 Innovation: Management, policy & practice (2010) **12**: 250–268.

Rethinking science, technology and innovation (STI) institutions in developing countries

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ABSTRACT

Developing countries need appropriate science, technology and innovation (STI) policies in order to absorb, diffuse and master advanced knowledge that fosters growth. They also need them in order to nurture new dynamic sectors. In many developing countries, public expenditures on R&D are invested in university research and public laboratories. Industrial R&D is most often lagging behind, in spite of several government incentives. Business expenditures on R&D (BERD), as a consequence, are small in absolute terms and as a percentage of GDP. The paper suggests that several factors explain this situation, including badly designed incentives, reduced government commitment to these incentives, lack of appropriate vertical STI policies, and high levels of causal ambiguity around specific policy incentives. This paper argues that increased government commitment, policy evaluation and the implementation of vertical STI policies aimed at creating new sectors can solve the technological stalemate.

Keywords: Science, technology and innovation institutions; development planning and policy; technological change; research and development; business expenditures; vertical STI policies

Economic development is primarily dependent on the adoption and creation of technological innovation. The nuts and bolts of innovation systems are institutions, and more specifically those institutions that are related to the production, diffusion and transfer of science, technology and innovation. The proper functioning of these institutions is thus essential for economic development. However, the right science, technology and innovation (STI) institutions are not always in place, particularly in developing countries (LDCs). This paper examines STI institutions in less developed countries from the perspective of evolutionary economics, and compares them with those in industrial countries. The central hypothesis is that in LDCs these institutions are either absent or highly inefficient, particularly policy incentives for private R&D. The first section of this paper recalls some basic notions of evolutionary economics, and introduces the evolutionary approach to public policy. The second section presents some STI institutions in industrial nations. The third introduces the corresponding institutions in developing countries, and argues that they are fairly inefficient and poorly funded. The public policy implication is that in order to accelerate growth, developing countries need to carefully evaluate, revamp and nurture their STI institutions.

1. Evolutionary economics, complex adaptive systems, institutions and learning

Economic development and catching up are less about increasing productivity in existing sectors than about adding new sectors to the economy (Saviotti & Pyka, 2004). Developing countries will not catch up with rich ones by just producing more minerals or agricultural products, or by producing them more efficiently; they will need to add other industries to the economy. More precisely, LDC need to incorporate new and more dynamic sectors, particularly those based on advanced technologies, to compensate for declining non renewable natural resources, as well as for wild fluctuations on the prices of resources. Also, these resources set a clear limit to the possible growth of LDC. Today, the only countries that are converging with developed ones are those of South and South East Asia and they are doing so not by exploiting static comparative advantages provided by resources, but by continuously adding new sectors, from software and automobiles in India to ICT and cars in Korea, to anything in China.

However, market forces alone will not produce medium and high technology sectors in LDC. Fairly sophisticated institutions are required to attract high-quality investments, absorb foreign technology and create human capital and new technology.

Institutions and systems of innovation

Evolutionary economics and management, in all its different schools and currents, has argued that institutions are those regular patterns of behaviour that constitute the canvass of society (Hodgson, 1999; Nelson, 2005). Institutions fulfil important roles. They gather and process information then make it accessible to economic agents. They provide rules and norms. At the same time, they constrain and enable action because they allow the anticipation of the behaviour of other agents.

National systems of innovation (NSI) are sets of institutions that contribute to the creation, adoption, diffusion and transfer of new products and processes. The core of these institutions is research universities, public laboratories, innovative enterprises, venture capital firms and those organisations, public or private, that support, finance and regulate the production of science and technology (Freeman, 1987; Lundvall, 1992; Nelson, 1993). National STI policies are a central component of the NSI.

Yet most NSI are collections of sectoral systems of innovation (SSI) (Malerba, 2004). These SSI are the industries, as well as their supporting institutions, in which each country innovates. Each advanced and emergent country is composed of a small number of innovative sectors. In Finland, telecommunications equipment represents over 50% of the country's R&D. In Singapore, information and communication technologies (ICT) and the bio-pharmaceutical industry represent over 90% of the country's industrial R&D effort[1]. In Canada, aerospace, pharmaceutical products, software and telecommunication equipment represent close to 80% of industrial R&D. As Archibugi and Pianta (1992, 1994) have shown, smaller countries tend to be more specialised than larger ones, and all industrial countries reinforce their specialisation through time. Only very large countries, such as the United States, need not to specialise in a few sectors.

Most authors bundle together very different kind of institutions. In this paper, four types of innovation institutions are to be distinguished. It is useful to keep the distinction in mind because they are fairly different from one another and they evolve under very different sets of conditions:

1. Public policies, first, are rules or norms designed and implemented by governments, and are thus most often compulsory. Policies evolve through several patterns and mechanisms. Policy analysts suggest that policy implementation occurs by small additions of policy evolution followed by

[1] It is worth recalling that the median country has a population of around 4.5 million, like Finland, Ireland or Singapore.

sudden periods of policy revolution (Sabatier, 1999). Increasingly since the 1970s, policies change through evaluation by independent parties (research institutes, consultants, academics) on behalf of the administration system. Evaluation has often produced policy refining and modification, thus change (Georghiou, 1998).

2. There are formal organizations or associations, such as private firms, government laboratories or universities, the individual adherence to which is, up to a certain extent, voluntary. Organisations are prone to inertia due to the fact that they are essentially bundles of routines. Inertia is generated by many concurrent factors, from bounded rationality of agents that stick to what they know and are able to do, to contracts regulating rights and responsibilities of agents, to the internal and external rules and regulations that shape them. Yet, some organizations change in response to environmental pressures.

3. We find routines within these organizations. These routines are norms, implemented hierarchically by the managers of these organisations, 'executable capabilities for repeated performance in some context that has been learned by an organisation in response to selective pressures' (Cohen et al., 1996). Routines are also the repositories of capabilities, but as Leonard (1996) has underlined, today's capabilities may be tomorrow's rigidities. Nelson and Winter (1982: 116) have argued 'organisations tend to resist change'. Yet, routines change from time to time, under the pressure of other, dynamic, routines, as well as environmental pressures (usually from government, markets, or suppliers). Routines change in a path dependent manner, and they build on the past; thus the possibility of 'competency traps', where organisations are locked in inferior routines because of their accumulated experience with the inferior ones, and lack of understanding of the superior ones.

