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V. An enabling environment for transformative change in society towards sustainable development through Science, Technology, Innovation (STI) and Culture.

Introduction

Technology and innovation account for a significant proportion of economic growth through increases in the workforce skill and knowledge levels, R&D investments and infrastructure, the introduction of capital equipment embodying new and more advanced expertise and changes in the types and varieties of goods. Science, technology and innovation (STI) also explain economic growth through the knowledge spill-overs they generate between countries, firms, and industries. Even in least developed countries innovation plays a role in economic development by helping to adapt foreign technologies to local conditions. Indeed, rises in living standards since the Industrial Revolution have been, by and large, the result of new and improved products, processes and services.

The rise in living standards has been dramatic, yet the growing prosperity has not been shared with all and heavy penalties have been imposed on the physical environment. Large income disparities within and across countries remain, economic and employment opportunities are still unequal for men and women and poverty still afflicts around 1.4bn people globally. At current rates of natural resource use the world may soon face major food, water, energy and other raw material scarcities and only energy related CO_2 emissions will double by 2050, with unpredictable effects over the climate and livelihood of the world population.

STI will have a critical role in tackling the economic, social and ecological challenges currently faced. While tasked with continuing to deliver the new products and processes that spur economic growth and improved living standards, emerging technologies and innovations will have to reduce drastically inputs and raw material use, to increase radically process and energy efficiency and to cut massively on waste. At the same time, STI will have to provide options that help reduce poverty while offering equal opportunities and fair recognition for all. Addressing all these sustainability challenges concurrently is no small feat and can only be achieved if the adequate environment and incentives are put in place.

Knowledge for innovation

Of all economic and social process knowledge generation is, arguably, the most complex and least understood. It is so because it is a cumulative multi-level process involving people, organizations, industries, countries and the world as a whole. Knowledge and learning are often the result of disorganized efforts and interactions and the resulting synergies of the cognitive abilities of the actors involved.

Individuals learn by making mental representations of their reality which they construct interactively with their history, physical and social context and the capacity of these representations to give meaning to their continually changing experiences. Firms contribute to knowledge generation by providing a platform for individuals to share and collectivize what they have learned and by converting individual 'tacit know-how' (what is learned through practice and experience) into codified and transmittable forms of knowledge, both under strict parameters of firm performance. Other firms and organizations contribute to learning by offering the possibility of comparing and benchmarking internal advances; by complementing internal knowledge with specialized knowledge, for example, scientific knowledge normally comes from universities or very large firms, or by opening a window to the unknown; and, by providing diversity, ie. the possibility of experimenting from a variety of options. Nation states and the international community provide the rules and laws, behavioral practices and the formalized structures under which learning and 'innovation systems' materialize.

Generating knowledge for innovation requires that specific conditions are met. Clearly defined goals are necessary to provide direction to individual and collective efforts but they have to be accompanied with a measure of freedom and autonomy so that actors can make their own decisions and explore unexpected opportunities. The ability to evaluate and use outside knowledge is, in turn, crucial to assess emerging scientific and technological developments. This 'absorptive capacity' is partially the result of the level of prior knowledge accumulated at individual, organizational and national levels and requires significant investment. The extent of outside communication, interaction and the degree of connectivity between innovation actors is vital to insightful thinking about complex problems as it allows benefiting from specialization and diversity at the same time. It is worth noting that these three conditions need to be met concurrently.

Old and new trends in knowledge creation and innovation

The last twenty years or so have witnessed remarkable shifts in the world economy. Globalization has proceeded apace, leading to more international trade, closer economic integration, greater geographic fragmentation of production and the arrival of new major economic players such as the BRICS and other middle income countries. G7 countries accounted for two-thirds of world manufacturing value added in 1990 but now account for less than half (UNIDO, 2011). China's manufacturing industry is nearly as big as that of the United States and BRICS high-tech exports are more than 30% of total exports, higher than those of the OECD (UNIDO, 2011; OECD, 2011).

