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Science, Technology and Innovation in Developing Countries: Some Elements for Defining Policies and Assigning Resources

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Industrial Development Report 2005 Background Paper Series

Science, technology and innovation in developing countries: some elements for defining policies and assigning resources

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Introduction

Nowadays, the relevance of knowledge and learning processes for the economy and for society at large is not under discussion, neither concerning industrialized countries nor in the case of underdeveloped countries. Consequently, the need to invest in building national capabilities in science, technology and innovation (STI) in developing countries is widely accepted.

An example of such emerging consensus can be seen in the conceptual evolution of the World Bank documents related to higher education; in fact, some years ago investing in higher education in developing countries was seen as a distraction of resources that should be assigned to basic schooling; more recently, the bank speaks of the "enrollment gap" to stress its worries concerning the widening gap between North and South in access to tertiary education (World Bank, 2002).

Nevertheless, important questions can be posed about the rationale for assigning to STI very scarce resources in regions with very urgent social demands. Such questions are related, on the one hand, to current deep changes in international knowledge production and, on the other hand, to different considerations about the efficiency shown up to now by investments in STI in underdeveloped contexts.

Knowledge production has been considered for a long time as an area where public investment is clearly justified. The main reason for that was that social return of investing in that area has been notoriously higher than the private return, particularly in fundamental research: "There is no reason to treat science as being 'private' rather than 'public' knowledge." (Nelson and Romer, 1996: 21) That is connected with the possibilities of appropriating the outcomes of research. Now, the conditions that shape such possibilities have been changing quickly. It is still difficult to establish more or less precisely the new relations between public and private returns of knowledge production, particularly in emerging disciplinary and applied fields; generally speaking, it seems clear that new ways of privatizing knowledge are deeply modifying the balance between public and private returns of STI activities.

If it happens that the main benefits flowing from investing in STI are privately appropriated, the rationale for public investment in that area needs to be reconsidered. This must be the case above all when assigning resources to STI has to be decided in the context of very urgent and pressing social demands. Such reconsideration is also urgent when it may be the case that the goods and services that are expected to be obtained by public investment in STI can be privately provided at lower costs.[i]

The need to revise the basic assumptions for public investment in STI stems also from other reasons. Such investment has given good global results in the very few cases of recently industrialized countries that have been able to significantly overcome their situation. But in the rest of the developing world, although many positive contributions can be listed, the average results have seldom been impressive. Several factors help to understand that. One of the most important is precisely that investment has usually been very low. It can also be said that often policies have been poorly designed and badly implemented; surely, both aspects should be improved. In fact, the actual consensus concerning the relevance of knowledge and learning processes does not include a similar degree of agreement concerning which policies are more effective in building advanced capabilities for problem-solving in developing countries. Now, since policy mechanisms are closely connected with justifications for policies, the last also need to be revised.

This paper aims to discuss the present-day rationale for public investment in STI in developing countries. The idea is that a good justification for such investment implies some general orientations for STI policies, gives also important hints concerning concrete implementations of those policies, and cannot be separated from the estimation of costs or the evaluation of results.

Section I considers the question, *why*: reasons for public spending in STI are analyzed. What does the experience of developed countries show? What does the situation of developing countries suggest? In Section II the questions, *for what* and *how*, are considered. Aims and means of Latin American public investment in STI are briefly reviewed. Some *building blocks* of STI policies in developing countries are proposed. An answer to the question "how to invest" is summarized by means of a matrix of building blocks and their corresponding policy instruments. In section III the investment needed for implementing such instruments is roughly estimated in the case of Uruguay as a partial answer to the question, *how much.* Then the evaluation issue is addressed. Indicators of results are discussed in connection with justifications and aims of STI investment. A matrix of building blocks and indicators is presented.

I. Investing in Science, Technology and Innovation: why

(I.a) On the experience of the North

History does not show any example where development is not associated with relevant efforts in STI. Almost every strong contemporary national system of innovation (NSI) has evolved from an *embryonic innovation system* with relevant support from the state. The recent comparatively very successful cases of the Republic of Korea and Finland stress again that lesson. Industrialized countries invest a lot in R&D; they have many students in tertiary education; they try to make their NSI even stronger by means of a large set of policies. Thus they aim to keep themselves on the 'high road' of competitiveness based on advanced capabilities.

The explicit rationale for public intervention in the realm of science and technology can be traced back to the last years of WWII. In 1944, the famous Vannevar Bush report, "Science, the endless frontier", was delivered at the request of Franklin D. Roosevelt; it stated that "a nation that depends upon others for its new basic scientific knowledge will be slow in its industrial progress and weak in its competitive position in world trade" (Bush, 1990, quoted in Stokes 1997: 4). This kind of reasoning had proved its might in the Manhattan Project, legitimizing public intervention in the orientation of scientific and technological efforts[ii]; it was again applied in the following decades to justify other huge projects like those in aerospace. This is as valid for the US as for other developed countries. One of the justifications traditionally given for spending taxpayers' money in complex problems has been that, precisely because of their complexity, the always present uncertainty of research outcomes is even more extreme in these cases, and so no private actors would have ever undertaken the risk of investing money in the search for solutions.[iii]

However, the rationale for public investment in science, technology and innovation has not been confined to big, complex and prestigious projects. A general argument was advanced in a famous article by Arrow, in the early sixties, in which it was argued that given the high uncertainty that surrounds untried inventions and the research leading to them — not to mention the difficulties associated with the appropriation of the eventual results — private investment in knowledge production will probably be below the necessary and desirable level. (Schonfield, 1981: 7) "...For optimal allocation to invention it would be necessary for the government or some other agency not governed by profit-and-loss criteria to finance research and invention" (Arrow, 1962: 602, quoted in Schonfield, 1981: 8). The classic work by Mansfield in the early seventies adds arguments to Arrow's statement: in general terms, the private returns to innovation are much lower than the social ones. Further work by the National Science Foundation concurred with these arguments, going as far as to say that "...the order of magnitude of the *additional* social returns provides a prima facie case for a generous policy in making public funds available to support investment in R&D, even when the marginal expected rate of private return is low". (Schonfield, 1981: 9-10) The market failure argument is as strong today as when it was first stated: in a recent European Commission policy document, "Investing in research: an action plan for Europe", it is clearly said that "Public support (for R&D) is justified by the recognized failure of the market to induce business investment in research at an optimal level" (Commission of the European Communities, 2003: 19).

Arrow's analysis included the argument that even if the process of knowledge production implied a cost for the firms involved in such type of activities, the cost of transferring that knowledge was negligible, that is diffusion was not a main issue of concern. In this sense, both Vannevar Bush's and Arrow's insights contributed to the dominance of the idea of a "linear model of innovation" — innovation started with basic research and the *transfer of knowledge* from the stage of basic research to the stage of applied research and further on — was smooth and essentially without costs, even if it is also acknowledged that the main cost of R&D goes to D rather than to R. Evolutionary theories of economic change, as well as detailed empirical studies on innovation processes, showed a far more complicated picture.

First of all, knowledge cannot be equated with blueprints: "Rather than a page from a book of blueprints, a new technology is a complex mix of codified data and poorly defined 'know-how'" (Mowery and Rosenberg, 1994: 7). This view is expanded in the classic work of Nelson and Winter (1982: 201): "Exploration of technologies that have not been used before involves in an essential way the characteristics of 'innovation'...". This means that using knowledge for solving one's problems is, in general, a difficult and uncertain process that cannot be successfully achieved only by access to that knowledge, be it disembodied or embodied in machines and artifacts. "The ability to adopt a new technology, to evaluate a new technique, or even to pose a feasible research problem to an external research group may require substantial technical expertise within the firm" (Mowery and Rosenberg, 1994: 8).

This is a key finding, which led the way to a wealth of reflections on the thorny issue of capabilities. It is worth, then, to have some characterization of the concept that will be useful to address our main concerns.

"To be capable of something is to have a generally reliable capacity to bring that thing about as a result of intended action. Capabilities fill the gap between intention and outcome, and they fill it in such a way that the outcome bears a definite resemblance to what was intended" (Dosi, Nelson, Winter, 2002: 2). Moreover, "Dynamic capabilities are the ability to reconfigure, redirect, transform and appropriately shape and integrate existing core competencies with external resources and strategic and complementary assets to meet the challenge of a time-pressured, rapidly changing Schumpeterian world of competition and imitation" (Teece, Pisano, Shuen, 1997: 339). Managing information is a fundamental part of the deployment of capabilities. However, as Eric von Hippel (1999: 61) has suggested, information is "sticky"[iv], and "...information stickiness involves not only attributes of the information itself, but attributes of and choices made by information seekers and information providers."

Regarding the attributes of information itself a main issue relates to the underlying knowledge embodied in it and how explicit it can be made. As forcefully put forwards in all the "neo-Schumpeterian" literature on innovation, the tacitness of many aspects of knowledge adds to the stickiness of information.[v] The attributes of people and organizations searching for cognitive inputs to perform tasks, including information, relate to the concept of capabilities, intimately intertwined with a paramount issue associated with science, technology and innovation: the issue of learning.

How learning takes place has been analyzed from many perspectives — learning by doing, by searching, by interacting, by solving. A main point to be stressed here is that, in the experience of the North, the issue of learning has received great and detailed attention. In particular, the relationship between learning and innovative capacities has been thoroughly scrutinized, giving rise to some influential conceptualizations, like that of "absorptive capacities" (Cohen and Levinthal, 1990)[vi]. These authors are particularly emphatic about the importance of the knowledge base mastered by individuals and organizations in innovation or problem-solving processes: "...diversity of knowledge plays an important role. In a setting where there is uncertainty about the knowledge domains from which potentially useful information may emerge, a diverse background provides a more robust basis for learning because it increases the prospect that incoming information will relate to what is already known. In addition to strengthening assimilative powers, knowledge diversity also facilitates the innovative process by enabling the individual to make novel associations and linkages." (Ibid: 130)

The importance of learning has in recent times been highlighted not only for individual firms but for societies as a whole (Lundvall and Borras, 1997; Archibugi and Lundvall, 2002). In this sense, the concept of a learning economy has been put forward: "A learning economy is one in which the ability to attain new competencies is crucial to the performance of individuals, firms, regions and countries" (Lundvall, 2002: 101); their success "will, more than anything else, reflect their capability to learn" (Ibid: 4).

Most economies and societies in the North can be conceptualized as "learning" economies and societies, but this is far from true in the South. However, there is no single reason to consider less important the development of capabilities and learning in the South than in the North, because all the theoretical and empirical findings that stress its importance are valid for both. The problem of capabilities and learning as posed in the South needs to be specifically addressed, though, because it presents particular features and difficulties.

(I.b) The South and the relevance of capabilities

"The key challenge facing developing countries today is to meet intense global competitive pressures while avoiding the 'low road' of reducing wages, devaluating exchange rates, and disregarding labor or environment regulators, each incompatible with sustained growth." (UNIDO 2003: 1) Nevertheless, in practice, many of them accept that they are not able or do not know how to improve their STI capabilities. "Most developing countries continue to languish at the bottom of the technological ladder" (UNIDO 2003: 1).

It is also the case that some developing countries assume that an effort in that realm is not really necessary, because it is being done by others and the corresponding benefits can be "imported" in some way or another. But: "Among the drivers of technological performance, R&D is statistically the most important, in both 1985 and 1998 and over time. This finding highlights the need for domestic technological effort even at a low level of industrial development. [...] The capability-building literature shows that technological effort (formal and informal) is as critical a driver of competitive industrial performance in developing countries as it is in industrialized countries." (UNIDO 2003: 70)

As is shown by the main theoretical contributions concerning absorptive capacities and tacit knowledge, the capabilities needed are much stronger and wider than those usually seen as sufficient for adapting knowledge generated elsewhere. "...The import of technologies is very far from the costless diffusion of perfect information assumed in pure versions of neo-classical economic theory. Technologies cannot be taken 'off the shelf' and simply put into use anywhere. Without infra-structural investments in education, training, R&D, and other scientific and technological activities, very little can be accomplished by way of assimilation of imported technologies" (Freeman, 2002: 156). In the same vein goes the following reflection: "Structural improvement in the industrial competitiveness of developing countries requires more than passive adoption of new technologies generated elsewhere. Using a new technology efficiently usually requires a firm to gather considerable know-how about its underlying scientific and engineering principles. New knowledge is also needed to make adaptations, which are frequently needed in a environment which differs in many ways from the setting in which the technology was developed initially. Such technological capabilities cannot be transferred quickly and without cost along with equipment, blueprints and user manuals. It has to be built up through purposive 'technological efforts': investment in time and resources aimed at assimilating, adapting and improving known technologies, and (ultimately) creating new technologies in-house" (Caniëls and Romijn, 2004: 39)

Investing in capability-building implies that learning processes are seen as a central issue for innovation and development. Focusing on learning implies paying special attention to "change-generating" activities (Patel and Pavitt, 1994); these authors assert that differences among countries in the resources devoted to the promotion of this kind of activities explain a good deal of international differences in economic performance. We would add that they explain a good deal of differences in levels of development as well. Learning is an interactive process: the absorptive capacity of firms are critically dependent on the way the internal world of the firm interacts with the NSI in which it is embedded.

The relevance of learning and skills emerges directly from the UNIDO scoreboard: "Most of the top 20 economies are industrialized, but there are notable exceptions. The Republic of Korea led the world in skills in both years [1885 and 1998] because its high tertiary enrollments and high share of technical skills in the population. [...] Finland moved up in the skill ranking between 1985 and 1998, displacing the United States of America in second place." In skills Taiwan Province of China was ranked eighth in 1998. In R&D spending per capita in 1998 the Republic of Korea was 13th, Singapore 14th and Taiwan Province of China 20th. (UNIDO 2003: 59)

Recapitulation of section I

Why is public investment in STI necessary in developing countries?

Such investment has been fundamental in every known historical process of upgrading productive levels and living conditions. Such investment is still fundamental in advanced industrial countries. There, in spite of having well-developed markets and important amounts of private investment in STI, it is seen that private returns to innovation are lower than social returns. Consequently, the lack of public investment would mean under-investment and, in turn, a threat to economic competitiveness and social standards. Governments in the North simply don't take such risks; they invest heavily in STI.

Developing countries that are not able to upgrade the STI contents of their production of goods and services will not be able, either, to increase wages, reduce unemployment and informal labor, or protect the environment. The intertwined processes of diminishing competitiveness and deteriorating social standards will shape their future. Upgrading STI levels requires adapting and generating knowledge; both activities are needed; both, and not only the second one, require a permanent expansion of learning and endogenous capabilities. In fact, such activities can't be separated, because adapting knowledge is very difficult without generating knowledge, and conversely.

In developing countries, private investment in STI is usually very weak; it is hampered by uncertainties and difficulties that are greater than in the North. Its level and scope is much below the necessary and desirable level; it must be enhanced, but it can only be enhanced with the help of strong public investment. Private returns to STI investment depend on the expansion of the absorptive capacity of firms, which in turn are critically dependent on their interactions with the innovation system as a whole and on the strength of other components of the system. Fostering interactions and ensuring that basic potential actors are actually present requires *public action*.