4. Customs, habits of thought, or inherited rules of the game that are not usually supported by law, but are mostly consuetudinary, and supported by beliefs, such as religious practices. In many cases, these habits of thought are even more resistant to change than routines. But they have an impact on economic development, and on the adoption of science and technology, as the studies on the relationship between Islam and underdevelopment show (Kuran, 1997).

Institutions are not optimal, nor do they tend to optimality (Burns & Dietz, 2001). All economic and policy-making agents are bounded rational, and even if they sometimes change institutions for their own benefit, the result may be that most or even all agents reduce their well-being. This unexpected result occurs because economic systems are complex adaptive systems:

- They are made of dispersed interaction among heterogeneous agents
- No global controller can exploit all opportunities
- They contain multiple hierarchical organizations
- Agents continuously adapt through learning
- There is permanent novelty in technologies, markets, behaviours and institutions
- Out of equilibrium dynamics because of the introduction of novelty (Arthur et al., 1997)

Under such conditions, agents operate not by accurate calculations, rational anticipations or perfect knowledge about future states of the world, but by a trial-and-error kind of behaviour (Axelrod, 1997). Policies that are introduced in order to correct problems often result in poor outcomes because of system resistance (Sterman, 2002). Complex systems have their own dynamics that individuals are often unable to understand. An evolutionary approach and some research and modelling may help to uncover their hidden patterns.

Due to inertia, path-dependency, sunk cost both in infrastructures and learning, the special interests supporting them, among other factors, policies, organisations and routines can survive for long periods of time even if they are inefficient, as the story of Soviet communism has shown. The elementary components of innovation systems, thus, are as efficient as the systems themselves (Niosi, 2002).

The government sector is a system in itself, where information keeps flowing in, agents learn, and novelty occurs in missions, personnel, policies, and routines. Ideally, policy implementation, including STI policy, occurs through a four-stage process:

I. Identification of system or market failures, usually by the top levels of bureaucracy and government
II. Determination of goals and priorities
III. Policy design and implementation, and eventual creation of public bodies or adding missions to existing ones
IV. Policy evaluation and reformulation (Sabatier, 1999)

All these stages require a continuous flow of information in the form of data provided by statistical agencies and departmental studies, benchmarking exercises comparing the specific incentives, investments and outcomes of different policy schemes, with those in different countries and regions. Figure 1 summarizes the policy process.

2. STI institutions in industrial countries

In industrial countries, STI institutions have developed through decades of trial and error, redesigning and tinkering. If one were to pinpoint a major landmark in government intervention for the promotion of research in industry, the 1945

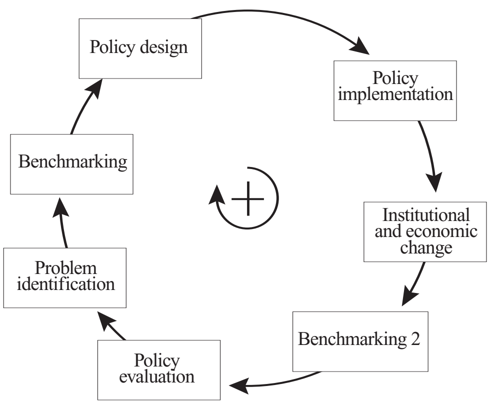

Figure 1: The policy process

Report to the US President by Vannevar Bush would certainly be close to the top of the list:

> The most important ways in which the Government can promote industrial research are to increase the flow of new scientific knowledge through support of basic research and to aid in the development of scientific talent. In addition, the Government should provide suitable incentives to industry to conduct research. (Bush, 1945)

The incentives that governments designed were not optimal, but they attained their goals in a fairly satisfactory way. History explains why similar incentives display a particular set of characteristics in one country as opposed to other ones. Later on, Romer (1986) gave this idea a more elegant treatment: scientific and technological knowledge was the source of increasing returns. Rediscovering Schumpeter, he understood that, for capitalism to grow, science and technology needed to be internal or endogenous to the business enterprise (Rosenberg, 2000).

Many authors have underlined the key role of STI institutions in economic development. In the systems of innovation current, Crow and Bozeman (1998), Nelson (2005), Mazzoleni and Nelson (2007), among others, have studied the key role of public research laboratories and universities in economic development. Aghion et al. (2009) have related the performance of academic institutions to their autonomy and competition for financial support.

The World Bank (WB) has also emphasized the role of such institutions as contract enforcement, intellectual property rights, and democratic processes. The WB suggested that there is a unique set of institutions ('one size fits all') that represents the pre-condition for development. On the contrary, other authors have brought evidence *against* the theory that democratic institutions and the rule of law cause economic growth. Conversely, they argue: (a) human capital is a more basic source of growth than are (democratic) institutions; (b) 'poor countries get out of poverty through good policies, often pursued by dictators'; and (c) only later do countries improve their political institutions (Glaeser et al., 2004). The authors recall that South Korea, Taiwan and China have grown rapidly under dictatorships and only then the first two adopted democratic institutions. In sum, not all institutions support growth, but only those related to the production, the absorption and the use of human capital in the public and private sectors. And innovation systems theory suggests that each developed country has developed its own set of STI institutions, none of them being optimal but just satisfactory and more or less adapted to the country's historical conditions. Each developing country needs to invent its own institutional road to economic growth.

These STI institutions, are mainly composed of sets of horizontal and vertical policies, as well as science and technology organizations such universities and public laboratories, and routines for the generation of innovation in business firms, academic and research organisation. These institutions are extremely diverse from country to country. Let's pinpoint some central differences among industrial countries and their institutions.

2.1 Horizontal and vertical policies

Two main types of STI policies are to be differentiated. Horizontal STI policies are those that apply equally to all industries, without targeting any sector. Tax credits for R&D are the archetypal horizontal policy. Many public subsidies for R&D in smaller firms are of a similar nature. The main advantage of such policies is that they apply to all firms. They are easy to implement and they do not often establish a basis for political corruption. However, they cannot be used as an incentive to support the growth of a particular industry. If a developing country wants to avoid a dispersion of efforts in many different industries, and intends to establish comparative advantages in one or several sectors, it will need to add a set of vertical policies applying to the desired sector.