Changes in the location of production have been accompanied by changes, albeit slightly less pronounced, in the geography of STI. R&D expenditure increased between 1993 and 2009 from 1.7% to 1.9% of GDP (WIPO, 2011). Developed countries still account for the bulk of R&D expenditure (70%) and many of them are establishing world centres of excellence to improve the efficiency, quality and impact of their research (OECD, 2011; WIPO, 2011). Business R&D (BERD) account for the lion's share of R&D expenditure in developed countries and, despite the rapid increases in services R&D, manufacturing still accounts for more than three-quarters of the total BERD as it is a sector that doesn't only innovate for itself but also for many other economic activities (MGI, 2012). Yet, developing countries had seen their global share of R&D increased by 13% during the same period, mainly due heightened R&D efforts in China and Asia (WIPO, 2011). There is also evidence that in specific subjects such as ICT and life sciences, world leading universities are beginning to appear in Asia (OECD, 2011). In China, BERD intensity rose from around 0.4% of GDP in 1999 to 1.3% of GDP in 2009 and today accounts for around three-quarters of total R&D expenditure (OECD, 2011).

The widening of the geographical scope of innovative activity has also broadened the extent of STI collaborations. Facilitated by advances in ICT and telecommunications knowledge creation processes and innovation are increasingly being undertaken by groups of individuals, multiple institutions and internationally (OECD, 2011). While the production of scientific articles has been increasing over the last ten years the proportion of co-authored articles in the total has more than doubled and there is a positive correlation between research openness and scientific impact. Institutional collaborations have widened as indicated by a growing number of affiliations and geographical locations of co-authors and co-inventors in scientific publications and patent documents. Scientific collaborations are also expanding geographically. The number of co-authored articles between North America and BRIC countries, for example, has grown between 1998 and 2008 from 8% to 14% of total co-authored articles (OECD, 2011).

Developing an enabling environment

To avoid paying lip service to sustainability considerations while building on the increasing share of R&D intensity and its wider geographical scope, as well as on the increasing trend towards scientific and technological collaboration, any enabling environment aimed at STI performing a transformative role must begin by putting ecological, economic and social considerations up front. This means that the environment to be established and the incentives to support it must be clearly framed in a sustainability context.

Minimizing or eliminating ecological degradation requires production process innovations focused on either reducing resource and energy use per unit of value added or keeping resource and energy use and ecological impacts steady or declining while value added is growing. These gains need to be over and above what would have been achieved as the result of the introduction of new vintages of capital equipment if ‘true’ ecological benefits are to be achieved. Process innovations should also focus on decreasing or phasing out GHG and/or CO_2 emissions, pollutants and toxic or hazardous materials and facilitating the generation or use of renewable energy sources. Product innovation design should aim at reducing material use and fossil fuel energy consumption (or recovering the energy), reusing the artefact as many times as possible or its discarded components for other purposes, and recycling the artefact after full usage or use discarded components for the manufacture of other products. Avoiding ecological degradation will also require efforts during the diffusion stage of innovations aimed at generating awareness and educating users and consumers on the advantages of ecological conservation.

Making growth economic and socially inclusive demands innovations that provide solutions aimed at reducing living standards gaps between the richest and poorest groups in society. It requires innovative methods and new forms of organization of production and work that allow for the integration of marginalized groups as well as fosters entrepreneurial activity among them. It involves novel approaches to reducing income and wage inequalities. And, it necessitates of purpose specific designs and low cost products aimed at very low income sectors of the population, often located in poor rural areas. While a major focus should be initially to satisfy basic needs, 'bottom of the pyramid' innovation should also eventually address more advanced types of consumer demands.

Within this overall sustainability framework, an enabling environment that allows STI to perform a transformative role will need to address the conditions under which knowledge is created and innovation ensues. The first two conditions, clarity of objectives with operational freedom to provide overall direction to innovation and the availability of absorptive capacity to provide the capacity to understand available knowledge are addressed at the national level as they are under the direct reach of national authorities. The third condition, the degree of communication and connectivity to expand knowledge is addressed at the international level as, while domestic communication and connectivity are important for innovation, to be fully effective they will need to transcend national borders.