Now, if public investment in STI is absolutely necessary in developing countries, it is obviously not sufficient just to upgrade STI capabilities. Answering *why* it is needed gives some clues concerning *for what* and *how*, that is, orientations and implementations which may ensure that public efforts in STI learning and capability-building are successful. To such issues we turn our attention in the next sections, emphasizing two conclusions of the previous discussion: (i) public investment in STI should aim to enhance "developmental" systems of innovation, and (ii) the guiding thread could be the concept of learning. The latter means that the different aspects of NSI, the concrete policy instruments and the evaluation of results should be discussed in connection with the experiences of different actors acquiring – or failing to acquire — new learning capabilities.

II. Investing: for what and how

(II.a) On the Latin American experience

In Latin America public investment to foster science, technology and innovation has been backed by the Inter-American Development Bank (IADB) by means of its special loans for science and technology, which have been received on several occasions by many countries in the region. The organizations through which such investments are channeled include those with very precise aims — typically the Institutes for Agrarian Research[vii] — and others whose mandate is to foster the production and use of knowledge across a wide range of actors and technologies, typically the national research councils. These councils vary significantly from country to country in their institutional setting, their national budgetary endowment and their operational range; however, all of them include as main goals the improvement of the country's economic behavior and the national competitive position, with its sequels of better jobs and other welcome social outcomes, by means of STI.

Two extremely different examples are the national councils in Brazil and Uruguay. The former, CNPq, was envisaged quite early in the 20th century, as part of a "desarrollista" project. It belonged to the Planning Secretariat until the Brazilian government decided to create a Ministry of Science and Technology, within which it was incorporated. Its endowment is quite substantial and its mandate is federal. Its actions add to efforts in S&T at the level of the states. In the State of São Paulo, its Foundation for the Advancement of Research (FAPESP) has an important income guaranteed by law; it is considered one of the strongest R&D financing agencies of the world. The CNPq is a main source of financing for basic research, for postgraduate studies — the main goal of Brazilian higher education efforts — and for a great diversity of endeavors related to fostering R&D in firms and university-industry linkages. Its "clients" include individual researchers, research groups and main Brazilian research institutions, as well as firms, individually and in associations.

It is difficult to establish the causal relationships between the legitimacy CNPq enjoys and the fact that Brazil is the Latin American country that shows the best performance in many indicators related to science and technology. Is the country's performance the reason why CNPq can be an efficient partner in STI, or it is because it is a strong and well-endowed institution, financially as well as in human resources, that it has been able to play an important role in linking knowledge production and economic performance? Surely there is some truth in both ways of looking into the issue.[viii]

Uruguay shows a striking contrast to Brazil. Its National Council for Science and Technology was almost without any own endowment since its beginnings, and it is institutionally attached to a ministry without any relation to production or the economy at large — the Ministry of Education and Culture. Poor in resources, both financial and human, the council developed some activities when the IADB granted the country two S&T loans. Some money was reserved for innovative activities in firms, but the money went under-used due to lack of demand for the program. In part this resulted from bad policy design — innovative entrepreneurs found the grant applications too cumbersome and with few advantages in relation to commercial loans — but the weak demand from business enterprises for innovation support was also an important reason. No pro-active policy of the "technological extension" type was developed, and so SMEs, that account for more than 95% of all productive units, continue to be orphans in technological terms, squeezed between their intertwined twofold lack of capabilities — to solve problems inside the firms, and to search for technological support elsewhere.[ix] Another characteristic of the council, derived from the fact that the only important funds it administers come from external loans with tight requirements, is that support is not available for some areas, such as the social sciences — including economics — and the humanities. Most other Latin American Councils cover a broader disciplinary scope.

The Chilean case is interesting because the National Council for Science and Technology belongs institutionally to the Ministry of Economy. On a smaller scale than Brazil, it shows the same degree of diversification of its programs, several of which are devoted to fostering innovation in firms. Chile is one of the first countries in the region to have conducted a national innovation survey, in 1995, based in great part on the OECD Oslo Manual. One of the aims of the survey was precisely to monitor the outcomes of public spending in S&T; more precisely, to find out if the innovative efforts of business enterprises were adding to or substituting for public money. A successful example of scientific and technological research involved in the achievement of important economic outputs, like salmon production, was supported all the way long by different programs of the council.[x]

In the Venezuelan case, the council belongs to the Ministry of Science and Technology and is not too badly endowed. An interesting exercise was made some years ago, trying to link research agendas to national priorities. Five great problems were defined, including social ones like urban violence, and a call for projects directed to foster the search for solutions was issued. "The agenda process was designed as an instrument to connect research, knowledge and technology to the needs and opportunities of society. Its methodology should be understood as an interactive public policy based on the coordination of various social agents around common problems supported by the legitimacy and autonomy of diverse participants interests, and oriented towards positive negotiation approaches" (Avalos and Rengifo, 2003:188). It was not, however, an easy process. As these same authors stated, "...conflicts with existing stereotypes, hierarchies, and authorities in diverse social spaces were unavoidable" (Ibid: 191).

The Colombian council, named COLCIENCIAS, is an important institution at national level with a wide mandate, belonging to the Planning Secretariat; innovation as a tool for the competitiveness of Colombian firms is explicitly stated as a main goal. It seems, though, as in many other cases, that public expenditures are more avidly sought by the relatively strong academic realm than by the relatively weak innovative part of the business world.

In general terms, the role of the national councils for science and technology, that were instituted mainly forty or fifty years ago, has been changing in Latin America. Their first aim was to give support to an emergent scientific community, concentrated in public universities with very tight budgets, and therefore needing external financing sources to cope with all type of demands, from laboratory infrastructure to international mobility. In the last twenty years the focus shifted sharply towards analyzing the use of the knowledge produced in the academic realm — not only fostering its production but asking if it was being correctly diffused: if it was of use for different actors, particularly business firms; and if it was being directed towards broad priorities at national, regional or local level. A main concern emerged with competitiveness and with the ability to articulate knowledge production and knowledge use, and consequently new types of programs enriched the councils' strategies. In this sense, Latin America follows a worldwide trend.

However, even if many of the arguments used in the region to legitimize the public budgetary allocation to these councils, and to S&T in general, have a strong resemblance with those utilized in developed countries — mainly the role of knowledge in economic growth and social welfare — contextual and cultural factors make these legitimizing arguments weaker and less operational. We briefly review some of those factors.

The fundamental role of basic science, as a source of knowledge and ideas and, equally important, as an intellectual tool in the training process of creative applied scientists and engineers, has never been totally accepted in Latin American countries. Nobody has argued that basic science does not deserve to be cultivated, and lip service to its importance has never failed to be present. But in some way, the frustration with the weakness of innovation and with the difficulties to build prosperity upon research have led to blaming basic science with the argument that it exhausts all the available resources for S&T.[xi] Scientists are often depicted as an aggressive and self-referenced resource-seeking community. The applied-knowledge community and the clusters of innovative firms, on the other hand, are consequently seen as unfairly under-funded. This sterile dichotomy led to ill-conceived policies and recurrent conflicts.[xii]

The former point is connected with the issue of the absolute size of investments in S&T, which has been historically very low in Latin America. In fact, setting aside Brazil, which a few years ago reached the threshold of 1% of GDP invested in R&D, the majority of countries average 0.5% of national GDP, in sharp contrast with the OECD countries and some newly industrialized countries like Taiwan Province of China and Singapore. When absolute spending in R&D is low, there is a natural tendency to concentrate on basic science, because it is "cheaper" than applied science and, even more so, than technological development. This is why small developed countries and some developing countries make a disproportionately high contribution to the world's basic science in relation to their population or to their local R&D effort. (Walsh, 1988: 44) Increases in public investment in R&D as a proportion of GDP have been announced several times by different Latin American governments, but scant progress can be seen in the more recent figures. On the contrary, some countries have even reduced their national effort in this respect. The contrast with the developed countries could not be more striking. In Europe, for instance, the Barcelona European Council of 2002 put forward the goal of attaining 3% of GDP in R&D by 2010, two-thirds of which was expected to be expended by the private sector. The arguments for that aim were reinforced a year later: "Given the current economic downturn, it is all the more important to ensure that budgetary policies favor instruments that will lead to higher sustainable growth in the future, among which research is a strong priority" (Commission of European Communities, 2003: 4). Furthermore, "...the Commission has repeatedly made the case for refocusing public spending towards more productive investments, notably in support of research and innovation, since they are conducive to higher growth in the future" (Ibid: 18).

When stated priorities are not backed by facts, it is reasonably to think that such priorities are not so strong: the gap between discourses and budgetary efforts in science, technology and innovation in Latin America suggests that this is the case. This can explain also the difficulties encountered in trying to build a bureaucracy well-trained and skilled in R&D, able to develop the complex set of policies that are needed to make the best of the invested funds.

Perhaps the most important explanations for the lack of real legitimacy that R&D policies enjoy in Latin America are to be found in the main trends present in the productive sectors, and in key related features, like educational structures and labor relationships. Recent research on the transformation of Latin American productive structure (Katz, 2000) underlines the fact that it is technologically less inward-oriented than in the past, due to a combination of factors that include the massive privatization-"foreignization" of public enterprises and the economic importance acquired by *maquila* processes in Central America and Mexico, and by natural resource-based commodities in South America, both with rather low local intellectual value-added. There are important exceptions to these trends, namely national firms, public and private, that make intensive use of knowledge are remarkably innovative and well-inserted in international markets: the Brazilian firm Embraer is among the most outstanding. But the broader trends point in a totally different direction. One of the most striking indicators of the present situation is the weak demand for trained researchers employed by firms: while in the United States 70% of researchers work for business firms, for instance, the figure for Argentina is 11.3%, for Chile 5.9%, for Colombia 4.1%, for Mexico 10.3%. The only Latin American country were business firms employ almost a third of all researchers (31.1%) is Brazil (RICyT, 2002). A second indicator is the low contribution of Latin American firms' R&D to total investment in R&D. With the exception of Brazil, where the figure is near 40%, in the rest of the countries the participation of firms in total R&D is very low. In Argentina and Chile, the figures are slightly over 20% (ibid). Taken together, these two indicators help to explain the weak interactions between industry and knowledge-producing institutions, which hampers the further technological improvement of industry.[xiii] Summing up: science, technology and innovation need to play a growing role in the industrial development of Latin American countries if they are to be able to attain growth through the enhancement of non-spurious [???] economic competitiveness. Public investment is crucial to that aim, for the same reasons that it is so elsewhere. A variety of reasons explain the difficulties encountered up to now in trying to foster STI and to put them efficiently to use for productive enhancement; a major one is the weak public investment in STI and the extremely weak investment of the private sector. So, to start with, a decisive thrust of public investment in STI is necessary. However, it is not sufficient. Public investment is STI must be channeled through efficient policies, aimed at redressing structural weaknesses that hamper its effective use. This leads to the fundamental question of how to invest in STI in ways that take into account the specific traits of each context.

(II.b) Some policy building-blocks

Several developing countries have more or less recently been trying to do the same as developed countries because "that is the good thing". They do indeed need to foster their NSI, but not necessarily in the same way as developed countries. In underdeveloped economies, capabilities are often weak and scarce; *infant capabilities* need specific support in order to be able to grow.

Capabilities expand by using them: *opportunities* are needed to use available capabilities and knowledge, thus learning by solving problems in creative ways. As Hirschman taught long ago, in developing countries capabilities are often hidden and wasted; a cause of that is the absence of a high-level demand for endogenous capabilities.

Using knowledge, learning and innovating are interactive processes; it cannot be assumed that they take place automatically, particularly in contexts where innovation has been historically scarce and knowledge demand has been essentially oriented to foreign countries, even in cases when that is neither the most efficient nor the cheapest solution.

The above assertions are both elementary and basic, because they shape the problem of *for what* and *how* to invest in STI in the South. Tentative answers are given by the following "building-blocks" of a policy for capability-building in developing countries. They arise directly from the previous discussion about why to invest in STI.

First building-block

CAPABILITIES

Strengthening learning possibilities

Learning capabilities include knowledge and technological capabilities. The latter are described by Bell and Pavitt (1997: 84) as a stock of resources including "the skills, knowledge and institutions that make up a country's capacity to generate and manage change in the industrial technology it uses".

Fostering knowledge and technological capabilities includes many activities: promoting an active approach to science and technology in the first levels of education; improving the level of primary and secondary teachers, by offering them possibilities to study and permanently recycle in creative research contexts; upgrading and dignifying technical activities; offering people with technical skills permanent and diversified ways of accessing studies at tertiary level; expanding both graduate and postgraduate enrollment. Summing up, a fundamental aim of STI policies is to pay increasing attention to the quality of education in general and to find ways towards the generalization of permanent advanced education, closely connected with working activities.

Advanced learning can't be separated from knowledge generation. Endogenous knowledge generation is a must also because of cultural motives, because it is needed to address specific problems and because without endogenous capabilities for knowledge generation, the benefits flowing from knowledge acquisition and transfer from abroad are often much below their possibilities. Thus, strengthening capabilities includes backing "research universities", seen in the South as institutions committed to three intertwined missions: teaching, research and cooperating with development; such institutions deserve to be called "developmental universities".

Second building-block

OPPORTUNITIES

Enhancing knowledge demand

Education is of paramount importance, but more has to be taken into account, since "problem solving and learning capabilities are so similar that there is little reason to differentiate their modes of development" (Cohen and Levinthal, 1990: 130). To enhance learning, opportunities are needed to use and expand knowledge and technological capabilities by applying them creatively to problem-solving. People that possess knowledge — basic knowledge, science-based technological knowledge, practical technological knowledge — must be able to apply what they know to problem-solving activities. In underdeveloped economies, there is a big gap between capabilities and opportunities. This is not so in developed countries, where the opportunities to apply knowledge are so great that they cannot be fulfilled with the knowledgeable people at hand, this being the reason why policies are set to attract researchers and engineers from all over the world, particularly from developing countries.

Opportunities for applying the required knowledge to concrete problems depend on the strengths of the knowledge demand exerted upon national capabilities. This has inspired many policy settings. "In the Nordic welfare states an important and increasing part of the international export specialization successes within high-tech products and services can be traced back to areas where the welfare state plays an active and sometimes determining role either as user or as regulator. This holds for hospital equipment and measuring instruments, transportation and traffic regulation systems, administrative information systems, telecommunication products and other good consumed collectively" (Gregersen, 1988: 262). In the case of the Republic of Korea, the import-substitution policy for electronics was set in 1976, when the country had the same per capita income as Guatemala: the measures introduced included a strong mobilization of learning capabilities, both through direct measures like building research and production facilities, and indirect ones like protecting the domestic market from foreign competition (Amsden, 1989: 82). From the point of view of knowledge, this type of policies acted as demand policies, fostering the deployment and enhancement of learning capabilities: "During these decades (1960s and 1970s), industrial policy measures, which brought about the demand side of technology by creating the needs for it, were much more effective in expediting technological learning at the firm level than science and technology policy measures (except for education)..." (Kim, 1997: 194). In other cases, like Japan or the Basque country, in Spain, policies were directed to strengthen the demand for knowledge through measures that fostered the user-producer relationship between private enterprises.