Vertical (or targeted) policies are those that apply to a particular industry or sector. A National Biotechnology Policy (such as those implemented in Canada, in 1983, or Singapore in 1988) may be a typical example. The principal advantage of a targeted policy is that it concentrates resources in the sector the country wants to nurture.

Is there a right sequence in STI policy implementation? Are horizontal policies to be implemented before vertical policies, concurrently with them, or after them? The empirical evidence reveals different patterns. Sometimes, though not often, governments have a clear idea of sectors whose growth needs to be stimulated, due to the resources (existing or potentially accessible) and historical dynamic or static advantages of the country; in these cases it is possible to develop concurrently horizontal and vertical policies. In the late 1940s and 1950s, Canada implemented at the same time horizontal policies (tax credits for R&D and subsidies for SME's R&D) and vertical policies (giving priority to aerospace, nuclear energy and telecommunications). Later on, in the 1980s, it chose advanced materials, biotechnology and software. In the 1980s, Ireland chose the software industry, and only then implemented horizontal policies (i.e., tax credit for R&D in 2004). In terms of horizontal policies, Finland has no R&D tax credits but a sophisticated grant system. The country selected communications equipment out of Nokia's successful experience in the industry; it is now trying to diversify in other industries through its government innovation fund (Sitra) and granting agency (Tekes) to avoid extreme reliance on one sector. The United States has no official technology policy, but chose agriculture and railways in the 19th century, while it protected its infant manufacturing industry. In the twentieth century, the US federal government picked defence technologies, health and space, which have been among the most subsidized sectors in that country. Federal US tax credits appeared late (1981) and do not represent a key policy incentive in the United States. State tax credits appeared in the US in 1982 in Minnesota; by 2005, 32 US states had implemented some kind of R&D tax credit. Direct subsidies to targeted sectors represent the unofficial but very active US technology policy.

2.2 Governments learn through evaluation

Market organizations learn through competition and market signals. Governments do otherwise. Audretsch et al. (2002) have underscored that public authorities are accountable to tax payers, and they thus must be able to document their performance through specific indicators and metrics. Thus, accountability is at the basis of policy evaluation. However, the processes through which such evaluations take place are extremely different from one country to the next. Also, the functions of evaluation are variegated. They include legitimating the policies, improving management and providing transparency (Becher & Kuhlmann, 1995).

Since the early 1990s, in the United States, the General Accounting Office (GAO) and the Chief Financial Officer have the mission of evaluating the performance of government programs. The goal of the Government Performance and Results Act of 1993 is to increase efficiency and improve management of the federal agencies and programs through evaluation by GAO. However, as Audretsch et al. (2002) have emphasized, data are not always available and not always credible, particularly about such key outputs as externalities and other public benefits.

In Germany, evaluation pursued similar objectives of accountability, improvement and transparency. However, science indicators and peer reviews seemed more in use for universities and government scientific organizations, while panels composed of industrialists assessed the usefulness of more applied government research institutes. Kuhlmann (1998) emphasized the scattered nature of these efforts in Germany, as different programs and organisations are using different metrics and indicators. The US evaluation procedures, though, seemed no better than the German ones in terms of homogeneity of procedures, regularity of assessments and publication of results.

Smits and Kuhlmann (2004) underlined the fact that financial incentives are most frequently used to promote R&D. Other STI policies include regulations, procurement, creation of networks, and building infrastructure.

A major point goes sometimes unnoticed and needs to be stressed:

> These horizontal and vertical technology policies generate demand for human capital within the firms.

Countries with few or inefficient industrial R&D policies run the risk of not having demand for scientists and engineers in industry. Business organisations thus become 'illiterate' in scientific and engineering matters. Their absorptive capacity is therefore limited. A few major examples of STI policies follow.

2.3 Horizontal policies: Tax credits for R&D

Tax credits are increasingly adopted as incentives for R&D in OECD countries. They have several advantages over direct subsidies. They do not discriminate in favour of any type of firm, sector, or region. They are easy to manage and to evaluate. They are less prone to political corruption than outright subsidies. They do not represent disbursements, so they attract less political opposition than direct subsidies for R&D.

The comparative data available for several countries point to the fact that fiscal policy matters for R&D and innovation (Bloom et al., 2002). However, although increasingly popular, fiscal incentives are used very differently in OECD countries (see Table 1). They are important in Canada, moderately so in Norway or Spain, and negligible in the United States, where direct subsidies are much more widely used to support private R&D.

Canada supposedly has the third most attractive fiscal environment for industrial R&D, after Spain and Australia. Yet, official figures show that Canada's tax credit for R&D is far more central to the NSI than Australian or Spanish incentives.

Among OECD countries, the US federal fiscal credit system is not a critical public R&D incentive. Implemented in 1981, the US tax credit funded 'research and experimentation' (R&E, meaning substantial technology advances), and not simply

TABLE 1: COST OF FISCAL CREDIT FOR R&D I+D, 2005, SELECTED COUNTRIES (US$ MILLIONS PPP) AND AS % OF GERD

Country	Cost of fiscal credit (US$ millions PPP)	GERD (US$ millions PPP)	Fiscal credit as % of GERD
USA	5110.0	3,244,664	0.16%
Canada	2290.4	21,777	10.5%
France	1009.9	40,684	2.5%
UK	937.3	35,171	1.13%
Netherlands	419.3	9992	4.2%
Mexico	401.1	5641	7.1%
Australia	355.6	11,751*	3.0%
Belgium	355.4	6434	5.52%
Spain	343.3	13,391	2.56%
Norway	137.0	3396	4.03%
Ireland	65.2	2030	3.2%
Argentina**	8.3	854	0.97%
Portugal	3.3	1705	0.19%

Source: OCDE (2007): *Science, Technology and Industry Scoreboard*, Paris.