Generating an enabling STI and culture environment at the national level

Overall direction

The starting point for establishing an enabling STI environment at the national level is *the preparation of a national strategy* that articulates the government's vision of the role of STI in development; sets clear priorities for public expenditure and investment and serves as a basis for engaging all relevant actors. The STI strategy can be part of an industrial development scheme were sectors rather than technologies are prioritized, de facto providing primacy to selected sector's technologies and innovations. Technology or sector prioritization is normally best done if it is undertaken cooperatively between academia, public and private sectors and international organizations. Indeed, UNIDO's policy advisory services have been assisting developing countries in identifying promising industries through a combination of advanced international expertise, purposefully developed methodologies, capacity building and facilitation of stakeholder interactions.

STI strategies must also take into account the coordination challenges involved in bringing together different ministries and agencies, business and workers' associations, universities and research institutes and private and public enterprises. They should include *proven coordination mechanisms* such as discussion forum, coordination committees, joint policy councils, dedicated agencies, evaluation instances, among others.

A clear STI strategy and its accompanying coordination mechanisms will not succeed in creating an enabling environment if it is not underpinned by a *pervasive innovation culture*. An innovation culture involves widespread awareness among the population of the critical importance of STI for their well-being. This is often reflected in the monetary compensation and/or social recognition of those involved in innovation. It is also reflected in the respect for, and the attractiveness of, science and technology careers. An innovation culture entails a universally shared recognition and practice of risk taking entrepreneurial approaches, tolerance of failure, creative thinking, intellectual curiosity, the ability to deal with fundamental uncertainties and the capacity to question even basic beliefs. Governments can promote an innovation culture through awareness and recognition campaigns that emphasize STI; by providing great visibility to the achievements of scientists and entrepreneurs; by encouraging creative accomplishments and risk taking; through campaigns appealing to the youth to get involved in innovation related careers; and, by improving the entrepreneurial environment within universities.

Absorptive capacity

Turning to the policy areas that would enhance the absorptive capacity and hence advance the STI environment it is *education* that, arguably, ends up at the top of the list. Education is important because it is the main mechanism to improve the supply of individuals and skills for innovation. At secondary level this can be achieved through raising the standard of mathematics, science and technology students while at university level by increasing the enrollment of students in the same areas as well as in engineering and entrepreneurship.

Policies in the educational field need to focus on providing universal quality education for all as a lever for acquiring the basic skills that will be required later for innovation. Beyond basic skills efforts need to be directed in secondary schools and universities towards introducing entrepreneurial competences in the educational curriculum. The importance of achieving these types of competences is such that UNIDO has developed the Entrepreneurship Curriculum Programme (ECP) which aims at stimulating entrepreneurial talents among young people in secondary and vocational schools. At higher education level the emphasis should be on encouraging careers in natural sciences and engineering while changing the nature of education towards enhancing non-disciplinary skills such as creativity, curiosity and collaboration. Supporting high quality doctoral and post-doctoral programmes that can attract the best available talent domestically or internationally is particularly necessary for countries that want to position themselves at the frontier of innovation. Policies supporting life-long learning may help adapt the skill profile of the labour force to the changing nature of technological change.

An active *public research policy* can bolster STI. The role of public research is to provide the basic research that will not be paid for privately because of the public good nature of the outcomes of the investigations and to examine issues of national interest. Basic research is normally carried out at research universities and public research centres and is a pre-condition for applied research and engineering work. Policy imperatives in this case focus on securing a stable source of funding for public research while ensuring that the highest standards of quality and relevance are reached. Institutional funding and grants are some of the main mechanisms. Policies also centre on commercializing research results through establishing technology transfer mechanisms such as science and technology parks, technology incubators, university spin-offs, technology transfer offices, and policies on intellectual property of public research. Finally, they concentrate on expanding industry-university collaboration through collaborative R&D

programmes, technology platforms, cluster initiatives and technology diffusion schemes.

Public funding and tax support for businesses developing new products and processes contributes significantly to strengthening STI. Firms, especially small start-ups and totally new firms, face a number of barriers to obtain loans and other sources of capital for innovation. These include asymmetric information between borrowers and lenders, lack of collateral, absence of a borrower's track record, and resource limitations in terms of firms' capacity to co-finance projects or in terms of their ability to produce a convincing business plan. Governments can provide direct financial support to companies investing in innovation by subsidizing interest rates, providing guarantees to act as collateral or simply by supplying grants to be used as seed funding. Policy can also encourage and support the development of private forms of funding such as business angels or venture capitalists which are particularly suited for innovation given the long-term nature of their funding and the often business mentoring role that some of the individuals involved in these funding companies take on. Tax incentives for R&D can increase the profitability and thus the attractiveness of investing in innovation.