The mismatch between existing capabilities and their use for productive purposes is a very well-known phenomenon in developing countries, and it appears also to have been the case in rather small industrialized countries. In both cases, lack of sufficient demand is a main explanatory cause. This lack of demand implies that few resources are directed to solve sophisticated technological problems, which explains the relative isolation of researchers from the productive milieu and the bias of the research agenda towards basic science and the international scientific community. The following statement, even if not intended to give account of the situation in developing countries, is pretty accurate in relation to them: "This turning towards the international community takes place at the expense of developing an ability to develop, orient, apply and diffuse science and technology towards the solution of problems and meeting the needs within their countries" (Walsh, 1988: 44). Thus, the knowledge demand influences important trends in terms of learning and capability-building, from the stimulus of concrete innovations to the setting of the research agenda.

Third building-block

LINKAGES

Promoting articulations between innovation actors, especially knowledge linkages and innovative circuits

Linkages is perhaps the most important single expression in connection with NSIs. An idea that foresaw the concept of NSIs, proposed by the Argentine Jorge Sábato in 1968, stated that knowledge would be put to work for development purposes once the three vertices of a triangle — government, industry and universities — were strongly interconnected. The interesting point was that Sábato insisted that more important than the strength of each vertex was the strength of the linkages between them. B.A. Lundvall developed a full-fledged conceptualization of NSIs with user-producer knowledge and innovation relationships at its center. Once the idea of markets alone providing the environment for a strong innovative behavior is discarded, the role of interaction between actors becomes a key factor not only for satisfactory innovations, but to innovativeness tout court.

From another point of view, von Hippel (1999: 118) stated that too much emphasis had been placed on innovators-as-manufacturers, while many other roles lead to innovative behavior. To truly understand innovation dynamics, a better approach is to look at it as a socially distributed system, where several actors — particularly users, but also policymakers — intervene. This approach helps to highlight the strategic importance of linkages between those actors. Now, linkages are established not just between actors that *want to do it* but between actors that are also *capable of doing it*. The importance of accumulating such capabilities has been explicitly recognized in the literature: "Over longer periods, the intensity with which (...) change-related resources are accumulated and applied will influence other variables, such as the strength of backwards and forwards linkages to suppliers and customers..." (Bell and Pavitt, 1997: 88).

A relevant example of linkages is given by *innovative circuits*, which are started when an actor with a problem meets another actor with knowledge that can help find the solution to that problem; the solution can be found if the circuit works, that is, if both actors are able to communicate and combine what each knows.

In underdeveloped countries, knowledge linkages are structurally weak, and many attempts to foster them, for instance between universities and firms, failed precisely because little attention was paid to the conditions that allow relationships to be developed between the concerned actors. In particular, potential innovative circuits should be detected and stimulated; emerging innovative circuits should be protected. Such circuits are main micro level components of innovation systems.

Fourth building-block

CITIZENSHIP

Fostering wide STI consensus between citizens, concerning aims and roles of STI in national development

NSIs, as well as innovations, develop in a cultural milieu. Porter (1990) has forcefully explained how long-term cultural biases influence the direction of technical change by highlighting features that people value. In a perhaps more diffused way, but by no means less influential, what people think about science and technology sets the scenery where different efforts towards innovation take place. Several key attitudes can be traced back to public perception on science and technology. The willingness of the youth to pursue scientific and technical careers, the importance attributed by businessmen to hiring highly competent personnel, the drive of young professionals towards starting their own knowledge based firms, are a few examples of such attitudes.

At a more aggregate level, a society's self-confidence regarding science and technology is an important driver of achievement in this area. It is hard to imagine Japan's high drive to replace every imaginable piece of western hardware by Japanese production, without the widespread conviction that they were able to do it. Conversely, the inability to rely on their own scientific and technological capabilities that many underdeveloped countries exhibit issues in part from the lack of awareness that those capabilities really exist.

Public perception of science and technology is also related to social cohesion. Given the importance of such issues to everyday life, people may have pro-active or reactive attitudes towards them depending on their perception of being taken on board when important decisions are made. An example of building pro-active attitudes is given by Denmark: "Denmark has developed institutions that systematically and constructively assess technological developments and their impact on everyday life. The Danish Council of Technology and the consensus conferences it organizes have a more central position in Denmark as a forum for instigating debate than corresponding institutions in other countries. Consensus conferences bring together panels of ordinary citizens with experts and the outcome is well reported in the press and used as input for parliament when it designs new regulations and laws" (Lundvall, 2002: 26).

Thus, this building-block points to getting many people involved in decisions about STI orientations, acknowledging their preferences and ensuring that people know that such is the way things happen — so on the one hand STI will be more socially driven and on the other hand the citizenry will be better disposed to back STI investment.

Fifth building-block

ANTICIPATION

Taking into account the prospective dimension, in order to prepare today ways to cope with the fundamental issues of tomorrow

The way leaders, and sometimes people at large, foresee the future, has important consequences for what is done — or not done — in the present regarding science, technology and innovation. The future vision of the Information Society was very early taken as a focusing device for contemporary actions in Japan; the failure to recognize the importance of science-based engineering and the training of professional engineers is one of the reasons provided by historians, like Landes or Hobsbawm, to explain the decline of the UK's industrial dynamism, a mistake avoided by Germany first and by the US later on (Freeman, 1992).

One of the reasons of the weakness of NSIs in developing countries relates to this dimension. The lack of a prospective culture usually leads to not preparing the ground for what will come to be mandatory technologies, leaving no alternative but to import them, off the shelf, when the needs become pressing. This trend, reiterated once and again, has weakened the development of endogenous capabilities and reinforced the lagging technological position of these countries.

Signals from trends not yet fully developed but nevertheless visible derive from several sources. Some are related to the development of new technologies, the new avenues that they open and also the avenues that they close. Other signals come from more purposive social events, related to regulations, standards and other commercial related issues. Prospective trends regarding the changes of fundamental variables, like the availability of natural resources, environmental patterns or demographic evolution also count as signals that influence the directions of science, technology and innovation. Following those signals, new ways for professional specialization can be opened, new research facilities can be provided, new institutional arrangements can be set and new investments can be made. In fact, many features of contemporary NSIs are related to the recognition of those signals.

Prospective exercises are made by many actors. Thus, promoting prospective activities is closely connected with two building-blocks already described, linkages and collective attitudes.

Sixth building block

SPECIALIZATION

Promoting studies, agreements and actions that shape an efficient long-term productive profile in selected areas

Specialization is very important for medium-sized and, especially, small developing countries, where main efforts must be concentrated in potentially rewarding sectors. Successful specialization characterizes recent examples of overcoming a peripheral condition. It does not necessarily mean specializing in high-tech sectors; in most cases the best choice will be different, probably based on using advanced technology and capabilities for upgrading traditional sectors, transforming comparative advantages into competitive advantages. In such sectors there is frequently a treasure of productive and commercial experience that should be enhanced by its combination with research, development, design, marketing, etc.

In this connection, it may be stressed that bio-innovation — that is, innovation based on life sciences — offers new possibilities. Biological research is comparatively strong in many developing countries, particularly in Latin America, where production is based on natural resources and can be upgraded to fully fledged agroindustrial chains (Arocena and Sutz, 2005). For example, the production of wood as a commodity, with potential risks for environment, can be upgraded by combining genetic, ecology, preservation of natural vegetation, differentiation of production, advanced engineering, furniture design, etc.

In fact, bio-innovation appears as a new generic set of technologies, with a very wide and relevant scope of applications, that will surely expand in the next years. This is an opportunity that calls for public action in order to have the necessary R&D, to incubate high-tech firms related to the specialization profiles, to anticipate the evolution of the corresponding sectors.

(II.c) Building-blocks and policy instruments

How to invest in STI capability-building can be illustrated by means of the following table, where examples of concrete policy instruments are associated to each building block. Now, "how" to invest can't be separated from "how much" nor from the actual conditions that shape what investment can obtain. To these two issues we turn our attention in the next section, where some policy instruments are discussed.

Table
Building-blocks of an STI policy and examples of instruments for each block

Capabilities *Strengthening learning possibilities*	***Opportunities*** *Enhancing knowledge demands*	***Linkages*** *Promoting articulations*	***Citizenship*** *Fostering STI involvements and consensus*	***Anticipation*** *The prospective dimension*	***Specialization*** *Selected productive areas*
Fellowships for undergraduate students	STI in social emergency programs	Promotion of innovative circuits	Interactive and mobile S&T museums	Center of STI foresight for development	Special R&D Institutes
National postgraduate programs	Knowledge demand of the public sphere	Joint academy-production projects	Divulging national STI achievements	Technological foresight of public demand	Resources and international cooperation
"Sandwich" postgraduate studies	Technological public procurement	Projects with national high-tech firms	STI civil service of students	Foresight exercises with multiple actors	Technical support
Graduates and postgraduates follow-up	Technological court of appeal	Technological "windows" in R&D centers	STI journalism	Wide public diffusion of foresight results	Technological public demand
Mobility programs	Technological awareness among SME	Advice for small firms and trade unions	Office of STI assessment for Parliament		Public financing of innovation

Capabilities	*Opportunities*	*Linkages*	*Citizenship*	*Anticipation*	*Specialization*
Strengthening learning possibilities	*Enhancing knowledge demands*	*Promoting articulations*	*Fostering STI involvements and consensus*	*The prospective dimension*	*Selected productive areas*
Connections with the S&T diaspora	Support for firms hiring STI personnel	Stages of advanced students	People's perceptions of S&T		Incubators in selected areas
Supporting research groups	STI extension		Citizen's participation in STI decisions		Divulging and foresight tasks
Registering and certifying high-tech SME	Financing innovation in firms				
Scientific and technological infrastructure	Loans for innovative initiatives				
Betterment of S&T general education	Public support for seed and risk capital				
	Incubators for knowledge intensive firms				

Recapitulation of section II

STI issues have not been forgotten in developing countries but they have usually been neglected. Nevertheless, the situation is far from uniform, even when only one region of the "South" is considered, for example Latin America, where important achievements can be mentioned. Notwithstanding that, the global picture is characterized by low investment, actions than on average are far short of official announcements, and lack of continuity. As a consequence, the results of STI investment are not impressive. Such and outcome is also heavily influenced by a more structural feature, the weak demand of endogenous knowledge from the productive sector, a lasting trend of Latin American history that has somehow been deepened by the recent economic changes. It follows that STI investment will not be a disappointing effort only if it is characterized by continuity in the long run, by clearly stated aims and by specifically designed policy instruments. Many success stories, even if partial, suggest that much can be obtained by such an effort.

In this section, six "building-blocks" for STI policies have been discussed; they are closely connected, and positive feedbacks between them should be expected, if none is neglected. Their aims are: (i) fostering knowledge generation and learning capabilities in society at large; (ii) enhancing opportunities for interactive problem-solving, that is, for innovating in a wide sense; (iii) articulating linkages and interactions in general between the different actors that are potentially related to the socially justified use of knowledge; (iv) promoting public perceptions of science and technology that favor participation in related decisions, attention to social priorities, confidence in national capabilities and wide consensus on STI efforts; (v) systematizing prospective activities, particularly by means of technological and social foresight exercises that involve different actors; (vi) carefully shaping a productive specialization profile by upgrading capabilities rooted in natural endowments, national traditions, accumulated experiences, examples of successful innovations and new possibilities opened by international changes and new technologies.

Many ways for working with such aims are well known from international comparative studies. As an example, this section includes a matrix of building-blocks and related policy instruments.

III. Evaluating amounts and results of investing

(III.a) A tentative estimation of costs in the case of Uruguay[xiv]

CAPABILITIES

Strengthening learning possibilities

(i) *Fellowships to allow full-time studies in science and technology for undergraduate students*

In Uruguay, around two-thirds of the research is done in the public University of the Republic, which is also the academic institution where the vast majority of university students of the country train for their careers. According to its last student census of 1999, 62% of its students came from public high schools. Not surprisingly then, 60% of them work at the same time as they study. Given that this work is seldom related to their academic or professional interests, the need to work is a main cause of late exit: for the university as a whole, the number of students enrolled in 1997 totaled 11,482, while the number of students that graduated in 2002 was 2,983, a bare 25%. There is in place a system of fellowships aimed at supporting students in a very low economic situation and who could have not attained tertiary studies otherwise; those students are mainly not from the capital, Montevideo, where almost all university facilities are located. However, a specific line of fellowships, aimed at allowing full-time dedication, can be a tool to ensure that a group of young bright people obtain their science and technology degrees fairly quickly.

Some 6,300 students began science and technology studies in the University of the Republic during the last three years. If we want to include 10% of them in this fellowship program and we equate a fellowship with a part-time first teaching degree, the cost of the instrument would be around US$ 1,200,000 a year.

(ii) *Support for national postgraduate programs on science and engineering*

Uruguay has an important experience in supporting the re-birth of a scientific community, the basic science community, that almost disappeared during the dictatorship (1973-1984). The Program of Development of the Basic Sciences, mainly supported by international organizations like UNDP, was extraordinarily successful, in particular in fostering postgraduate studies. The thrust of fourth-level studies reached the country pretty late, even in comparison with other Latin American countries: actually only a few thousand students are enrolled in postgraduate national programs, of which science and technology barely account for 15%. Given that the part of basic sciences is already in place, it would be specially useful to develop technological programs, that, at first sight, could be endowed with an amount similar to what the basic sciences program had at its beginning for its postgraduate section, around US$ 500,000 a year.

(iii) *Fostering "sandwich" postgraduate studies*

Uruguay has a small research community and a incipient postgraduate system; this makes imperative for young researchers to go abroad to pursue fourth-level studies. Even if this need is not disputed, it must be acknowledged that it poses some problems. One of them is that students who work on the research agenda of a big and well-endowed laboratory in a developed country find great difficulties to re-integrate at home. Another is that sometimes the knowledge they acquire is objectively difficult to apply in the country. A way to foster high-level postgraduate studies abroad and, at the same time, foster the development of an "own" research agenda, is to have what has been called "sandwich" postgraduate programs. In such programs each student has two tutors, one in the developed country and one in its own university, and conducts the field work of his research in the country.

The instrument we are proposing to foster such programs allows for 50 students a year who are pursuing their postgraduate studies abroad to spend a year in Uruguay conducting their field research. The base to calculate the cost of this instrument is the salary of a full-time university teacher in the second level of the academic hierarchy, leading to a cost of US$ 425,000 a year.