* Figures for 2004; ** FONTAR (www.agencia.gov.ar)

R&D. Besides, the credit only funds up to 20% of any *increment* over a base R&D figure, not to the *total* R&D expenditure. Thus, if companies do not increase their expenditure, they have nothing to claim. Also, during its 25-year history, the law has been changed 11 times making its precise advantages blurrier to innovative companies (Tassey, 2007). In addition, the precise calculations of deductible items are cumbersome for the companies, and difficult to monitor for the government. Finally, the tax credit is not refundable; it is thus useless for new small technology firms, such as biotechnology or semiconductor companies, which incur losses during several years before turning a profit. On the top of that, the US tax credit system is not permanent, and has to be renewed every year, therefore it does not help companies wishing to establish permanent R&D centres in the country. In 2004, over 55% of the credit went to 100 companies and the remaining to slightly more than 10,000 other firms. Tassey (2007) concludes that, at best, the federal US tax credit has had a marginal effect on business expenditures on R&D in the country. Billings (2003) argues that the ineffective US tax credit is a deterrent for both foreign and domestic companies to conduct R&D in the US, and an incentive for them to conduct R&D abroad. In November 2008, the US President's Council of Advisors on Science and Technology recommended to 'Update and enhance the R&D tax credit to make it a more stable and effective incentive for industry to perform R&D' (US Council, 2008).

The relative success of Canada's program for fiscal credits for R&D, to which close to 20,000 companies of different sizes submit a claim for the rebate each year, is due to its particular design[2]. Large companies may deduct up to 20% of eligible expenses, and smaller firms are eligible to 35% of up to C$2 million of R&D expenditures. Unused credits can be carried forward for 20 years and backwards for three years, and are refundable in case smaller firms have no tax to pay in a particular year. The Canadian system is permanent and it has no limit on the amounts that firms can request, except for smaller ones, or on the number of firms that may obtain the credit. Yet the program has been criticised, because smaller companies that already entered the stock market are not considered eligible to the 35% deduction. It was also suggested that the C$2 million maximum rebate was too low for many smaller firms particularly in such domains as biotechnology or nanotechnology.

Our short review shows no optimal fiscal credit programs but many different versions, more or less adapted to their particular environments. The much criticised US tax credit system is partially compensated by more efficient direct subsidies for R&D, as we see later. To conclude this section, it is worth noting that some countries without any type of R&D tax credit, such as Finland and Sweden, rely on direct subsidies for R&D, and are among the most active in the world in terms of R&D and innovation.

2 In 2004, almost C$ 3.4 billion in assistance was provided to 19,600 companies through the R&D tax credit; 80% of the companies were smaller firms and they received some 23% of the tax claims (Canadian Chamber of Commerce, 2007).

2.4 Horizontal policies: R&D subsidies for SMEs

Subsidies for R&D in small firms are a common STI policy component in all OECD innovation systems. Their specific policy design varies widely from one country to the next.

In 1962, Canada launched its Industrial Research Assistance Program (IRAP). Its goal was to 'stimulate wealth creation for Canada through technological innovation' and 'to stimulate innovation in Canadian SMEs' (NRC, 2010). The program incorporated several components, including non-refundable R&D subsidies for SMEs, and a technology counsellor program. Some 260 technology counsellors visit thousands of SMEs every year and suggest them technical improvements in products and processes; they also help SMEs to request financial support either within IRAP or from other programs, and assist them to find academic or government research centres that could conduct collaborative R&D with the firms. The latest evaluation of IRAP found that in the 1996–2001 period the program had funded 12,300 projects that resulted in over 39,000 innovations; C$11.3 billion of sales were linked to those IRAP-assisted innovations.

In 1982, the US implemented its highly regarded Small Business Innovation Research Act (SBIR) that launched the SBIR program. The goals of the program are 'to more effectively meet R&D needs brought on by the utilization of small innovative firms … and to attract private capital to commercialize the results of Federal Research' (Wessner, 1999: 19). SBIR provides up to US$850,000 for early stage R&D activities to entrepreneurs or new technology based companies that wish to explore advanced technologies. All government departments with a budget over US$100 million have to contribute to the program. In fiscal year 2007, SBIR invested US$1.14 billion, with the Department of Defence (DoD) representing close to 65% of all SBIR funds. The requesting companies must have less than 500 employees, they must conduct R&D in the United States, be controlled at 50% or more by their managers or employees (a provision, though, that makes it difficult to fund SMEs that have already received venture capital). The program is two-phased. In Phase I, a peer-review committee assesses the project, and may grant up to US$100,000 for feasibility studies during 6–12 months. The most promising projects move to Phase II that funds the primary R&D process for two years, the typical grant being $750,000. After Phase II, the SMEs are supposed to apply for private funds (i.e., venture capital). From 1983–1999, SBIR made 45,000 awards for a total of US$8.4 billion (1998 dollars). A more recent evaluation, concentrated on the DoD, a one billion section, found that the program was successful, but did not allow enough funds for the management and metrics of the results on a regular basis (RAND Corp, 2006).

In 1995, under its worst economic recession since World War II, Japan introduced its first law for the support of innovative SMEs in order to revitalize the Japanese economy (Eshima, 2003). It was the Temporary Law concerning Measures for Changing Business in Specific Small and Medium Enterprises. The program took inspiration from the US SBIR Program. It encouraged innovation through SME cooperation with universities and public laboratories. Like SBIR, the Japanese program allocates subsidies in two phases. The main subsidies are granted in Phase II. In the first three years of the program (1995–97), over 3000 SME were supported, with over ¥61 billion (over US$6 billion). These 1995–97 phase II awards included over US$1 billion for R&D activities in 902 firms, as well as venture capital investments in some 300 SME, for ¥14.2 billion (US$1.4 billion). Japan's Small and Medium Enterprise Agency runs the program that is now in its 13th year, following substantial improvements, introduced particularly in 1999. The new Law has four goals: promoting business innovation, launching new business start ups, strengthening the management base of SMEs, and offering a safety net. By 2007, and thanks to the government program, over 50% of Japanese manufacturing SME were conducting R&D and in most cases it was collaborative R&D, partnering with universities and public laboratories (Japan SME Agency 2008).

2.5 Vertical policies: Biotechnology and software

Horizontal policies may strengthen existing sectors; they will seldom be a major contributor to the generation of new ones. For new sectors to emerge, particularly high-technology ones, scarce resources and sophisticated policies need to be concentrated in those sectors. Concentration of resources represents, at the same time, investing in human capital, attracting industrial organisations that will create demand for skilled labour, and implementing incentives for R&D.

