who should be connected?

A specific characteristic of developing countries is that the connections cannot be limited to the national knowledge ecology, as it is incomplete. The connections must therefore link elements of the national knowledge ecology to foreign sources of knowledge and technology. This is likely to happen through technology transfers between firms based in developed countries and local entrepreneurs operating in the developing world.[9]

As noted earlier, countries that are still trapped in a low-level equilibrium, with little exposure to foreign technologies and poor absorptive capacities, should not rely only on FDI and trade to ensure proper exposure to foreign technologies. TTs are needed as a principal objective (not just as a joint product or a by-product of FDI). In this case, the incentives are shaped by the cost and benefits of the TT only. In other words, incentives cannot be combined with other intervention is support of, for example, FDI. When the TT is a principal objective there is no other economic operation to "help", and the prospect of returns solely on the TT operation must be sufficiently attractive to encourage the technology holder to enter the transaction. This means that host governments will often have to provide additional incentives.

Should governments encourage any "model of firm" in both countries to enter this kind of transaction, given the constraints in low-income countries (disarticulated system, weak capabilities, low affordability among potential buyers)? If the answer is in the affirmative, government policy should identify those firms and enrol them in TT projects.

Demand for technologies

On the demand side, the importance of innovations that target local needs and potentially generate spillovers that can be captured by the local economy has been emphasised. TTs in these areas should be encouraged so as to help entrepreneurial efforts meet local needs on local markets. The social gains of serving the local market in regard to consumer surplus may be very large, for example in the area of medical care. Moreover, local spillovers may in some cases be more significant and more widespread when innovating for the local market, if only because of the demonstration effects.

Supply of technologies

On the supply side, Arora *et al*. (2001) develop interesting case studies of specialised technology suppliers in the chemical industry. They look at how the development of specialised upstream technology suppliers in developed countries improves technology access and lowers investment costs for downstream firms in developing countries. Testing this idea, they show that there are more investments in chemical plants in less developed countries when a large number of technology suppliers operate in developed countries. According to the authors, what matters is the vertical organisation of the industry in the developed world: investment takes place earlier and more rapidly than if developing countries had to rely solely on chemical producers in the developed world to transfer the technology. The mechanism is quite simple: specialised suppliers develop technological capabilities which are then sold to downstream firms. Because the expertise and the technologies developed are process- and not location-specific, they can be made available to downstream firms in other countries. Moreover competition between suppliers implies that the expertise and the technology will be made available at prices close to the marginal cost of transfer. The economic logic of this story is therefore that the industries or countries that emerge earlier pay the fixed cost of developing the technology, while later industries or countries pay only the marginal cost.

As a consequence of a certain stage of vertical disintegration of the industry, the presence of independent suppliers that do not produce the downstream product is important: downstream producers (chemical firms) are less likely to sell technology to potential competitors (located in less developed economies). Thus, specialisation and division of labour can benefit industrial growth, because of the ability of independent suppliers to operate TTs while not undermining their competitive position.

The need for specialised agents to facilitate public-private partnerships

The complexity and difficulty of the TT operations supported and encouraged by governments of rich countries make it necessary to use "specialised agents" with experience in TT operations.[10] Such agents specialise in linking public donors, private firms and local entrepreneurial activities to ensure the effectiveness and efficiency of the operation.

The specialised agent compensates for critical deficits of institutional mechanisms both in less developed and developed countries in order to address problems arising from the management of a TT as a principal objective.

Public research organisations and industry

Strong connections between the public research sector and local industry are of critical importance. In an LDC, there are no large companies acting as "anchor tenant", that is to say, with high absorptive capacity and incentives to be connected, or networks of highly sophisticated small and medium-sized enterprises with a similarly high level of capacities and incentives to collaborate with public research organisations. Public research organisations have to cope with a system of small farmers or small entrepreneurs with very little absorptive capacity. Tacit knowledge is hard to transfer but so are the codified forms which disseminate more easily in an advanced country through archival publications and other impersonal broadcast media. In an LDC, the codified and tacit knowledge and information generated by public researchers has to be transported and delivered to the sites of innovation. There is no "self-service arrangement"; rather, what is needed is a "*service à la table et à la carte*".