(iv) *Graduate and postgraduate follow-up*

The follow-up of graduates and postgraduates can yield a particularly interesting type of information, namely, if the graduates from a professional, disciplinary or cognitive direction that is objectively important for a country's economic sector actually find employment opportunities in the business firms of that sector. If this is so, we can speak of "harmonic" NSIs, in the sense that one important condition for robust innovation processes is present. If this is not so, as is usually the case in developing countries, we can speak of "dissonant" NSIs. In fact, NSIs will probably not be consistently harmonic or totally dissonant, these categories best fitting individual productive sectors. However, as a proxy, they can give a quick qualitative image of the ability of the system to use the learning capabilities available; this ability is one the most significant strengths of a NSI.

This instrument presents two aspects, one related to information gathering and information organization, and the other related to making information available. To accomplish the first aspect, an up-to-date database on the present labor situation of graduates and postgraduates is needed. This requires collecting the needed information — a hard task over some time — and keeping the information updated afterwards. The first part of this task can be done by a specialized team, consisting of five students or young graduates, as part-timers in a first university position, and a senior computer specialist. Its cost, for two years, amounts to US$ 50,000. This should be done at a research university level, in the Uruguayan case at the University of the Republic. After the database is in place, it should be made available to several places within the state and, particularly, to business organizations. This aspect, as well as the updating of the database, can be absorbed by the university ordinary budget. The team responsible for the latter will also be in charge of providing information to any interested actor.

(v) *Mobility programs*

This type of programs helps local researchers to present papers in international congresses and to spend some time at centers of excellence abroad; they also enable inviting relevant specialists to conduct seminars and discuss research achievements in different university departments, public research institutes and other interested organizations. As a proxy, we take the annual cost of a university program directed to these aims and we propose an additional national effort of similar size: US$ 500,000 a year.

(vi) *Connections with the scientific and technological diaspora*

This instrument presents three aspects. The first is gathering information; the second one is organizing and diffusing information; the third aspect includes actions directed to systematically relate the scientific and technological diaspora to local research. Gathering and organizing information about the S&T diaspora will be a difficult and lengthy effort: we estimate that it will need the work of a specialized team for three years to have the instrument perfectly operative. This would cost US$ 75,000, calculating the same type of team as the one involved in the graduate and postgraduate follow-up. This professional task force should work within the Ministry of Foreign Affairs, and the results should be distributed among several public institutions, including the universities. After the database is in place, its management and updating should be the responsibility of a permanent team that can be absorbed by the regular budget of the ministry.

A special endowment should be assured to foster the mobility towards the country of scientists and engineers living abroad; the experience of the public university in managing programs for the mobility of human resources suggests the convenience to put this endowment under its responsibility. The proposal consists of 10 researchers spending their sabbatical years in the country, and 100 other researchers spending stages of two months per year, giving classes and seminars, supervising thesis, etc. Calculating that each researcher will receive a salary equivalent to the highest university academic position, and taking into account an average cost for travels, the cost of this instrument rounds US$ 500,000 each year.

(vii) *Supporting research groups*

To estimate the cost of supporting research groups we take as a proxy the information gathered in a recent research on that matter (Unidad Académica de CSIC, 2003). We start from the following proxy: 500 research groups, in all cognitive areas, at national level, 65% of which involved in experimental work. To allow research groups to mature and to be able to produce sound results, support must be spread over a reasonable period of time, and must provide what such groups need most: human resources and financial resources to assure appropriate working conditions. Some of them will additionally need resources for small and medium-range research infrastructure. The proposal is to make a call for five-year working programs directed to research groups. To calculate the amount of this part of the instrument we estimate that 60% of the groups will be supported, that is 300, of which 195 will need somewhat more resources than the others for experimental infrastructure. Every group will have the possibility of hiring two young full-time researchers: this amounts, for five years, to around US$ 5,800,000. The groups involved in experimental work will receive US$ 3,000 a year for working costs and a total endowment of US$ 50,000 for research infrastructure: this amounts to US$ 12,675,000. The remaining 105 groups will receive US$ 2,000 for working costs and a total endowment of US$ 20,000 for research infrastructure (including specialized bibliography); this amounts to 3,150,000. The total cost of this instrument over five years is US$ 21,625,000, which gives an annual amount of US$ 4,325,000.

It is important to have an accurate map of the national research groups, including all their research lines and a fair description of the kind of expertise they are able to provide: this is a main tool to articulate knowledge supply and demand. This exercise is similar to those already described for other instruments, but being simpler and shorter its cost can be absorbed by the regular budget of the public university, the institution where this exercise should be performed, taking responsibility also for the diffusion of the results obtained: a complete catalogue, available on line, of all the research groups of the country with related relevant information

(viii) *Registering and certifying knowledge-based and high-tech SMEs*

This instrument presents two aspects. The first one is aimed at identifying and registering; the second one at certifying the technical quality of these SMEs, as well as providing information about the kind of problems each firm can address and the main clients it has served so far. The first aspect implies the opening of a register to be filled by the interested SMEs: the cost of this part is a minor one, involving some software work. The main issue is to visit, evaluate and complete a file for each registered firm. This implies a six-month effort for 10 advanced students or young professionals, accompanied by two or three senior specialists in the main detected fields, probably electronics-software, biotechnology and fine chemicals. Some resources must be provided for the confection and wide diffusion of a "certified catalog" of the firms finally retained for their quality and experience. The cost of this instrument would be, for its first edition, around US$ 50,000. Its updating can be absorbed by the regular budget of the agency that takes responsibility for organizing it.

(ix) *General scientific and technological infrastructure*

This instrument is directed, in particular, to the improvement of the electronic connectivity of universities and to foster on-line access to bibliography. This is a key aspect of the enhancement of capabilities that should be provided on a centralized base, precisely to assure the greatest possible distributed use. Based on past experiences of this sort, a rough estimation of US$ 80,000 a year can assure that this aim is fulfilled, given the physical infrastructure and the human resources already in place.

(x) *Improvement of science and technology education in primary and secondary levels*

This is a big and difficult challenge, and not only for developing countries. A strong effort must be made in this direction, particularly devoted to primary and secondary teachers. This instrument includes the teaching part, that can be achieved mobilizing human resources without extra costs and the didactic experimental facilities. The latter can be imported; in fact this was done in Uruguay with very disappointing results, due both to lack of coordination and inadequacy of the facilities. So a project to support the local development of some didactic tools for the experimental teaching of science and technology can have the double effect of providing what is needed and fostering the emergence of a small specialized industry. The cost of a pilot project of this sort can be calculated as the salary of 5 young full-time science and technology specialists – equivalent to a full-time third teaching position at the university— during a year and allowing for tripling this amount for the development and implementation of the designs at operative prototype level. Following this proxy, the cost of the instrument would be US$ 215,000 each year.

Capabilities. *Strengthening learning possibilities*

Estimated cost of policy instruments during five years (in US$)

Instrument	*Cost each year*	*Additional costs*	*Total cost in 5 years*
* Fellowships for students	1,200,000		6,000,000
* Postgraduate programs	500,000		2,500,000
* "Sandwich" studies	425,000		2,125,000
* Follow-up studies		50,000	50,000
* Mobility programs	500,000		2,500,000
* Connection with diaspora	500,000	75,000	2,575,000
* Supporting research groups	4,325,000		21,625,000
* Surveying high-tech SME		50,000	50,000
* S&T infrastructure	80,000		400,000
* Betterment of *S&T education*	215,000		1,075,000
TOTAL	7,745,000	175,000	38,900,000

OPPORTUNITIES

Enhancing knowledge demand

(i) *STI teams in social emergency programs and related projects*

Social policies are among the most legitimized public policies in Latin America, especially so in Uruguay. This is due, precisely, to the backward movement experienced by almost all social indicators in the region, particularly the number of people living below the poverty line. As stated by the recently released report of the UN Millennium Development Goals' Task Force on Science, Technology and Innovation (UN, 2005), STI can—and must—contribute to the fight against poverty and social exclusion. This instrument is aimed at fostering the encounter between knowledge and those social-policy goals.

Two aspects must be covered to be able to detect and to start fulfilling the scientific and technological demand arising from social emergency programs: the detection of the demand, on the one hand, and the elaboration and financing of proposals able to achieve the detected goals on the other. This instrument is related to these two aspects. For the detection of demands and fostering the elaboration of projects aimed at solving them, three teams of four well-trained people working for six months will be needed, establishing close interaction with those charged with the implementation of the emergency plan. Each team would work in three of the most important realms of the plan, for instance, housing, nutrition and health. The cost of this aspect of the instrument, approximated by the salaries of full-time university teachers in the second and third levels is US$ 60,000. As a working hypothesis, based on past experiences, we expect that 50 important and worthwhile projects will be elaborated: estimating a cost of US$ 25,000 per project per year (over two years per project) we reach the figure of US$ 1,250,000 a year. To this must be added the cost of a thorough ex-ante and ex-post evaluation, in the order of US$ 10,000 for the ensemble of projects.

(ii) *Detecting the technological demand of the public sphere*

This is an overwhelmingly important instrument, that has no extra cost, because it must be done by permanent technical staff in several public institutions. To build such an instrument in a way that allows for a fair estimation of the amount and type of technological public demand, a common methodology must be developed. Moreover, to connect this demand effectively to the problem-solving capabilities at national level, some coordinating mechanisms must be developed. All this can be done by the internal forces already in place: this is an example of a key instrument that needs clarity of purpose and systematic effort but that does not need financial support to be put in place.

(iii) *Public procurement of technology*

This is an instrument widely used in developed countries as well as in newly industrialized countries. It must be used wisely, that is, avoiding vested industrial or lobby interests; it must be transparent, avoiding corruption practices. But it must be used, because in countries where productive sectors are technologically weak, the strongest knowledge-based demand comes from the public sphere. In fact, public procurement of technology can be conceptualized as one of the strongest manifestations of innovation policies (Edquist and Hommen, 1998). Moreover, "Government procurement has often influenced the diffusion of new products, but it can also affect the generation and development of innovations. New markets can be created by the demand of new products and product development influenced by performance specifications and provision of testing sites" (Hutton and Hartley, 1985: 205).[xv] In developing countries—the experience of Uruguay being quite telling in this regard—the exclusion of local firms from public tendering for technology is done a-priori by setting unattainable requisites, like having 25 years of experience, or having conducted many projects of the same type. The rationality of these requisites is highly disputable: it seems that they are requested more to provide a safety net for the local decision-makers, to say the least, than to really assure the best technological fit to the identified demand. This instrument is complex to design, but once in place it can be further refined and honed. It does not involve extra costs, because it must be developed by people involved with technological issues in each institution.

(iv) *Technological court of appeal*[xvi]

As referred above, a main goal of any innovation policy in developing countries with under-utilized capabilities is to use the technological demand of the public sphere to develop a public technological procurement policy able to mobilize such capabilities. However, this cannot be a centralized policy, because the demand must issue from the diversified structure of the public sphere, where each institution enjoys a fairly wide autonomous status in terms of procurement. This situation opens the field to particular interests that can exclude legitimate national participants from international technology bids. To avoid this, it is important to have a centralized body to fulfill two roles. One is to examine the terms of the bids to assure that all the included requisites are really necessary for the successful completion of the project; the other is to act as a court of appeal for those national firms that feel that they have been excluded without sound technological or commercial arguments. A reasonable hypothesis is that the existence of this court of appeal would lead to better ex-ante practices, diminishing the need to act ex-post to correct possible deviations. This court should be formed as a permanent body with a mandate to ask for advice from the best experts in the country and even abroad. It is without extra cost, because it must be formed by permanent public servants.

(v) *Fostering technological awareness among SMEs*

This instrument is part of the technological "extension" effort among industries that we consider crucial to enhance technological culture and technological demand, and thus open up new opportunities for the local capabilities in problem-solving. It is devoted to particularly weak technological firms and is based on a personalized attention to firms in a part-time modality provided by young professionals or researchers in some main fields of engineering or applied sciences. The scheme is as follows: each of these young professionals will work systematically with five firms during a year, to help detect problems and suggest public institutions that can provide further help as well as technologically-based firms that can provide solutions. To attain a certain impact, the proposal consists of having 50 "technological awareness missions", providing as well for 10 senior technologists to supervise the work of a group of five young professionals each. This would lead to reaching 250 firms a year: however, before going on with this instruments in the following years a sound evaluation of its perceived impact would be necessary. The cost of this instrument is around US$ 600,000 a year.

(vi) *Support for firms hiring STI personnel*

This type of program has been implemented in various European countries, where it has been considered quite successful. The European schemes vary from 100% subsidies for first-year hiring to taking care of the social security costs of the new technologist hired by the firm. We propose an instrument that would subsidize 75% of the cost of hiring one scientifically or technologically trained person by firms that do not have any employee with this type of qualifications. The type of tasks that these professionals should perform will not be routine production work, but more akin to what a R&D department would do. Taking as a proxy the salary of a full-time university teacher of a third level of hierarchy, subsidizing 75% of the cost, and reaching with this instrument 200 firms, the overall cost of this instrument is US$ 1,600,000 a year. The idea is that in the following years new firms will enter into this scheme.

(vii) *Technological extension*

This instrument consists of a series of teams that visit firms to help them upgrade the way they use knowledge and technology, in a manner similar to agrarian extension schemes. To have a perceptible impact with this instrument, an important number of firms must be reached from the first year. If we provide for 10 teams and if each team makes a two-day visit to individual firms, 100 firms can be reached per month and almost 1,200 per year. Each team should be formed by two full-time specialists, one in technology issues and the other in commercial and financial issues; a consultant team of the highest level to conduct the work and provide advise during the process should be designed. The latter can be provided by existing institutions; the former need to be formed from scratch. Taking as a proxy the salary of a full-time third-level university teacher, each team would cost US$ 21,500 a year; the yearly cost of the instrument would then be US$ 215,000.

(viii) *Financing innovation projects in firms*

A classical and important instrument is to subsidize innovation projects in firms. This is usually implemented through a call for projects, which implies a complex process of evaluation. Furthermore, ex-post evaluation or ex-post follow-up is needed to assure that this instrument is used for what it has been designed. Public support for this type of projects could be up to US$ 30,000 a year, for two years. If the technological awareness program, the technological hiring in SME and the technological extension program work reasonably well, it can be expected that the proposals will come from a representative sample of firms. One hundred firms a year is a fair reach to begin with; allowing 2% of the total cost of the program for the ex-ante and ex-post evaluation, the total cost of this instrument would be US$ 3,060,000 a year.

(ix) *Changes in the conditions of loans for innovative initiatives*

One of the outstanding weaknesses of NSIs in developing countries is the absence of financial mechanisms to foster innovation. In particular, commercial loans are not prepared to take well-evaluated innovative ideas and projects as a sufficient warrant to take small risks. Some experiences in this direction were put in place in the region and were quite successful, like the Area Jorge Sábato of the Banco Provincia de Buenos Aires, in Argentina. Public banks need to define specific new "banking products" directed to innovative proposals backed mainly by the quality of the underlying ideas. Other institutions, for instance those related to fostering SMEs, can act as technical and commercial referees of the innovative projects submitted to loan scrutinies in the new modalities. This is an instrument without extra cost.