At independence, in 1965, Singapore was a poor South East Asia country, a former British trade post. With only 310 square miles, and no natural resources, it may be difficult to understand how it moved from trading outpost to high-technology manufacturing centre. Since independence, the government managed to dramatically increase the education levels of the population, put English as the first language of the country, establish a modern infrastructure and attract overseas industrial companies. At the beginning, all types of manufacturing firms from abroad were welcome. By the 1980s, electronic parts manufacturing emerged as the major sector in Singapore's secondary industry. The industry required little space and a disciplined and fairly educated labour force. However, after the mid-1980s recession, the government understood that innovation, R&D and a highly skilled labour force were essential. Industrial policy turned from luring MNC's manufacturing activities to attracting R&D centres and creating national companies in technology-intensive sectors. Electronic products had become the leading manufacturing sector. Pharmaceuticals followed suit. While some MNC were already producing drugs in Singapore, R&D was absent from the country. In 1988, Singapore launched a National Biotechnology Program, and implemented a large series of policies to become one of the major drug development, genetic therapy and human biotechnology hubs in Asia. New public laboratories were established and in 2000 the Biomedical Sciences Initiative was launched (Parayil, 2005). Singapore implemented tax holidays for MNC establishing drug production and/or R&D in the country. In 2003, Singapore inaugurated the first phase of Biopolis, a major science park dedicated to life sciences, the second phase of which was completed in 2006. The park is hosting seven research institutes, legal and patent services, and all types of private firms, from global multinationals to emerging start-ups. The total cost of the Biopolis Park was US$392 million; by the end of 2007, some prominent tenants included GlaxoSmithKline (GSK) from Britain, Novartis from Switzerland, and Takeda (Japan) (JTC, 2007). At the end of 2007, Singapore had invested over US$2 billion in these organizations. With a total population of 4.5 million, Singapore was also exporting over US$125 billion in high technology products, more than all Latin American countries combined.

In the last 20 years, Israel has become a small but active exporter of domestic software products (Breznitz, 2005). Behind the Israeli software miracle one finds a very supportive state, heavily investing in human capital through education and attraction of foreign talent. Also, in 1984, the software industry became eligible to the substantial direct grants offered by the Office of the Chief Scientist. The Israeli government promoted the emergence of a private sector venture capital industry through its 1992–97 Yozma program (Avnimelech & Teubal, 2005). Israeli venture capital is essentially aimed at high-technology new ventures. The result was a very fast growth of the sector: exports moved up from US$90 million in 1990 to US$2.6 billion in 2000 and US$23.6 billion in 2008.

2.6 Horizontal and vertical policies: Public laboratories

In industrial countries, government research laboratories fulfil many different missions. Some of them help government in the quest of specific public missions, such as defence, environment and health (Crow & Bozeman, 1998). Other institutes, such as particle accelerators or astronomical observatories, pursue objectives of basic science. Many are related to specific industrial sectors such as aerospace, agriculture, biotechnology, energy or telecommunications, and are sometimes part of vertical industrial policies. The mandates and missions of these are variegated. At their most basic level, they include 'extension' (the application of agricultural or industrial best practices through education) such as teaching farmers how to analyse production problems or industrial SMEs how to conduct quality control. At a higher level, they include conducting R&D on behalf of farmers or manufacturing firms and transferring the results of the research project to them, be it new or improved crops to farmers or product designs to industry. At its highest level they could develop entirely new technologies for government or industry, including satellites, semiconductor manufacturing processes or chip designs, and spin-off new companies for the purpose of transferring them to the private sector.

In 2006, federal agencies and federally funded R&D centres in the United States have spent US$37 billion in R&D expenditures; this amount exceeds the total national expenditures of every country in the world except China, Germany and Japan (National Science Foundation, 2008: 4–12). They accounted for 11% of all US R&D expenditures and were performed in some 800 laboratories.

In 2006, Canada's federal and provincial intramural expenditures on R&D represented some 10% of GERD. These more than 100 national institutes included scientific research organisations (including those working on atomic energy, defence, health, and space) and more industrially related laboratories such as those working on biotechnology, communications, construction, and measurement standards.

Also in 2006, in the OECD, the government sector performed 11% of GERD. Former communist countries such as the Czech and Slovak Republics, Hungary and Poland together with France, Italy and Greece were spending well above the OECD average (OECD, 2008).

How did these government institutes perform? The evaluation of public R&D is not easy and it has been done using different metrics due to the very different missions and activities of such organisations (Georghiou et al., 2000). They go from counting publication, patents, spin-off companies, new or improved products or processes transferred to companies, as well as networking activities, to measuring customer satisfaction with services rendered by the institutes. Also, the evaluating agencies vary, from national and international academics, research institutes and consulting firms (as in Canada or the US), to in-house evaluation by the same laboratories, as in Japan.

2.7 Conclusion

Through different horizontal and vertical incentives, a set of industrial countries has managed to attain some level of endogeneity in the production of innovation. In these countries, business enterprise normally performs a high percentage of the country's R&D, usually well over 50% of the national total. But the set of incentives that produced such change in the behaviour of private enterprise varies from country to country and is always subject to improvement through continuous evaluation.

3. STI institutions in LDC

Developing countries are not without STI institutions, but these are often poorly funded and managed, and their evaluation procedures are weak. Also, one hears a frequent complain from developing country academics about the 'puzzling' low involvement of industry in R&D (Arocena & Sutz, 2001). The evolutionary approach suggests that developing-country STI institutions, and particularly those that are aimed at increasing R&D in industry, are flawed, badly funded, and/or were not implemented with the necessary persistence. Thus they were unable to make science and technology endogenous to industry. A few cases can illustrate the pattern.

3.1 Tax credits in Argentina and Mexico

Both Argentina and Mexico have implemented tax credits for R&D. Yet these policies did not produce the expected outcomes.

Mexico

In 1976, Mexico launched its fiscal incentives for R&D, but put from the start a cap on the total fiscal cost of the credit; this is a major difference compared to Canada, France or the US, where any company can request such credits almost without limits. In 2006, the Mexican government allowed some 400 million in tax rebates to 887 companies over than 3000 projects. Some 30% of expenditures in R&D, including the training of R&D personnel, could be deducted from business taxes. In 2008, Mexico had increased its fiscal budget for tax credits to some 4,500 million pesos (450 million US dollars approximately). Table 2 shows the evolution of the Mexican fiscal incentives in the 2000s. The table shows that, over a five-year period, only 52% of the fund applications but almost 90% of the demands were accepted. Yet the number of companies is exceedingly small: just 4.5% of the Canadian total of around 20,000 firms obtaining the credit, or ten percent of the US firms. Also, tax credit concentration in large Mexican firms has been strong: in the 2001–04 period, some 505 Mexican companies received the credit, but only 92 companies received some 70% of the fiscal credit, and 69% of the credit to these large companies went to foreign firms (Foro Consultivo, 2006). An independent study cited in the Foro survey (2006), calculates that, in the 2001–04 period, only some 1020 companies conducted R&D in Mexico (over 20,000 in Canada). Finally, contrary to the US or Canadian system where no public official has the authority to choose who will get credit, the Mexican system gives to an inter-institutional committee the power to distribute the national tax credit. Representatives of the Economics Department and other agencies form the committee (Foro Consultivo, 2006: p. 57).