Building networks is, therefore, the key objective. However, in much policy discourse, invocation of the power of networks is essentially a mantra. Yet the now-fashionable "network" metaphor does not represent the same thing as a well worked out economic model from which one can legitimately move, by way of institutionally grounded empirical inquiries, towards a fundamental reorientation of policies to encourage the local adaptation and distribution of knowledge to potential "clients".

In the case of agricultural innovation, the transferability of knowledge from public research organisations needs to be supported by the development of extensive networks of publicly funded research stations with advisers who reach out to small farmers (Collier, 2008). Organisational models such as technology consultancy centres or technology platforms are important for building effective interfaces between R&D activities in public research organisations/universities and local demand for technologies and knowledge. These interfaces are particularly useful when they involve available expertise from universities and other public research organisations for consultancy work; the transfer of technologies for industrial development through the establishment and co-ordination of campus-based production units; and the use of such centres as a clearinghouse for technical information and services to and from the public research organisations (Enos, 1998).

Conclusion

Novel ways of conceptualising innovation processes and systems are only interesting if they lead to new insights. The framework presented – involving a key distinction between the knowledge ecology and systems of innovation – defines three categories of policy responsibilities:

- One involves supporting the process of entrepreneurial search and discovery of relevant areas for advancing science and technology.
- Another involves developing the knowledge ecology to ensure that the ecology of research organisations and knowledge is sufficiently rich and diverse and that research expertise is available in all areas of relevant knowledge. Improving the quality of the knowledge ecology primarily involves the formation of research capabilities and the knowledge base for innovation.

- A third involves the responsibility for improving the chances of forming innovation systems from the ecology, which entails dealing with barriers and incentives to collaboration in solving innovation problems.

The organisation of the ecology, the areas of science and technology specialisation, and the incentives and barriers for co-operation among different elements in the pursuance of innovation are central issues in the design of an empirically and analytically informed innovation policy in less developed economies.

Notes

1. Here a knowledge ecology consists of the institutions and organisations dedicated to the production, dissemination and utilisation of knowledge. It is distinguished from an innovation system in that there are weak or no linkages among institutions and organisations and with other actors in the system.
2. When TT is referred to as a joint product or by-product, it relies on the accounting definition of these concepts. Joint products are two products that result simultaneously from one shared cost, and they have comparably high (sales) value. By-products are produced along with a main product. The latter constitutes the major portion of the total (sales) value. By-products have a considerably lower (sales) value than the main products. These concepts are applied to TTs, substituting "perceived value to technology holders" for "sales value".
3. A least developed country (LDC) is a low-income country which faces severe structural handicaps to growth. The United Nations list of LDCs may be found at: *www.un.org/esa/policy/devplan/profile/ldc_list.pdf*.
4. See Enos *et al*. (1997) for a development along the same lines applied to the special case of Africa.
5. The discussion in this section draws heavily on scholarly exchanges and many discussions with M. Trajtenberg, whose views on these issues for LDCs can be found in Trajtenberg (2009).
6. S. Metcalfe made this point very forcefully during the January 2009 workshop.
7. The centrality of government laboratories is appropriate at a certain stage of economic development when the main challenge is to build a science and technology infrastructure and the fastest way to do it is to create these "mission-oriented" institutions. However, when those countries are catching up, the need for more resources in research universities is obvious: research universities become central for generating externalities in the form of human capital and basic research which have the status of "joint products" (and give rise to economies of scope and internal spillovers) while government laboratories break the intimate relations between research and higher education and only provide a small fraction of the total amount of positive externalities that research universities are able to provide.

8. Henry Ergas is an influential economist who has worked at the OECD.
9. See Chapter 6 in this volume for an overview of the economic opportunities offered by North-South technology transfers and an analysis of the conditions required to ensure effective and efficient modes of knowledge sharing.
10. TT is a decreasing cost activity (Mansfield, 1982; Teece, 1997): the more extensive the experience previously acquired by the organisations involved in the process, the lower the transfer costs in relation to total project size.

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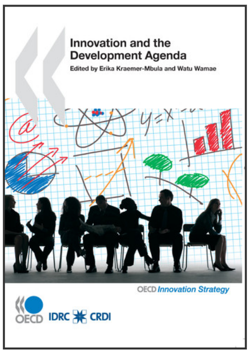

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