(x) *Public support for seed and risk capital*

Special support should be given to NTBE (New-Technologies-Based Enterprises) to start and consolidate truly innovative projects in existing firms. This is one of the purposes of seed and risk capital: to help new ideas to develop into business. Seed capital is the money that allows the exploration phases that can indicate if it is worthwhile continuing to seek funding for more formal entrepreneurial development. Risk capital involves bigger amounts and must help to develop full-fledged business lines based on new products or new processes. Programs for seed and risk capital must be managed by some specialized agency in the public realm. Hopefully, if the instrument shows not only successful outcomes in terms of innovation but also in financial terms, private actors may eventually get interested. The idea is that this money should be repaid, with interest, if commercial success is achieved by those to whom it was granted. In this way, the initial fund is replenished and even enlarged. Proposals need to be fully evaluated in two aspects: techno-productive and commercial (market and export prospects, for instance). A good place to start operating it would be a development bank. A modest start could be to support, the first year, 20 initiatives of seed capital with an endowment of US$ 25,000 each, and 10 risk-capital initiatives with an endowment of US$ 100,000: this amounts to US$ 1,500,000. Probably during the first five years no return will be seen, entailing a total cost of 7,500,000; afterwards this can change and the instrument can reach a larger number of recipients.

(xi) *Incubators for knowledge-intensive firms*

In a country like Uruguay, where research is highly concentrated in the public university, the probability of knowledge-intensive firms being created by advanced university students, university graduates or university teachers is high. This points to the convenience of thinking of incubators located in university premises or, eventually, in any of the buildings already in place devoted to scientific and technological activities. In this way the investment of scarce resources in new buildings can be avoided, using them integrally to help create start-ups. Of course, initiatives not originated by university people would also be evaluated and eventually accepted, on the same grounds. The conditioning of two spaces—related to the scientific and technological faculties—including well-developed communication facilities, can need US$ 50,000. Providing each space with two administrative staff costs US$ 15,000 a year; hiring a team of two part-time managers that can provide guidance and advice to the two incubators can cost approximately US$ 36,000 a year. To ensure full-time dedication to their projects by the incubator users it could be good to offer them, for a period of two years, a small salary, equivalent to a second-degree teaching position on a 40 hour per week basis, amounting to US$ 10,000 a year. In the hypothesis of five users in each space, US$ 100,000 a year are needed. The total amount of this instrument is US$ 200,000 the first year, and US$ 150,000 the following years. Of course, in due time, part of this money should be recovered by repayments made by the start-ups that turn commercially successful.

Opportunities. *Enhancing knowledge demand*

Estimated cost of policy instruments during five years (in US$)

Instrument years	*Cost each year*	*Additional costs*	*Total cost in 5 years*
* STI in social emergency programs	1,250,000	70,000	6,320,000
* Knowledge demand of the public sphere			
* Technological public procurement			
* Technological court of appeal			
* Technological awareness among SME	600,000		3,000,000
* Support for firms hiring STI personnel	1,600,000		8,000,000
* STI extension	215,000		1,075,000
* Financing innovation in firms	3,060,000		15,300,000
* Loans for innovative initiatives e			
* Publics support for seed and risk capital	1,500,000		7,500,000
* Incubators for knowledge intensive firms	150,000	50,000	800,000
TOTAL	8,375,000	120,000	41,995,000

LINKAGES

Promoting articulations

For development thinking, the notion of linkages is central, as explained by Albert Hirschman on the strength of his deep understanding of the Latin American situation: "The linkages capture much of the development story for a reason that has already been given; development is essentially the record of how one thing leads to another, and the linkages are that record, from a specific point of view. They focus on certain characteristics inherent in the productive activities already in process at a certain time. These ongoing activities, because of their characteristics, push or, more modestly, invite some operators to take up new activities" (Hirschman, 1981 :75). The importance of linkages for innovation arises from its very definition: "A linkage exists whenever an ongoing activity gives raise to economic or other pressures that lead to the taking up of a new activity" (Ibid: 76).

(i) *Detecting and supporting innovative circuits*

Examples of linkages are the "innovative circuits", defined as processes in which pressing production problems are solved by the encounter of the actors with the problem with "knowledge" actors, be they faculty teams, public laboratories or high-tech firms, thus leading to joint work on related problems, in a sort of growing or virtuous spiral (Arocena and Sutz, 2000). "The study of NSI can be enriched by the analysis of such innovative circuits, of how and why they appear, succeed and multiply, or disappear. The capability of profiting from them is a measure of development, considered, in Hirschman's sense, as a process where one thing takes to another or, in an equivalent formulation, where the attention to needs and problems links activities previously disconnected thus generating new combinations and activities" (Arocena and Sutz, 2002).[xvii]

Detecting innovative circuits is not straightforward, because they do not respond to any previously determined organizational scheme: they are situations, embedded in society and in economic behavior, that are known by many people but that usually are not recognized as the seed of virtuous circles of learning, capability building, technological upgrading and potential growth. To make a first move in the direction of detecting innovative circuits, a task force composed by 5 young scientists and technologists, working on a full-time base for six months, can do the job: this would cost US$ 25,000. Examples of these innovative circuits in the Uruguayan case are sheep breeders working with teams devoted to inventing biological tools to determine ancestors' characteristics, wool producers working with electronic firms to develop automated systems to control industrial wool-scouring machines, veterinarian laboratories devoted to pharmaceutical developments for cattle health working with teams researching virus behavior. The idea is to take 10 of the most promising innovative circuits and provide for support than can give the thrust for finishing a product, testing it and, eventually, initiating an export experience. Such a support, amounting to US$ 30,000 each, would lead to a cost of US$ 300,000 a year.

(ii) *Subsidizing joint academy-production projects*

Following the experience acquired in a similar university program, this instrument can subsidize 50 projects a year, a number that can grow if a new culture of technological awareness and cooperation develops. A reasonable yearly amount for this type of support, at least in a first experimental stage, is US$ 20,000: this leads to a cost of US$ 1,000,000 each year.

(iii) *Subsidizing projects with participation of national high-tech firms*

This instrument has antecedents in the re-industrializing policy of the Basque country, in the early nineties. It is related to the instrument *Registering and certifying knowledge-based and high-tech SME,* belonging to the "capabilities building-block". The idea is that many problems present in local production, particularly traditional production, can be technologically and financially best served by local high-tech firms acting as "technology tailors", that is, acting as developers of specific new solutions or as smart articulators of already known ones. The encounter between a prospective "problem holder" and such technological tailors needs to be further supported to arrive at a concrete joint project: in the Basque country a special state policy subsidized 75% of the cost of formulating the project and 50% of the cost of carrying it out. We propose to allocate an amount of US$ 5,000 to the study stage and, if the project is well formulated and promising, to support it with a sum of US$ 30,000. The hypothesis is that 50 projects will be studied a year, leading to US$ 250,000, and half of them will be supported, leading to US$ 750,000, which totals US$ 1,000,000. The studies are worthwhile in themselves, because if they detect small problems, this can lead to linkages that do not need to be subsidized to be exploited.

(iv) *Technological "windows" in research centers*

This instrument should be implemented in each research center with their own resources. But given that quite frequently the budgets of these centers are so tight, we make the following support provision: 10 windows at national level, served by two young part-time staff, amounting to US$ 80,000 each year. These windows would work with the register of the national research groups to provide rapid and accurate answers to the frequent question, "who knows something about such and such?" made by different social actors. They would also work to maintain the research groups database updated.

(v) *Technological advice for small firms and trade unions*

The least an actor knows about technology, the more difficult he finds thinking critically about it, finding ways of using technology to his advantage or avoiding its possible negative impacts. It is for this reason that a public and widely diffused organization labeled, for instance, "Technological Advice Office", could be of importance. Its aim would be to provide a space for "common people", like SMEs, cooperatives or trade unionists who perceive an opportunity or a problem related to technology but do not have the knowledge to identify possible advisers, to talk with someone about their concerns. This office can be sited at the organization devoted to SMEs; two part-time senior technologists can do the job, accompanied by some administrative support, at least at the beginning: this would cost approximately US$ 25,000 a year.

(vi) *Stages of advanced students*

A system of advanced-student placements in different kind of firms is a win-win system that provides students with hands-on work opportunities and encourages firms to state some of its problems in a formal way so the students can tackle them. The students' work should be doubly supervised: by a formal tutor at the university side and by an on-the-job adviser on the firm side; those tasks do not need to be financially rewarded, but the students should be given a small fellowship to facilitate full-time dedication to the placement. On the basis of a US$ 400 monthly fellowship, 200 stages would cost US$ 960,000 each year.

Linkages. *Promoting articulations*

Estimated cost of policy instruments during five years (in US$)

Instrument	*Cost each year*	*Additional costs*	*Total cost in 5 years*
* Innovative circuits	325,000		1,625,000
* Academy-production projects	1,000,000		5,000,000
* Projects with high-tech firms	1,000,000		5,000,000
* Technological "windows"	80,000		400,000
* Advice for SMEs and trade unions	25,000		125,000
* Stages for advanced students	960,000		4,800,000
TOTAL	3,390,000		16,950,000

CITIZENSHIP

Fostering STI involvements and consensus

(i) *Interactive and mobile S&T museums*

In Uruguay there are some very well conceived experiences of interactive science and technology museums, highly connected with a Latin American network on those issues and with special field work in the countryside, which is really important. They face several restrictions, particularly in relation to the mobility of the experimental infrastructure. To help them achieve a better coverage and to expand their work to primary school teachers is an example of how a little money can have a wide reproductive impact. An endowment of US$ 30,000 a year can be adequate.

(ii) *Divulging national accomplishments in STI*

This is a particularly important cultural instrument. National pride in science and technology is a key ingredient of the "national scientific and technological imagery"; that imagery shapes what is conceived as possible and not possible for national endeavors and achievements. All the analyses made about Japan and the Republic of Korea's "miracles" stress the shared conviction, expressed by government officials and public alike, that the country was "capable". It is reasonably to expect this type of attitudes from countries where small children learn, from primary school onwards, not only about the value of science and technology but also that some of its main contributors are nationals of their countries. In Uruguay, for instance, there are a few of these "legendary" figures, that have made significant contributions to world science, to technology and to medical practice. However, they are mostly unknown. Moreover, the work of present researchers on science and technology, that can have a "demonstration effect" for high-school students, is also widely unknown. A move to change this is necessary. The proposal is to prepare 10 short video-films a year on national achievements in S&T, well researched and produced – in technical, historic and artistic terms—some of them animated to better reach small children, and to make them widely seen and discussed all over the country. The cost of each video-film is approximately US$ 10,000, which leads to a yearly cost of US$ 100,000.

(iii) *STI civil service of students*

Most Uruguayan university students go to the University of the Republic, where access is unrestricted and free of charge. This suggests the convenience of providing for them some non-monetary system of "social restitution", so those students can "repay" the effort made on their education. One of such systems could be a scheme like those implemented in some European countries for youngsters who do not want to pursue military service: a socially oriented service. In this way, science and technology students, among others, can be organized to collaborate with a national effort aimed at improving the scientific and technological culture, for instance by helping in "assisted-homework" schemes with primary school teachers. Such a system should not imply any type of payment for the students, nor for those providing the logistics and organization. However, given that one of the main impacts of a civil system of this type would be in the countryside, some resources should be provided to allow travel and short stays. Taking the total number of students who entered the university in the last three years to pursue scientific and technologically oriented careers – around 7,000—and expecting that half of them can enter a scheme of this type, providing each US$ 100 a year to facilitate their work, would imply a total cost of US$ 350,000 a year.

(iv) *STI journalism*

This is an important initiative, the justification of which is akin to the one on "technological imagery". It should not need to be endowed with specific resources, but taken on board by the communication careers already in place. In any case, priority should be given in the mobility programs to demands to invite specialists in this area.

(v) *Office of STI assessment for the legislature*

The legislature should have, as occurs in many countries, a specialized body on STI to be able to get independent advice on related issues. This body cannot possibly cover all the fields of expertise, but needs to be able to interact with all the expertise available in the country and be aware of the regional and world experience in main fields related to legislative decision-making associated with S&T as well as to conflicts arising from S&D issues (GMOs, stem cells, nuclear power, potentially environmental damaging industries, new international regulations that affect production and need S&T approaches to be taken into account, etc.). This office would need two senior part-time people, two young full-time people and some administrative support: its cost amounts to US$ 40,000 a year.

(vi) *Studies on people's perceptions of science and technology*

The legitimacy of public actions in science, technology and innovation depends, to a certain extent, on public perceptions of these issues. This means that what is done, at least in a democratic society, reflects in some way the public's perceptions, priorities, hopes and fears regarding new knowledge and the use made of it. On the other hand, it is important to analyze how elites perceive these issues. How do actors with a special capacity to influence government, business, academia and mass media, perceive society's innovative strengths? Which mechanisms do they think are necessary to improve them? How do they integrate science and technology in their visions of the nation's future? Are they "market-driven", "state-driven" or "actor-driven"? These are some of the questions that help understand the support and the opposition than STI policy design will probably elicit. The methodology for this is well known, consisting of semi-structured individual interviews, complemented eventually by group workshops. The proposed instrument is to conduct, once each five years, a national survey and a focused study on public perceptions of science and technology. This amounts to US$ 50,000 in the whole period of five years.

(vii) *Citizen's participation in decisions about STI priorities and conflicts*

This is a difficult instrument to design and put in place. Some international experiences exists, like the Dutch Science Shops or the Danish Consensus Conferences, but given their cultural bias they are impossible to copy. It has no extra cost in monetary terms, but it would need hard extra thinking to be devised and implemented. The ensemble of working teams devoted to advise on S&T matters should be involved in devising how to bring people on board to participate on decisions related to those issues. Journalists are of extreme importance for that aim. Experimentation will be needed and, above all, willingness to follow that path.

Citizenship. *Fostering STI involvements and consensus*

Estimated cost of policy instruments during five years (in US$)

Instrument	*Cost each year*	*Additional costs*	*Total cost in 5 years*
* Interactive and mobile S&T museums	30,000		150,000
* Divulging national STI achievements	100,000		500,000
* STI civil service of students	350,000		1,750,000
* STI journalism			
* Office of assessment for the legislature	40,000		200,000
* People's perceptions of STI		50,000	50,000
* Citizen's participation in STI decisions			
TOTAL	520,000		2,650,000

ANTICIPATION

The prospective dimension

Prognostication is, by its very nature, tentative. As a well-known analyst of this subject underlined two decades ago, prognostication is a tool for action and safeguard against fate characterized by seven key ideas: i) illuminating present action in the light of the future; ii) exploring multiple and uncertain scenarios to come; iii) adopting a global and systemic vision; iv) taking into account qualitative factors and actors' strategies; v) permanently bearing in mind that information and prevision are not neutral; vi) choosing pluralism and complementary approaches; vii) revising received ideas (Godet, 1985).