Another major problem with the Mexican system was its high concentration in just one sector, the auto industry. In 2005, the car industry dwarfed all the others, with a towering 45% of all tax benefits. The 2006 distribution by sectors appears in Figure 2. The automobile sector still represents the major portion but new areas appear (including biotechnology and pharmaceuticals) that were absent a few years before.

Probably in response to such criticisms, the 2007 version of the Mexican fiscal credit law reserves 22% of the sums to small firms and for R&D in the area of new energies.

Some evaluation is performed in Mexico, and the Foro Consultivo is a key agent of this evaluation. The Foro was created in 2002 as an independent consulting organism of the Mexican government. Its mission includes the analysis of policy incentives for science and technology, and the proposal of new measures to develop the science and technology capabilities of the country. It regularly publishes evaluations of different science and technology policies.

In spite of its centrality, the Mexican incentive does not change the landscape of the country's reduced business expenditure on R&D. In 2005, Mexico's GERD was only 0.46% of GDP and BERD represented 41% of that amount.

Argentina

Argentina launched its tax credits on R&D in 1997, with a US$20 million cap in 1998 and

Table 2: Mexican fiscal credit for R&D demand and supply (2001–06)

	2001	2002	2003	2004	2005	2006
Companies receiving the credit	192	242	275	398	643	887
Projects supported	679	1067	1197	1606	2361	3155
Credit demanded (M$ m)	735	911	1251	2301	4658	8351
Credit offered (M$ m)	500	500	500	1000	3000	4000
Credit offered as a % of demand	68%	55%	40%	43%	64%	48%

Source: CONACYT (2007): *Estímulo fiscal para la investigación y desarrollo tecnológico*, Mexico

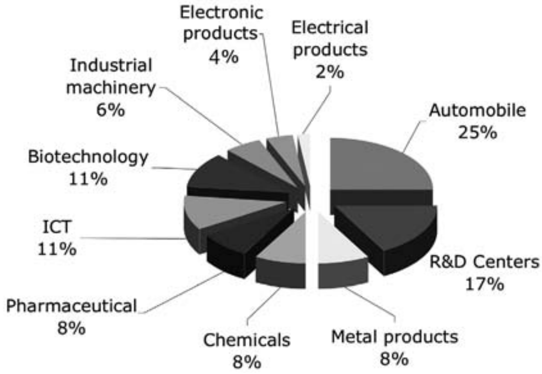

FIGURE 2: MEXICAN TAX CREDIT FOR R&D 2006 BY INDUSTRY
Source: CONACYT (2007)

1999. The Argentinean Technology Fund (FONTAR) manages the credit; FONTAR is an office of the National Agency for Science and Technology Promotion of the federal government. Public servants thus, as in the case of Mexico, distribute the credit, which can represent up to 50% of eligible costs of the project. The government certificates are valid up to three years after they are emitted, and they serve to cancel federal government taxes. In the first year, 125 companies presented 147 R&D projects; 94 of these projects were considered innovative and were accepted. They emanated from 79 firms, 82% of which were SME. Also, 90% of the funds were allocated to the manufacturing sector. At that time, the Argentinean manufacturing sector consisted of some 1000 large and medium-sized companies as well as 14,000 SME. Thus the credit, was beneficial only to 0.5% of Argentinean manufacturing firms (Chudnovsky et al., 2000).

After the major financial crisis of Argentina in 2001 and 2002, the credit was maintained with similar characteristics. The amounts were preserved in pesos, but because of the abrupt devaluation of 2001–02, they were reduced by 66% in US dollar terms. In 2007, the allocation was slightly increased to 25 million pesos (US$8 million), and in 2008 the government allocated 45.4 million pesos (or some US$15 million) to the credit, under similar conditions as in the original program. With such very modest amounts, it is understandable that the business involvement in R&D of Argentina has not made any particular progress since the inception of the credit. R&D expenditure as a percentage of GDP was stagnant at 0.45% in 1999 and 0.46% in 2005. BERD was 26% of GERD in 1999 and 31% in 2005. Considering the fact that in 2005, Argentina's GDP was US$553 billion, the incentive, as in the case of Mexico is, to say the least, highly insufficient to stimulate industrial R&D and create demand for skilled scientists and engineers.

3.2 SME policy in Chile and Argentina

In most developing countries, except in South East Asia, innovative SMEs receive a timid support from the state. Chile and Argentina are cases in point.

Chile and subsidies for R&D

In Chile, CORFO is the national agency that supports innovative activities in firms of all sizes through many different programs including venture capital, long-term loans, R&D subsidies and other. The set of programs is handled by INNOVA Chile, a division of CORFO. In 2007, CORFO had a total budget of over 5000 million pesos or US$800 million. One third of this amount comes from the accumulated royalties the national government collects from its mineral exports. By the end of 2007, the total amount of funds accumulated through this royalty was 37,000 Chilean pesos (or US$6 billion). The price of copper, which fluctuated from US$0.50–1.50/lb (pound), increased substantially in the 2005–08 period, and the Chilean government collected major rents. By December 2008, however, it had gone back to its upper historical levels of US$1.50/lb.