Another way to boost the attractiveness of innovation investment and improve the prospects for STI is through strengthening the role of the *Intellectual Property Regime (IPR)*. The innovation process involves a range of highly risky problem solving activities that as the process evolves generate information with public good characteristics. Individual firms cannot appropriate to their benefit this information and hence, do not undertake the necessary investments. Through the IPR governments can provide the incentives for firms to undertake creative and innovative activity by enabling individuals to obtain exclusive ownership of their findings for a period of time. In industry, patent and utility models protect inventions with industrial application, industrial designs protect novel designs, trade secrets protect confidential business information and trademarks protect the source of a good of one party from those of other parties.

Investment in innovation can be raised through a series of measures designed to increase the *demand for innovation*. To ensure that innovation processes deliver what they are intended for often requires support not only at early stages, like the research phase, but also towards the end so that the necessary products and processes materialize. Indeed, often it is necessary to provide a specific focus to innovative efforts, particularly where societal demands are involved, as in the field of health or climate change technologies. Governments have at their disposal a range of innovation-oriented public procurement and innovation-related regulations and standards mechanisms that can be used to satisfy specific types of demands. Governments can also establish the organizational support to comply with domestic and international standards. UNIDO, for example, delivers assistance to member states through its programmes to support countries' quality and conformity infrastructure. These programmes help to establish or improve the ability of national organizations to set industrial standards, to offer industrial metrology and product testing services, to carry out certification and product traceability schemes and to accredit relevant bodies.

Generating an enabling STI and culture environment at the international level

Intense communication, interaction and connectivity between STI actors allows them to acquire the specialized knowledge unavailable to them while at the same time relate to different perspectives to address problems at hand. Communicating challenges faced during innovation helps to organize the information and clarify issues and thus helps understanding the initial problems better. Feedback then improves understanding even further and coordinated action within knowledge networks may follow, leading to synergistic gains. Interaction with a broad range of STI actors allows focusing the domain of intervention more precisely as what others can contribute to addressing existing problems can be clearly separated. When the communication is international and widespread, access to the frontier of knowledge may be achieved.

One of the most important communication and interaction mechanisms is the *mobility of personnel*. While personnel mobility may imply a loss of training investments for some companies it stimulates knowledge transfer and the application of knowledge to new problems. International mobility, especially within and across international companies in different locations and by higher education students as well as doctorate holders and post graduate researchers contributes to the adoption of best practices, greater openness, more creativity and to the advancement of research and science.

Governments and the international community can facilitate mobility by reducing regulatory barriers in institutions and labor markets, encouraging the mobility between universities and the business sector and by facilitating the transition from the last years in advanced higher education to employment. Policies can also focus on bridging the demand for technical skills, especially by small and medium enterprises and the supply by technical and vocational schools. UNIDO and Scania, a leading manufacturer of heavy trucks, buses and engines, for example, are collaborating to train local heavy equipment mechanics in the Iraqi industry. Governments may also want to initiate programs to attract highly trained students and researchers as well as 'diaspora' nationals in science and technology fields.

A major source of improvements in the local STI environment has been the interactions arising from *international technology transfer*. International technology transfer refers to cross-border movement of knowledge either embodied in goods, services, people and organizational arrangements or codified in blueprints, designs technical documents and the contents of training programmes. International technology transfer can lead to learning and innovation through design and engineering knowledge to use and operate, to replicate and change, and to create, technology.

Benefitting from the design and engineering knowledge available, however, is not straight forward and is a learning process in itself involving continuous exchanges between suppliers and receivers of technology as well as other stakeholders. As in any knowledge generation situation, mastering a technology requires significant effort and time. Often technologies need to be adapted to local conditions and require the transfer of 'tacit knowledge' components unavailable in documents and manuals.