The organizational models to perform systematic foresight exercises have been changing. "In Denmark, Germany, Great Britain and the Netherlands, for example, participatory technology assessment has tended to emphasize objectives as 'finding solutions together' and 'generating dialogues', thus extending the classical Office for Technology Assessment (OTA) model which has focus on 'speaking truth to the power'" (Salo and Kuusi, 2001: 460). The idea of participatory foresight is the one that orients the proposed instruments.

(i) *Center of STI Foresight for Development*

For small industrialized countries as well as for developing countries, it is of little use to make a list of the fancier scientific and technological developments and take it as a guide to organize innovation efforts. This, however, is often the case, at least in developing countries. The point is instead to detect, the more focused the effort the better, developments that can be dangerous to the present productive status-quo, on the one hand, and developments that could open new opportunities to solve problems at national, regional or local level, on the other. To conduct national foresight exercises of this type and to advise the government on that matter, a permanent effort is necessary, organized in a center that should be placed at a high governmental level. Tentatively, two senior researchers and three young researchers on a full-time base should be provided, plus some administrative support. The cost of such a structure is about US$ 60,000 a year.

(ii) *Systematic technological foresight exercises in public institutions to anticipate its future demand*

This instrument is of paramount importance. The lack of technological prevision in the public sphere is one of the reasons why existing capabilities are underutilized and technological opportunities are lost. Usually, the need to use a new technology or the mandatory character of some technical requisites does not arrive out of the blue: a long process, sometimes years long, takes place to arrive at new technological procedures. This is true for the digitalization process of telecommunication devices as well as for the requisite of certifying the health story of each animal through a electronic earring affixed to it to be able to export its meat to some particularly demanding markets. When no S&T technological prognostication takes place, what usually happens is that at the last moment and as a last resort, the needed technology is bought, turnkey, from some provider located in a developed country. This might be necessary even if S&T foresight is exercised: perhaps the majority of the new scientific and technological requisites to cope with world trade are too advanced and sophisticated to render reasonable the attempt to fulfill them locally. However, for a developing country, each opportunity is important. Well conducted S&T prevision can identify trends that, with due awareness, can lead to train human resources, look for regional complementarity, define a path for technological participation, all this leading to the opening of new opportunities. This instrument should not be centralized, but should be distributed among all significant technological demanders in the public sphere. Given that it must be performed by permanent staff, it involves no additional cost.

(iii) *Systematic foresight exercises with multiple actors*

Different actors are affected differently by the evolution of S&T; it is then advisable to conduct foresight exercises with them. A way to do that is to organize foresight workshops with several interested groups; this can be done through the Center of STI Foresight for Development, referred to above. Ten workshops a year, at a unitary cost of US$ 3,000, would lead to a total annual cost of US$ 30,000.

(iv) *Wide public diffusion of foresight results*

The Center's activities as well as the results of the foresight workshops should be widely diffused, to help creating a foresight culture, particularly needed in countries where short-term considerations are usually amply dominant. For that purpose several instruments are available, of which one specially efficient is the development of a well designed and maintained web page and the elaboration of some audio-visual material. It is worth to devote to this some financial effort: an amount of US$ 25,000 a year is adequate for that aim.

Anticipation. *The prospective dimension*

Estimated cost of policy instruments during five years (in US$)

Instrument	*Cost each year*	*Additional costs*	*Total cost in 5 years*
* Center for STI foresight	60,000		300,000
* Foresight of public demand			
* Foresight exercises with multiple actors	30,000		150,000
* Diffusion of foresight results	25,000		125,000
TOTAL	115,000		575,000

SPECIALIZATION

Shaping a productive profile in selected areas

Countries usually show some idiosyncratic strengths, originating in historical trends as well as from natural endowments, which suggest promising paths of productive specialization. Given the "knowledge-based and innovation-driven" evolution of the world economy, one of the strengths that should be taken into account to visualize such paths is the cognitive one, that is, the fields of knowledge where scientific and technological accumulation have taken place. In Latin American countries in general and in Uruguay in particular, one of such strengths lies in the life sciences. Moreover, bio-innovation strengths, that is, innovation based on life sciences, can be found in sectors like agriculture, human and animal health and the environment. Productive specialization around life sciences can open a high road of insertion in the world economy through two main paths. Firstly, through the systematic growth of the intellectual value added to the production of basic resources. Forestry, meat, wool, rice, to mention only a few, are all sectors able to absorb in very different ways life-sciences knowledge and bio-innovation to raise the market value of their products, as well as to find some niche strategies to alleviate the difficulties associated with commodity production. Secondly, bio-innovation can lead to a path of high-tech specialization, typically in medical devices and some pharmaceutical products. The latter, by providing high-quality products at lower prices than those imported, can have important social impacts like, for instance, making possible for public health policies to widen the access to medical devices that were severely restricted before. Moreover, such a specialization path can lead to new export prospects, particularly in markets of the South. Supporting the development of such a productive profile can be done through several instruments, different in nature. We shall briefly mention and quantify the cost of some of them that are strictly related to knowledge, capability-building and innovation issues. As an example, we shall refer in all cases to bio-innovation.

(i) *Special support for R&D Institutes in selected areas*

A research institute, inter-disciplinary in nature, devoted to R but especially to D, in different fields of bio-innovation, is an effort worth undertaking in a country like Uruguay. An example of a line of R&D in such an institute can be the design of electronic chips to be used for implanted devices, in humans and animals. Many other examples can be given; this one was selected to show that bio-innovation is not only related to life-sciences but to applications related to life as well. Such an institute can start with a staff of 20 young full-time researchers and some endowment for research facilities and prototype building and testing. The annual cost of such an institute would be US$ 200,000 a year. The necessary advice and supervision would be provided by the permanent staff of various R&D institutions.

(ii) *Special programs for human resources training and international cooperation in selected areas*

Support for 20 fellowships a year specifically oriented to bio-innovation and 10 invitations to top specialists in the field to spend two months each in the country, is a first step to assure that capabilities for bio-innovation will be in place. The cost for an instrument like this one would be approximately US$ 290,000 a year.

(iii) *Special program to provide technical support to selected areas*

Some special support is needed to incorporate some existing institutions, for instance public technological laboratories entitled to control and certify quality, to the bio-innovation field. This implies the development of new sections, the hiring of new specialists and the incorporation of new infrastructure. An endowment of US$ 100,000 once every five years can be recommended for that aim.

(iv) *Special attention to selected areas in public demand*

This is a key instrument, as it was already argued; this instrument is without extra cost. The international experience, particularly in bio-innovation related to medical devices, shows that public demand has played a key role in the development of national firms with high international competitiveness. Denmark, Sweden, Finland, Austria, Israel are all examples of this: it is worth exploring this path in a country like Uruguay.

(v) *Special attention to public financing of innovation*

Again, this is an instrument without cost. What is needed is to establish that bio-innovation projects, after complying with the general requisites and criteria to be supported by any of the financial instruments devoted to foster innovation, should have some priority. The idea is that bio-innovation projects, if successful, can easily lead to exports, given that their products were designed to take into account -and to overcome- restrictions that are also present in developing countries in general.

(vi) *Special attention to incubators in selected areas*

A special endowment to support bio-innovation start-ups should be provided. Using the same amount of support suggested for general S&T incubators, US$ 10,000, and providing for 5 initiatives a year – besides the ones that could appear in the former case—would lead to a cost of US$ 50,000 a year.

(vii) *Special attention to dissemination and foresight tasks*

This is a question of emphasis more than of money. It is an important instrument to accompany efficiently the efforts towards a specialized productive profile, but without any extra cost.

Specialization. *Shaping a productive profile in selected areas*

Estimated cost of policy instruments during five years (in US$)

Instrument	*Cost each year*	*Additional costs*	*Total cost in 5 years*
* Special R&D Institutes	200,000		1,000,000
* Human resources and international cooperation	290,000		1,450,000
* Technical support for selected areas		100,000	100,000
* Technological public demand			
* Public financing of innovation			
* Incubators in selected areas	50,000		250,000
* Divulging and foresight tasks			
TOTAL	540,000	100,000	2,800,000

(III.b) Constraints, preconditions and results: some indicators

Globally speaking, results up to now of investment in STI in the South have not been very encouraging. In most cases, approximating stated goals has proved to be a very difficult task. Many causes can be invoked, and some have already been mentioned earlier. In several cases, lack of political will has been quite evident; in some others the main problem has been a mimetic behavior that ignores specific aspects of the country or region. And of course, the weight of sheer complexity should not be forgotten. Be it as it may, very often it is quite clear that certain things *must* be done, but governments and related actors *can't* do what they need to do.

Consequently, what is needed includes – among many other things, some of them more important – sets of STI indicators of constraints, preconditions and results. Such indicators should help to gauge, at the same time, the main restrictions and requisites for success in STI; they should help also to draw a dynamic picture of how restrictions are overcome, requisites built and goals approximated.

STI indicators are characterized as relevant sets of qualitative and quantitative information organized in such a way as to help in the orientation of STI policies and their evaluation. Thus, indicators must be closely related to each fundamental chapter or "building-block" of an STI policy. Blocks define at the same time fundamental goals and general strategies for approximating them. Thus, indicators as well as instruments are tools for "operationalizing" each block. In what follows we briefly recall some indicators that can give an idea of the situation and perspectives concerning each policy block.

Indicators of the first building-block
CAPABILITIES
Strengthening learning possibilities

(i) *Graduate and postgraduate levels*

Strengths in advanced capabilities are usually measured through supply-side indicators, such as the number of science and engineering graduates, of master and doctoral degrees, of researchers, and their relations to the university graduate population or to the whole population.

These indicators give a preliminary view of learning strengths, and are quite telling in comparative terms. For example, it is seen that developed countries have ten times more researchers per million inhabitants than the developing world in general and five times more than Latin America as a whole (UNESCO 2001). The following table is eloquent.

Table
Number of researchers (sciences and engineering) per million people, last date available in the period 1996-2000

Latin America, Africa and Asia	*R 10^6 p*	***OECD***	*R 10^6 p*
Argentina	713	Norway	4112
Brazil	323	Sweden	5695
Chile	370	Australia	3353
Colombia	101	Netherlands	2572
Costa Rica	533	USA	4099
Cuba	480	Canada	2985
Mexico	225	Japan	5095
Uruguay	219	Denmark	3476
China	545	Finland	5059
Singapore	4140	France	2718
Sri Lanka	191	Germany	3161
India	157	Spain	1921
Vietnam*	274	Italy	1128
Mongolia	531	Israel	1563
South Africa*	992	Portugal	1576
Egypt *	493	Korea	2319

Source: Human Development Report, 2003, 274-277.

* Data before 1996.

Lack of qualified people is clearly a constraint on development; keeping an eye on those figures helps to assess the results of capability-building policies.

Nevertheless, such numbers are not sufficient to evaluate how capabilities have been enhanced in developing countries, so we suggest also taking into account the following ones.

(ii) *Graduate and postgraduate follow-up*

One of the most important potential innovative strengths of any nation is the educated people it is able to prepare, especially in sciences and engineering. But a pre-condition for transforming such potential in actual strengths is that graduates from these orientations find places to work creatively and get involved in problem-solving activities. This is why the information around how many of these graduates work, where they work, doing what, using to what extent what they have learnt, constitutes a key piece of information for evaluating results of STI policies.

Such information may also help to face some realities. If, for example, a high level of graduates from given areas are not able to find jobs as such, even if in the country that type of knowledge is significantly applied to producing goods and services, a "dissonance" becomes evident, and its study may suggest ways of overcoming it.

Interesting elements emerge, for example, from statistics on the distribution of researchers between three main occupational spaces: government, business firms and universities.

Table

Percentage of research personnel by sector of occupation in several countries. Data corresponding to the period 2000-2002, presented as FTE (Full-time equivalent) or R (researchers)

Countries	*Government*	*Business firms*	*Higher Education*
Argentina FTE	37.6	11.3	49.3
Brazil FTE	10.5	31.1	58.0
Chile R	19.7	5.9	69.4
Colombia R	4.5	4.1	88.9
Mexico FTE (1995)	31.0	10.3	57.8
Uruguay FTE	13.4	1.0	85.7
OECD FTE		64.0	
China FTE		52.0	
India FTE		37.0	
Singapore FTE		51.0	
USA R (1999)	11.0	70.0	19.0
Canada FTE	7.6	59.0	33.2
Spain R	12.0	20.3	67.3

Source: RICYT, 2003; OECD 2003

The tables give a clear comparative image: the developed countries not only have much more researchers in their population, but the distribution of researchers in terms of occupation is totally different. Researchers mainly concentrate in business firms at OECD level; they concentrate in higher education in most developing countries, particularly in Latin America. A first approach to the gap that separates learning opportunities and industrial dynamics in developed and developing countries emerges from this comparison.

From a learning perspective, however, R&D is only one of the activities where learning has opportunities to expand. The strength of the learning capabilities approximated by the kind of activities knowledgeable people are able to perform cannot be fully grasped by looking too narrowly at R&D: production, marketing, design, technological extension, scientific and technological forecasting, open opportunities for creatively addressing problem-solving activities that are, as learning opportunities, probably as significant as R&D. So, it is important to know where graduates and postgraduates work in a more detailed way; in Latin America at least it would be very useful to know also where the graduates from non-university technical education institutions work.

(iii) *Connections with the scientific and technological diaspora*

We are not talking here about mobility, which implies a temporary stay in a different country from the researcher's own, but about migration. In that sense, the existence of an important scientific and technological diaspora means that researchers abroad can be considered qualitatively and quantitatively a significant part of the country's total research community, a phenomenon mainly related to underdevelopment. In developed countries, more than brain drain, a current and growing practice is brain circulation, activated by strong policies supporting academic mobility.

It is not easy to estimate the scope of the developing countries' scientific and technological diaspora. The National Science Foundation stated in 1997 that 12% of the people with an university degree in sciences and engineering living in the US were born in developing countries. It stated also that the higher the academic degree the higher the proportion of foreigners — they accounted for 26% of all the PhDs and even 50% in some branches of engineering and computer sciences. Among the 50 countries that at that time had the greater numbers of its citizens with degrees in sciences and engineering living in the US, 13 were Latin American, accounting for 10% of the total (Pellegrino, 2004: 52). The same source asserts that the total number of researchers from developing countries working in the US, Europe and Japan represented around a third of the total in their country of origin. Recent data from the World Bank (2002: 18) indicates that 50% of migrants from South America and 75% of migrants from Sub-Saharan Africa hold university degrees. Information gathered around 1990 indicates that Argentine migrants to the US had on average four more years of formal education than the Argentine population; in the case of Brazil and Guatemala the difference was of six years (Massey et al 1998: 236)

The numbers show a relevant constraint; since the migrated research community can be considered, at least in principle, as part of a national learning-capabilities endowment, to be able to use this potential effectively appears as an important requisite for success in STI. This is what several countries from South East Asia, particularly the Republic of Korea and Taiwan Province of China, have done, developing quite successful policies for recapturing their important scientific and technological diaspora, sometimes through the moving back of researchers and sometimes profiting from their positions to establish different modalities of collaboration. As important as the numerical dimension of the migrated community are the academic and productive positions occupied by many members of this community, that can eventually be mobilized to help in effective ways their fellow-countrymen scientists and engineers. In Latin America, different ways of connecting with the diaspora have been tried, with different degrees of success. One of the most telling experiences is provided by the "Red Caldas" of Colombia. The scientific and technological diaspora is a potential learning strength, that can be made real by state policies, reversing partially the losses derived from the brain drain. Measuring the diaspora, mapping its distribution and evaluating its connections with domestic actors may give important indications about the results of those policies.