In the area of support for innovative projects for R&D, CORFO has funded 409 projects in 2005 and 798 in 2006; 85% of them were SME. Yet, in 2006, only 204 Chilean firms represented some 80% of BERD. Most SMEs requesting subsidies for R&D are in agriculture, fish production and other primary activities, and request and obtain small amounts. An academic evaluation (Benavente et al., 2007) estimated that Chilean subsidies for R&D had a positive effect on private innovative activities. The 'crowding out hypothesis' was rejected and a fair level of additional R&D was found. Yet, in October 2008, the national association of small firms (CONAPYME)[1] requested an evaluation of CORFO programs for SMEs, managed by private banks, under the argument that banks were not channelling all available funds to small firms. At the same time, in September 2008, a study published by the National Statistical Institute of Chile found that only 2.4% of the country's SME use CORFO's programs. Again the intermediary banks were pointed as the main obstacle to more adequate financial support to SMEs. The funds are there and the instrument produced some good results, yet total business expenditure on R&D remains low: under 30% of GERD.

In 2004, Chile invested 0.68% of GDP in R&D, or some US$635 million. That same year, 46% of that amount was the nation's BERD. However, during the affluent years, according to preliminary estimates, the country's GERD remained at 0.6–0.7% of GDP. This score is slightly better than in the cases of Argentina and Mexico and a minor improvement with respect to previous years. In spite of favourable conditions, Chile's R&D effort is far from the average 2.26% of GDP that OECD countries devote to R&D.

Argentina

In Argentina, FONTAR is the main agency that distributes fiscal credits, subsidies and loans for R&D. In the latest year available, 2006, FONTAR had supported some 527 projects for a total of US$50 million; this amount includes fiscal credits, non-reimbursable R&D subsidies and other supports. The non-reimbursable funds were exclusively aimed at SMEs. In 2006, these funds amounted to some US$10 million on 271 projects; in the 2003–06 period, some 1100 projects were approved for US$33 million.

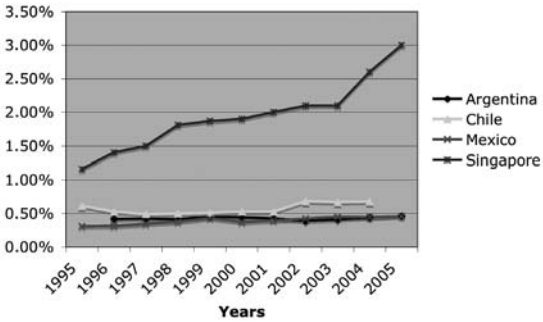

FIGURE 3: GERD 1995–2005 SELECTED COUNTRIES

By comparison to IRAP, with annual budgets of C$150 million dollars, of which some C$65 million are distributed annually in non-reimbursable grants for R&D, the Argentinean program seems, once again, poorly funded. Compared to SBIR or the Japanese programs, even when normalised by population and GDP, the Argentinean effort looks irrelevant. If Argentina decided to invest the equivalent of US$1.4 billion annually (the present SBIR program), or IRAP, it should spend at least US$50 million annually in direct subsidies to R&D.

3.3 Vertical policies

Vertical policies are often implemented in developing countries. Many of them aimed at the creation of advanced technology industries such as aerospace, electronics or pharmaceutical. With a few exceptions they failed. Alcorta and Peres (1997) summarized some of the shortcomings of these policies under the following headings:

(a) *Lack of clarity*. Many developing countries imposed restrictions on technology transferred to them by MNC under the rationale that foreign firms used technology to extract royalties. Thus, they generated obstacles to local learning. In the 1970s, countries such as Argentina and Brazil created offices of intellectual property (IP) or foreign collaboration not so much to generate local IP, but to control incoming technology from abroad. India made a similar move with the India Investment Agency.

(b) *Lack of priorities*. Too many institutions and policies, as well as too many sectors being nur-

[1] www.conapyme.com

tured at the same time. Brazil intended to promote an electronics industry without any lack of specialization. Today its list of target sectors includes 25 industries.

(c) *Excessive complexity and detail, as well as out-of-control scope*. Brazil New industrial Policy in 1988 was to promote too many industries at the same time through import liberalization for machinery and equipment, under the proviso that all industries were connected. However, the sectoral import quotas, market access and equity participation restrictions generated obstacles to growth.

(d) *Technology policies and organisations are rarely assessed*. Evaluation and particularly independent evaluation are seldom part of developing countries' culture.

One may also add lack of persistence and low investments. Argentina's promotion of a domestic aircraft industry through a government enterprise that, with many ups and owns, produced several hundred units of different locally designed models since the 1920s, was revived in the 1940s and 1950s (with the help of French, German and Italian immigrant aircraft engineers), and knew a short restoration in the 1970s and 1980s. By the mid 1990s, however, the government aircraft manufacturing company was sold to Lockheed Martin. In December 2008, the company was being nationalised again.

In 1984, Brazil implemented import restrictions to support the growth of a national pharmaceutical industry. Also, in order to nurture domestic production the government invested over US$5 million in laboratories in the city of Campinas. However, the weaknesses of the research infrastructure generated major obstacles for a local industry to grow and import restrictions were lifted in the 1990s.

3.4 Public labs: Agricultural and industrial extension versus industrial promotion

In developing countries, government institutes perform a larger share of GERD than in OECD countries. This is due partially to the weakness of private sector R&D activities for promoting agriculture, health or industry: public laboratories appear to occupy a major role only because private R&D is almost non-existent. Most of these institutes perform basic service and extension activities. In a few cases they have succeeded in managing large research projects as in the case of EMBRAPA, the Brazilian agricultural research institute (Dalhman & Frischtak, 1993).

It was suggested that research in public laboratories and universities did not represent a major factor in catching up, with a few exceptions in Brazil (aircraft), Korea and Taiwan (electronics) (Mazzoleni & Nelson, 2007). Yet, Linsu Kim (1997) thought otherwise in the case of Korea:

> Given the inadequacy of Korean university research, the government developed a network of R&D institutes (GRIs) to play a major role in advanced industrial R&D. The Korea Institute of Science and Technology (KIST) spent a large proportion of the nation's total R&D funds in the early decades, but they suffered from poor linkages with industries in the 1960s and 1970s. (Kim, 1997: 201)

Kim identified two problems: lack of demand from industry and insufficient manufacturing know-how in the GRIs. In order to establish linkages, 'the government coerced large firms to undertake joint research with GRIs' (Kim, 1997: 202) in the automobile, chemical, electronics and other industries. These GRIs strengthened the bargaining power of local firms with foreign multinationals, reverse engineered technology, and provided prior knowledge to firms in a wide range of industries. They conducted global technology scanning, educated industrialists, provided common infrastructure to firms unable to conduct R&D by themselves, and served as catalysts of skills and competencies (Lim, 1999).