National and international collective action eases the acquisition of foreign technologies through a range of policies, regulations and international treaties. Governments may consider mechanisms to target and/or regulate the level, type, quality and timing of foreign technology acquisitions. Attracting Foreign Direct Investors (FDI) as a way to bring advanced technologies and diffuse them in the domestic economy is a very popular approach to technology transfer. International organizations have a major role in assisting national governments to attract foreign technology. UNIDO, for example, supports its member states with a network of Investment and Technology Promotion Offices (ITPOs) located in key countries. ITPOs specialize in brokering investment and technology agreements between developed and developing countries' firms. ITPOs offer up-to-date information on screened and validated investment and technological opportunities, including manufacturing facilities and technology supply sources.

Ensuring that the technologies are properly diffused, adapted to local conditions and generate spill-overs into the rest of the economy requires an additional set of policies and initiatives. These normally include measures aimed at facilitating and providing information about equipment purchase or licensing abroad; offering training and capacity building in relationship to the acquisition of foreign technologies; and, supporting technology transfer related R&D. UNIDO in collaboration with UNEP, for example, has established 47 National Clean Production Centres (NCPCs) in developing countries aimed improving resource productivity and environmental performance of businesses and other organizations in developing countries. These centres perform the following functions:

- Raise awareness of the benefits and advantages of Resource Efficient & Cleaner Production (RECP);
- Demonstrate the technical, environmental, financial and social benefits of RECP through in-plant assessments and demonstration projects;
- Help obtain financing for Resource Efficient & Cleaner Production investments;
- Provide policy advice to national and local governments;
- Disseminate technical information.

In developing countries policies may also focus on collaborating and interacting with other developing countries. Sharing experiences with other developing countries or south-south cooperation complements north-south cooperation efforts. South-south exchanges take place between countries and companies facing similar economic and social conditions and that are following comparable pathways in building their STI capabilities. This means that sharing takes place between countries that are still confronting or have confronted not so long ago the same issues currently being faced by other developing countries, reducing the ‘cognitive distance’ and saving on learning time and efforts. Policies to enhance south-south learning includes increasing imports of capital goods and FDI, expanding technological collaborations between firms, intensifying scientific and technical assistance programmes and encouraging the mobility of skill personnel and researchers across borders.

International organizations can support governments engaging in south-south knowledge exchanges, through assisting in international technology transfer. UNIDO has established several international technology centres in areas such as manufacturing, materials and environmental technologies; small hydro and solar power, and hydrogen energy technologies. The centres allow access to applied research and development and training in these new technologies for participants from developing countries. Each centre has networks consisting of industrial R&D institutes, universities, industrial associations and professional societies working in the same subject area and having their own sub-networks of partners with strong links to industry.

International knowledge networks can also help governments create a conducive STI environment. International knowledge networks of practice or sometimes referred as communities of practice are a prime mechanism for exchanging information and knowledge. Their main advantages are that members interact with the aim of performing their work activities and that communities of practice are non-hierarchical and are often large, voluntary and multidisciplinary. They contribute to generating a shared context of issues, solving specific technical problems and can be the beginning of a more formal technological collaboration. Knowledge networks operate formally and informally, bring together individuals or organizations and emerge at bilateral, regional or multilateral levels.

Governments can encourage active participation in international communities of practice. Policies include sponsoring their establishment, encouraging participation, contributing to the membership and running costs, supporting the required infrastructure and coordination activities, convening certain topics and helping to their formalization should the need arise. Developing successful international communities of practice, nonetheless, normally requires working tapping into international resources which is neither costless nor timeless.

Over the years UNIDO has built several networks that support international knowledge exchange and put them at the service of its member states. UNIDO and UNEP's NCPCs has led to the establishment of the global RECP*net* as well as several regional networks in the Africa, Arab, Asia-Pacific, Europe and Latin American regions. The different RECP*net*s are already contributing to the effective promotion and implementation of RECP and fostering North-South and South-South collaboration and transfer of methods, policies and technologies. Web-based knowledge management systems are supporting the network and pilot demonstration projects of cleaner production techniques and environmentally sound technologies have taken place and are being discussed in some regions.

Other similar initiatives by UNIDO include the Subcontracting and Partnership Exchanges (SPXs) with the objective of helping local enterprises to exchange information and knowledge of the emerging technological and business opportunities that evolve from industrial subcontracting, outsourcing and supply chain opportunities. A more recent effort is the 'Networks for Prosperity' initiative, which focuses on creating knowledge exchanges in the field of management systems for the development of the private sector in developing countries.

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