(iv) *Identification and attributes of research groups*

To better approximate the strength of research capabilities, it is particularly advisable to choose a unit of analysis that is as near as possible to real-life knowledge production. This implies that such unit should be a direct and focused research space, instead of a formal unit, generally constituted by aggregation of disciplines or fields of work, like institutes or departments. It is also reasonable to avoid the contingent nature of research projects and to look for a more stable structure, where the social reproduction of knowledge through postgraduate teaching can take place. Finally, such a unit should reflect the collective nature of research activities, going beyond the individual researcher. All this points to the research group as an adequate unit of analysis for the identification of the strengths of research capabilities.

We have here a difficulty, though, associated to the precise definition of what a research group is. Taking one of the most comprehensive exercises of identification and characterization of research groups at country level, done since 1992 by the Brazilian National Research Council (CNPq), a research group is "an ensemble of researchers, students and support personnel, organized around a recognized scientific leadership, that develops lines of research with regularity" (CNPq, 1995: 27). Other Latin American countries that have systematically studied research groups—Colombia, Uruguay—use slightly different definitions. But the main point is that due to their relatively stable nature, research groups in Latin America are a good unit of analysis to characterize research strengths; in that region and in other countries as well, they may turn out to be much more telling than general statistics if a methodology to systematically identify them is developed. Numerical information already available, for example in Brazil and Uruguay, include: (i) number of groups, institutional and geographical location; (ii) average size of groups and educational levels of their members; (iii) distribution of research groups by cognitive areas, strengths and weaknesses; (iv) main sectors of application of the research results; (v) connections of research groups with firms. The latter is a good indicator of linkages between research and production. It leads also to the identification of successful situations and to study them qualitatively. The lessons learnt in these studies can be extremely important to improve policies.

(v) *Identification and attributes of small and medium-sized knowledge-based and high-tech enterprises*

Small and medium-sized knowledge-based or high-tech enterprises constitute a particularly appropriate vector for solving problems for other economic and social sectors, besides the role they play in some countries as direct engines of economic growth, as Rothwell and Zegfeld (1982) and Rothwell (1986) have highlighted. In developing countries, these firms play a strategic role as "technological tailors", able to find or build adapted solutions making use of the newest scientific and technological tools. This is particularly important as a diffusion mechanism, given the differences in sophistication between productive systems in the "technology supply" countries and in the developing ones. Without such technological tailors—who must be able to establish trustworthy relations with the would-be users, speak the same language and share similar codes—firms will have difficulties in getting in contact with the latest technology, because prêt-à-porter high-tech solutions will probably have an inadequate relation performance/price for them.

We can conceptualize small and medium-sized knowledge-based and high-tech firms as learning assets, because they frequently establish user-producer relationships where important learning processes occur on both sides of the relationship. Once those firms are identified, the network of their clients and the projects performed can give a good idea of the dynamism in the introduction of knowledge into the economic and social fabric, which justifies the inclusion of this component in the analysis of NSIs. Information concerning these firms is thus relevant for assessing both the STI situation of a given country and the results of capability building policies.

Indicators of the second building-block

OPPORTUNITIES

Enhancing knowledge demand

(i) *Resources dedicated to social urgencies*

To our knowledge, this is a seldom-used indicator, in spite of being of utmost relevance. It offers information related to the principal justification for STI investment in poor countries. And, at the same time, it is a fundamental indicator about the long-term strength of STI structures in developing countries, because it is not easy to assume that such countries will invest systematically in STI capabilities if these capabilities are weakly connected with the solution of pressing social problems.

Concrete elements related to this indicator can be given, for example, by: (i) absolute and relative numbers of scientists and engineers working in social programs; (ii) data about members of the scientific and technological diaspora connected with those programs; (iii) information about research groups working in health, housing, food, environment, etc.; (iv) connections of public and private organisms dedicated to the solution of social problems with knowledge-based and high-tech firms.

(ii) *Evolution of the knowledge demand of the public sector*

Internal technological public demand is important everywhere to foster learning opportunities, even nowadays, when the process of privatizations has restrained the range of state actions almost without exceptions. Long-range and scientifically and technologically sophisticated projects, that need sustained investments and a broad scope of cognitive inputs, are more likely to be assumed by public efforts. In developing countries, where the business sector is quite weak in technological terms, the role of the state is even more significant. This does not mean that the state effectively assumes there a role as a "user leader". Frequently this is not the case, and the public demand for technology, which is quite strong in several areas, is not used as a window of opportunity to apply and enhance endogenous solving problems capabilities. The situation is quite different in highly industrialized countries: the name of this issue can, thus, takes two similar but not identical denominations: knowledge demand (in the public sphere) in the first case and potential knowledge demand in the second case. Such potential public demand can be strong in diverse types of infrastructures, for example, in health, including medical equipment and pharmaceuticals; in environmental protection, concerning design and implementation of nutritional programs; or design and building of houses for low-income sectors.

An exacting and sophisticated public demand addressed to domestic capabilities in developing countries is a precondition for expanding the knowledge supply as well as a stimulus for addressing private demand to those capabilities.

Domestic technological demand in the public sphere is not so difficult to trace, and it gives quite significant information about NSIs dynamics. For instance, this demand in a welfare state will probably be different — in size, direction and intended beneficiaries — from the one present in a more market-driven economy, this having consequences for the welfare of citizens and for social cohesion (Dalum, Johnson and Lundvall, 1992). Social cohesion is one of the variables that counts as regards innovative behavior, particularly through the normative directions that derive from it. Thus, the technological demand of the public sphere can be a interesting way of looking into NSIs and its relations to human development processes.

In the case of developing countries, information on the potential domestic knowledge demand of the public sphere allows to conduct two interesting exercises. The first one is to estimate the gap between the public demand that is satisfied domestically and that which goes abroad, understanding here by "going abroad" the turnkey imports and not the eventual association of domestic and external capabilities. This gap is a good proxy for the degree of cohesion of NSIs: the smaller the gap, the higher the cohesion. The second one is to combine information on the potential demand with the one about existing learning strengths; this can show concrete directions that can be followed in the short run to enhance learning capabilities through problem-solving. This is extremely important to devise policies aimed at strengthening NSIs.

(iii) *Evolution of the private sector's knowledge demand*

It can be argued that the technological demand of the business sector is in part influenced by the settings of the NSIs and, conversely, that it influences such settings. This is nothing else than recognizing, again, the fundamental role of users in innovation and the influence they exert on the institutions around it. Even acknowledging that there is no such a thing as a "perfect" system of innovation, it is reasonable to evaluate some features as good ones for a NSI. One of them is the match between what the business firms know they need today and what they will probably need tomorrow—even if they do not recognize the need right now—with the research agenda of all the knowledge producers in a country. If there are big mismatches, because some pressing problems are not being taken on board in the research agendas, or because the latter are too narrowly focused to adequately take the future into account, the innovation dynamics will suffer. Some degree of convergence between the actual research agenda and the anticipated needs of the productive sector is thus a precondition for long-term growth. But that convergence is unlikely to take place if the actual knowledge demand of the productive sector neglects domestic producers of knowledge.

From the point of view of mapping, measuring and comparing NSIs, the inward-oriented scientific and technological demand of the business sector is a significant factor. That demand is not a direct consequence of the relative weight of each sector in the economic structure, because sectors having the same structural weight in different countries can have totally different domestic technological demands: a multinational firm in its home country and one of its affiliates in a developing country provide an extreme example of this.

This information is more difficult to collect than that related to the technological demand of the public sector, but reasonable proxies can be found through general innovation surveys. A second approach is based on studying highly innovative producers; their importance is stressed by the conceptualization of "lead users" as those "whose present strong needs will become general in a marketplace months or years in the future" (von Hippel 1988: 107). A related third approach is to estimate the knowledge demand of a productive chain by studying representative cases of producers organized in that chain.

Indicators of the third building-block

LINKAGES

Promoting articulations between innovation actors, especially knowledge linkages and innovative circuits

The indicators previously described in connection with the second building block—as well as some of the first building-block—provide basic information for evaluating knowledge linkages, albeit indirectly. Here we propose some other indicators specifically designed to detect strengths and weaknesses that influence the occurrence of such linkages. As usual, their evolution is not easy to gauge; in fact, here we are focusing on an aspect that goes beyond preconditions and requisites. As Hirschman taught, economic development itself is akin to the expansion of productive linkages, and among them the influence of knowledge linkages is clearly growing.

(i) *Analysis of actual experiences concerning linkages*

These experiences are significant because they refer to opportunities to establish knowledge linkages that were effectively exploited. To be more specific, attention can be concentrated on knowledge linkages between academia and production. Information on this issue can be gathered from innovation surveys, but it is usually too aggregated and scantily detailed in cognitive terms. The comparisons that can be established from them can, however, be significant. For instance, developing countries exhibit consistently lower levels of relationships between universities and firms than highly industrialized countries; for all countries, small and medium-sized enterprises establish far fewer relationships with universities than big firms. In fact, innovation surveys could do more to give a better idea about firms' relationships with universities, perhaps through a specific module designed with that aim. However, if more detailed information is considered useful, it is convenient to identify experiences that flow from long-term research directions. This points to the linkages with productive units established by research groups.

The already mentioned systematic attempts to identify research groups made in Latin America—in Brazil, Colombia and Uruguay—provides this type of information. The overall impression coincides with that given by the innovation surveys: the linkages between research groups and firms are weak, even in the most applied avenues of knowledge production. It is important to understand more accurately why this is so. Part of the explanation can be related to the subjects chosen by the groups – again the issue of the research agenda and possible mismatches with industry immediate needs. It can also reflect an incipient stage of development of many of the results obtained. However, perhaps a more consistent explanation is that the propensity of firms to establish linkages, with knowledge in general and with academia in particular, depends on the firms' human-resources structure. This aspect is explored by the following indicator.

(ii) *Levels of qualified personnel in firms*

It is not easy to estimate the optimal number of personnel with tertiary level of education in scientific and technological fields that a firm should have in order to be able to profit extensively from the supply of knowledge and the capabilities to create new knowledge at national, regional or local level. The difficulty arises mainly from the fact that the relationship between qualified personnel and total personnel is not linear. However, it is sensible assumes that firms which do not have any qualified personnel with higher education will find it extremely difficult to establish linkages with knowledge-supply actors such as universities, other high-tech firms or public research institutes.

There are several partial confirmations of this hypothesis. To mention just one of them: innovation surveys show that the demand addressed to public research facilities is clearly biased towards big firms, and that small firms are barely represented at all. As Gregersen (2000: 8) states for the Danish case: "The Disko survey confirms what many other studies have found, namely that size matters for collaboration with universities and research institutions, that is, large firms collaborate more frequently with universities and research institutions than the small firms". This does not seem reasonable at first sight: big firms usually have more internal knowledge resources than small ones, and so the latter are far more in need of external assistance than the former. Nevertheless, even to be able to ask for scientific and technological assistance, firms need to formulate their problems in adequate terms, which is quite difficult for a firm without at least some employees with university-level education.

Reducing the number of non-participants in knowledge linkages is a requisite for success in STI investment. A good proxy for that number is the number of firms lacking personnel trained at university level. This information, plus the characteristics of those firms, can be of great value to policy design. The number can be quite high: almost twenty years ago, three-quarters of all small and medium-sized firms in Uruguay did not have a single engineer. It is interesting to note that nowadays a similar fraction of Danish small and medium-sized firms do not have personnel with any academic degree. However, analysis of the Danish System of Innovation shows that the density of linkages of Danish firms, including small and medium-sized ones, is extremely high, in absolute as well as in comparative terms, this being one of the explanations of the good performance of Danish industry, where a majority of firms are small and medium-sized, in spite of such weakness (Gregersen, 2000). That means that there is more than one way to compensate the absence of qualified personnel in small firms.

(iii) *Levels of participation of usually neglected knowledge-weak actors in knowledge linkages*

Small and very small firms are frequently knowledge-weak actors. Of course, that is not always the case and, moreover, there are other such actors that deserve greater attention than they usually receive. But many examples point in an encouraging direction: for example, in some European countries, trade unions have publicly-paid technological advisors. If technical change is consistently unfavorable to workers, growth is not socially sustainable, and perhaps not even economically sustainable.

In developing countries, most actors are knowledge-weak; it is very difficult for them to participate in knowledge linkages, although their experience is potentially valuable. Moreover, only by participating in such linkages will those actors be able to upgrade their capabilities and defend their interests. If the last two conditions are not met, STI investment will have a weak political basis and a dubious future, so this is a major constraint.

Trade unions, cooperatives, NGOs and other "civil society" associations are not usually considered in STI policies and studies, but other kinds of studies furnish information related to the following questions: Do they have scientific and technical personnel on their staffs? Are they consulted systematically by governments when scientific and technical decisions are adopted? Do they participate in joint tasks with knowledge-generation organizations? Are they entitled to be considered partners in publicly-funded projects for fostering relations between academy and production? Even partial answers to such questions are useful for evaluating knowledge linkages. They are perhaps even more useful to evaluate if actual innovation processes foster or hamper "social capital" and social cohesion.

Indicators of the fourth building-block

CITIZENSHIP

Fostering wide STI consensus between citizens concerning the aims and roles of STI in national development

(i) *Studies of people's perceptions and attitudes concerning STI*

Information on these issues is available from opinion surveys that have been carried out more or less systematically at least in the US, Europe and Latin America. We present here, very briefly, some interesting results from an Eurobarometer exercise

– Europeans and Science and Technology, dated December 2001—and from a survey conducted in Uruguay in 2003 (Arocena, 2003):

- Europeans are more pessimistic about science than Uruguayans: in the former case, 50% tend to agree with the statement that the benefits of science are greater than the harmful effects it could have, while in the latter case more than 75% agree with it.

- However, Europeans are more optimistic than Uruguayans when extreme statements are proposed to them: 16,5% of Europeans agree that science and technology can solve all problems, while only 7% of Uruguayans agree. The level of disagreement in Uruguay and in Denmark is identical: 90% .

- Regarding GMOs, Europeans (86%) and Uruguayans (90%) agree that they would prefer to know if food includes GMOs or not.

- Uruguayans tend to think that science is managed in centers of world power: 45% agree that science is managed by MNCs and 41% agree that science is managed by the government of rich countries.