In Singapore, also, government biotechnology research institutes have played a major role as initiators and catalysts of local competencies in the late 1980s and 1990s (Parayil, 2005: 56):

Public research institutes and centres were mandated to work closely with firms and to recover part of their R&D expenditures from these industrial sources.

Finally, Taiwan's ITRI has played a key role not only in electronics but also in the machinery industry (Chen, 2009); other laboratories are playing a similar role in biotechnology (Dodgson et al., 2008).

The point here is that, if not connected to local industrial partners, and provided with a large set of useful mandates (none of which is the provision of basic science), as well as adequate funding, public research organizations (PROs) in developing countries will not play a key role in catching up. The examples of South East Asia show that they can and should play a major role. PROs should not need to wait from industrial demand to develop. Through appropriate incentives, governments must promote linkages and cooperative R&D between PROs and industry, and postpone the advancing of basic science.

In 2005, expenditure performed by Latin American government institutes was much larger than in the average OECD countries: Argentina (40%), Brazil (21%), Chile (45%) and Mexico (23%). But this is only due to the reduced involvement of industry in R&D and innovation. These countries had fewer government institutes than industrial countries, and all but a handful of them were conducting either basic science or agricultural and industrial extension. Few vertical institutes in advanced technologies existed in the region.

3.5 Conclusion

Developing countries have arrived later to science and technology. Many of them have underestimated the key role of institution building. For many reasons (lack of focus or resilience and/or adequate investment) their policies and organisations did not produce the expected results. More often than not, policies were abandoned instead of being assessed and improved. Government bureaucracies may also be less competent than those in industrial nations. This gives rise to a vicious circle of underdevelopment: local education systems produce few high-level graduates (and attract even less of them from abroad). Bureaucracies are unable to find highly skilled civil servants who would design, implement and assess sophisticated policies that would improve such education systems.

4. Conclusion and policy implications

Science, technology and innovation institutions must be revised under the light of evolutionary economics and learning. Two major issues seem important for catching up. First, developing countries must set up new sectors and for thus purpose they need both horizontal and vertical STI policies. Second, in order to make technology endogenous (Rosenberg, 2000), business enterprise must be stimulated to conduct R&D and innovate, to hire scientists and engineers. For that purpose, horizontal policies have to be redesigned and assessed continuously, and vertical policies need to be implemented in order to launch new, technology-intensive sectors.

This paper has argued several major points:

(1) In STI policies, there is no 'one size fits all', universal solution. Different countries apply various policy solutions to specific economic structures, strategies and local conditions. Also, the precise way in which these policies are applied is important, and there are many different ways of implementing what at arm's length appears to be the same program (i.e., grants for R&D in smaller firms) (Lach, 2002).

(2) STI policies, crucial components of the national and sectoral systems of innovation, are of variable efficiency and effectiveness. No clear movement towards optimal or merely more efficient institutions is in sight. The reason is the major and permanent ambiguity about best practices, incentive designs, outcomes, evaluation methods and factors that explain the results.

(3) Benchmarking and evaluation are, however, the key learning mechanisms. There is evidence that evaluation, particularly independent one, serves to improve policy designs, through continuous improvement. However, a substantial amount of trial-and-error and tinkering remains unavoidable.
(4) Horizontal policies are not enough. Vertical policies are required to create new sectors. Little vertical policies were to be found in these Latin American countries, but if found, they are flawed, poorly funded and badly coordinated.
(5) Also, Latin American countries invest little in business R&D. Their policies are often inconsistent, which reveals the modest managerial capabilities of their public bureaucracies. Although starting from much lower levels of governance sophistication than Latin America, several South East Asian countries are much more active and successful in all these STI policy fields.
(6) It is critical to plan, at the same time, both human capital supply (through investment in education), and skilled labour demand, the latter being promoted through increasing business R&D and stimulating private sector absorptive capacity. The lack of demand for human capital produces 'brain drain' conditions. An insufficient supply of human capital generates barriers to innovation in both public and private sectors.
(7) Because governments design and implement policy, the construction of an efficient public bureaucracy is another major condition towards the operation of successful STI policies.
(8) STI institutions in OECD countries may provide models for would be catchers up. But the virtuous circle of policy execution and learning also appears in South East Asian countries under fairly different models. Also, one learns not only from success stories, but also from errors and wrong policy decisions.

If any general conclusion is to be drawn from this overview, it is that each developing country, if it is to catch up, will need to examine previous successful and unsuccessful paths and policies, and develop its own road to innovation and development.

The policy implications are straightforward. Developing country governments need to pay much more attention to these STI institutions, invest in them, and evaluate them with the goal of continuously improving them. They also need to built a professional public bureaucracy of highly skilled civil servants in these areas, one that is able to design, implement and monitor the outcomes of public investments in science, technology and innovation. And they also need to coordinate human capital supply with demand, particularly with business sector demand.

A final caveat is necessary. Efficient R&D, science and technology institutions may not be sufficient conditions for catching up, without industrial policies, an intellectual property regime, and a stable macro-economic environment. Industrial policies include some type of infant industry protection either through tariffs, quotas and/or currency management. A wise use of these tools allowed Japan to catch up with the United States in computers (Anchordoguy, 1989) or Korea in automobiles (Kim, 1997). Currency management is important, particularly in developing countries such as those on Latin America where the curse of natural resources is too often evident: in periods of high resource prices, the value of their currency increases and industrial as well as sophisticated services exports become difficult. For decades Asian countries have chosen to maintain a low exchange rate in order to favour their exports.

An appropriate intellectual property rights regime (IPR) is also required (Mazzoleni & Nelson, 2007). In most industries, but more acutely in such sectors as biotechnology and pharmaceuticals, semi-conductors or software, the existing IPR regime in the world economy may restrict their ability to learn and master existing or incoming new technology. All Asian developing countries have chosen weaker IPR regimes with a view to increase learning and manage the transition from imitation to innovation

A stable macro-economic environment is another pre-condition (Cimoli et al., 2008). Many Latin American countries have suffered from prolonged periods of inflation accompanied by fixed exchange rates, and often such periods were followed by macro-devaluations. In the last 50 years, Argentina has been the classic example of such nations prone to chronic macro-economic instability.

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Received 29 November 2009
Accepted 28 January 2010