- A fair proportion of Europeans (58,3%) think that the best scientists leave Europe for the United States.

- Europeans believe that the measures most likely to improve the level of European research concern not the level of investment on science, being instead related to the organization of research. Uruguayans strongly believe that public investment in science is highly insufficient, a judgment shared by 88% of the respondents. Moreover, a majority thought, even in 2003, during one of the worst economic crisis ever undergone by the country, that scientific and technological research should be supported by national budgetary efforts.

- A vast majority of Uruguayans (95%) think that the country has at least some areas where scientific and technological activities are reasonably well developed; however, 66% of the respondent think that the results of these activities, even if potentially useful for the country, are not used.

How can it be shown that this type of results bears relation to NSIs and thus to STI policy? Two examples can give an approximate idea. The fear of Europeans of losing their best scientists to the US is probably behind the emphasis on building a European scientific and technological identity, with the Erasmus program, strongly committed to that aim, enjoying a high degree of legitimacy and approval. It can be said that one of the characteristic traits of European NSIs is the importance given to the regional dimension. In the Uruguayan case, public opinion reflects how the national system of innovation is perceived: weak and not making efforts to profit from the strengths the country has managed to build in science and technology.

(ii) *Opinions of special groups and qualified informants*

A study carried out in Uruguay in the late 1990s showed several interesting results, of which we will mention here one: the majority of selected interviewees, from all the influential sectors, agreed that the sphere with less innovation drive was the institutional one (Arocena, 1997). This is a quite interesting perception, because if institutions are not able to innovate upon themselves and have little drive to promote innovation in general, the probability they have of enhancing the national system of innovation is almost nonexistent. Identifying who thinks what about different aspects of innovation (that is precisely what studies of elites' perceptions do) provides a map of possible influences upon actions that are quite telling in terms of NSI dynamics.

(iii) *Analysis of decision-making processes in STI and results*

One of the constraints that hampers the overall coherence of STI policies in developing countries is that decision-making processes related to such matters are often diffuse and, moreover, are frequently not taken as STI decisions at all. For instance, if the Public Health Ministry decides to accept a special credit line from a developed country to buy some medical devices, perhaps the ministry is making a STI decision without realizing it. That happens if the country is trying to strengthen its infant medical-engineering industry; in that case, the coherence of this part of the STI policy design is destroyed. Thus, the analysis of the decision-making processes in STI, the kinds of considerations it takes into account, the kinds of actors that intervene, the immediate results achieved, are all important indicators of the scope of the policy, that is, if it is truly national or narrowly focused in its impact.

A precondition for more coherent and more legitimate STI policies is to thoroughly analyze who its stake-holders are, being widely inclusive in this respect. Afterwards, ways of understanding the interests and positions of all of them should be sought; it is almost never possible to have a total win-win scheme for all, but having identified the ensemble of interests at stake helps to design a more robust policy and to define a more robust communication strategy to back it. In that way, better results can be expected.

Indicators of the fifth building block

ANTICIPATION

Taking into account the prospective dimension, in order to prepare today ways to cope with fundamental issues of tomorrow

(i) *Prospective studies on risks and possibilities related to STI: opportunities opened by recent scientific and technological developments*

"Technological intelligence" on the avenues opened by new technologies, as well as possible dead-ends for traditional ways of doing things, are of utmost importance to every country. For developing countries the need can be even more pressing. An example of this kind of "technological intelligence" is related to microelectronics, an industry which in general terms is out of reach for the majority of developing countries. However, some technological developments, particularly those related to improvements in the design of semi-custom chips and in the manufacturing of small batches of semiconductor components, have provided a wealth of opportunities to those countries that recognized their potential for different applications. In Uruguay, for instance, internationally competitive electronic pacemakers were developed partly because this opportunity was seized by a research group that established knowledge linkages with the national firm producing them. Many other important applications can follow from the research capacity built around this issue, particularly to add value to the meat industry, one of the most important for the Uruguayan economy.

It is worth stressing that if a new scientific and technological development is to be applied to local problems, a sustained effort at the level of training and research will be needed. This demands selecting very carefully what should be done, because the selection will probably define the orientation of several actors for quite a long time. This highlights the importance of looking into the future through the mobilization of common learning processes. In any case, well-crafted visions of the future can shape the present.

(ii) *New orientations in the training of human resources*

To detect and to evaluate the roads opened by new technologies, many of them must be studied, certainly far more than those which will be finally followed. This is why it is not advisable to have too narrowly focused a policy for research and for human resources training, the two highly intertwined sides of the "knowledge coin". For instance, it is possible that for quite some time the results flowing from nano-technology will not be incorporated to any productive activity in a country like Uruguay. Is this a sufficient reason not to make a modest effort to gain knowledge on a technology that is perceived as truly revolutionary and with impact on a vast array of industrial fields? [deletion] Fifty years ago, a visionary researcher in the Institute of Electrical Engineering of the University of the Republic made the following statement, inspired by a prospective insight: "the world is digital" — an odd remark in a country like Uruguay. Guided by this inspiration, a research agenda on digital electronics was set, great world researchers were invited to the country, specialized infrastructure was installed and undergraduate curricula were updated. The result, fifteen years later, was that Uruguay was able to design, manufacture, install and maintain the world's first small and modular digital central exchange for telex communication.

The need to be aware of the many different avenues signaled by the emergence of new technologies should not be equated to trying to perform "big science", nor should it be understood as a reason not to define research agendas and training schemes adapted to the country's circumstances. The point is, precisely, to define both "thinking globally and acting locally". This way of thinking can overcome two common constraints in the design of STI: being too "provincial" and shortsighted, on the one hand, and being too mimetic, that is, too much of a "fashion-follower", on the other.

(iii) *New requirements and challenges issuing from transformations in world trade*

Nowadays, transformations in world trade are a powerful inducement to technical change. NSI configurations need to cope with these transformations. The building of high-level national thinktanks around technological issues to discuss at WTO, typically on levels of protection or intellectual propriety rights, is an expression of this need. In relation to the ability to cope with this kind of needs, and making a parallel with the concept of myopic and dynamic systems of innovation (Patel and Pavitt, 1994), we can think of "passive" and "challenging" NSIs. The former would be those that lack institutions capable of analyzing the impacts of the transformations in world trade and to formulate national positions to defend national interests and profit from new opportunities; the latter are those able to turn some aspects of globalization to their national advantage. In this sense, Costa Rica's position regarding environmental issues, or Brazil's and India's fights on pharmaceutical generics to treat AIDS, can be seen as manifestations of challenging NISs. In Uruguay, an important meat-producing country, signals about new requirements on meat quality control were not recognized as innovation opportunities, but only as new trade requirements. As a consequence, the country failed to design and manufacture millions of microelectronic devices to trace the sanitary history of cattle, because when the use of these devices became mandatory, almost ten years after the first signals began to appear, the only solution at hand was to import them from an foreign firm, due to previous inaction. This is a typical trait of a passive NSI.

Indicators of the sixth building block

SPECIALIZATION

Promoting studies, agreements and actions that shape an efficient long-term productive profile in selected areas

(i) *Knowledge demand in selected areas*

Coping with changes and challenges in selected areas is a precondition for fostering long-term productive profiles in such areas. Examples are the constraints in electronic pacemakers related to the rapid process of device miniaturization; in forestry, to the amount of water resources spent; in fruit production, to weather control, particularly in relation to frost. Studying such processes offers precious information for the setting of research agendas, the design of specialization and updating courses, and for international cooperation.

(ii) *Qualified personnel in selected areas*

In the same vein, a precondition to be able to follow some productive specialization paths is the availability of qualified personnel in related key scientific and technical areas. For instance, an indicator of Uruguay's capability of to excel in the food industry is the existence of a specialized career in food technology, that is, a single and specialized career, not the sum of several and separate fields of expertise. It exists, but it took too long to become operational. Today, an indicator of the country's capability of the to concentrate in biomedical devices is the existence of chairs in biomedical engineering and medical physics common to the schools of medicine and of sciences and engineering. In this sense, the diversification of the training offer is a good indicator of the vigor of the specialization processes.

(iii) *Export performance in selected areas*

Exporting is a key indicator of success for any productive area, and quite straightforward to measure. However, the success of a specialization should not be measured exclusively by what we may call "direct exports". In Uruguay, for instance, biotechnology, even without showing great export dynamism for the moment, makes a key contribution to the export prospects of other areas. The same can be said about microelectronics, which helped the wool-scouring industry gain in efficiency through tailor-made systems to control the operations of its productive plants. Even a field of basic science like evolutionary biology has made a contribution to raw wool producers by devising an instrument to detect ancestors, through which sheep breeders could select animals that did not have undesirable traits, thus increasing the price at which the raw material was sold in international markets. So, specific indicators of "indirect exports" need to be devised, as a way to gain a better understanding of the complex relationships between knowledge and production.

Recapitulation of section III

In the first part of this section, as an example, we offer a very preliminary estimate of costs in the case of Uruguay for a list of policy instruments that can help implement each "building-block" of an STI strategy. Summing up, we obtain the following table.

Estimated total annual cost of policy instruments for each building block (in US$)

Building block	*Average annual cost*
Capabilities	7,780,000
Opportunities	8,399,000
Linkages	3,390,000
Citizenship	530,000
Anticipation	115,000
Specialization	560,000
TOTAL	20,774,000

Although in-depth studies have not been carried out recently, it is usually assumed that Uruguay invests in R&D about 0.25% of its GDP; combining that figure with economic forecasts for this year, that would be more or less US$ 40 million. Adding the estimate summarized in the above table we would still be below 0.4% of GDP, not an impressive result really, but nevertheless such additional investment could make a big difference, in both the short and the long term.

In the second part of this section we discussed some indicators that may be useful for a systematically updated assessment of the STI situation and of the results of STI investing. The following table summarizes those indicators and indicates the "building-block" of policies to which each indicator is mainly related.

Table
Building blocks of a STI policy and examples of indicators for each block

Capabilities	***Opportunities***	***Linkages***	***Citizenship***	***Anticipation***	***Specialization***
Strengthening learning possibilities	*Enhancing knowledge demands*	*Promoting articulations*	*Fostering STI involvements and consensus*	*The prospective dimension*	*Selected productive areas*
Graduates and postgraduates		Analysis of experiences	Attitudes concerning STI	Prospective studies on STI	Knowledge demand
Follow-up of professionals		Qualifications in firms	Opinions of special groups	Opportunities opened by S&T	Qualified personnel
Connections with diaspora		Participation of weak actors	STI decision-making	New conditions of world trade	Exporting performance
Attributes of research groups					
Knowledge-based SME					

Concluding remarks

Innovation Systems are complex structures. They include many collective actors and different relations between them. In developing countries, actors are often weak and relations virtual rather than real. Strong investments and diversified policies are needed to back actors and improve relations. In this paper, six quite different but complementary "building-blocks" of policies and several policy instruments for each block have been considered; a preliminary evaluation of costs has been presented. That qualitative and quantitative description of 45 policy instruments can be useful in many ways, for example, by offering concrete alternatives to international cooperation. Indicators for each building-block have also been presented; jointly studied in a given situation, they may give an idea of how STI policies are working.

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Notes

[i] This consideration should include a differentiation between national and foreign providers, a distinction that has been blurred to a great extent by globalization, but has not totally vanished. Relying on the efficiency attained by developed countries in the provision of goods and services could lead to a worrying dependency on such providers. The thorny question of building capabilities, as a plus or a minus of technological decisions, should always be kept in mind.

[ii] "Wartime led to a dramatic increase in government involvement as supporter of academic and industrial research..." (Mowery and Rosenberg, 1994: 123).

[iii] "Scientific investigation is by nature surrounded by uncertainty, and even more so when searching for major scientific breakthroughs. On the whole, three scenarios can be identified in relation to the investment on targeted scientific research: (1) one searches for something but never finds it; (2) one searches for something and finds something else; (3) one finds what is being looked for" (Archibugi and Bizzarri, 2004: 1658). In this last case, "the massive concentration of human and economic resources on specific projects allows one to obtain the results one is aiming for", as a "consequence of strong financial and political commitment" (ibid.). This strong commitment, that can be found in many developed countries and in some cases in developing countries, always involves investment decisions taken in the public sphere with public money.

[iv] "We define the stickiness of a given unit of information in a given instance as the incremental expenditure required to transfer that unit of information to a specified locus in a form that is usable for a given information user" (von Hippel, 1999: 61)

[v] Michael Polanyi's short characterization of tacit knowledge –"we know more than we can tell"- can be enlarged as follows: "...an art which cannot be specified in detail cannot be transmitted by prescription, since no prescription for it exists. It can be passed on only by example..." (Polanyi, 1958: 52-53, quoted in von Hippel, 1999: 62)

[vi] "In this paper we argue that the ability of a firm to recognize the value of new, external information, assimilate it, and apply it to commercial ends is critical to its innovative capabilities. We label this capability a firm's absorptive capacity and suggests that it is largely a function of the firm's level of prior related knowledge." (...) "We argue that the development of absorptive capacity, and, in turn, innovative performance are history- or path-dependent and argue how lack of investment in an area of expertise early on may foreclose the future development of a technical capability in that area. (...) prior related knowledge confers an ability to recognize the value of new information, assimilate it, and apply it to commercial ends. These abilities collectively constitute what we call 'absorptive capacity'". (Cohen and Levinthal, 1990: 28)

[vii] Agrarian research in Latin America is carried out mostly in public institutes, a difference with most developed countries where this research is mainly done in universities. Outstanding organizations of this type are Brazil's Embrapa and Argenta's INTA. In almost all Latin American countries organizations of this type exist, and they have strong relationships with producers.

[viii] One of the explicit goals of CNPq, stated when it was created in 1951, was to help redress the Brazilian industrialization process, characterized at that time by the production of durable consumer goods and the imports of capital goods and foreign technology.

[ix] This marks another difference with Brazil, where a powerful institution, SEBRAE, devotes specific efforts in relation to the technological upgrading of SMEs.

[x] The FONDEF (Fund for the Promotion of Scientific and Technological Development) was instituted in 1991 with the aim of improving R&D. The objectives of FONDEF are to improve the productivity and competitiveness of the major economic sectors by means of better R&D, both in quantity and quality, better transfer of technology and techniques to the productive sector, and increased R&D in areas of great national interest.

[xi] The evaluation made by local officers of the IADB Uruguayan S&T loan went in that direction: given that more than 80% of the recipients of the projects awarded the first loan belonged to the public research university, they evaluated negatively the overall results obtained. The problem, however, was not a "predatory" behavior on the part of basic scientists, but the extreme cognitive weakness of the potential participants in the business sector, that was not correctly envisaged by the program design.

[xii] At a deeper level is the cultural problem of the lack of social value attributed to technical, hands-on work, that lead to a relative scarcity of technicians, a fundamental leverage of technological upgrading.

[xiii] Again, the contrast with the situation in developed countries is striking. When the European Commission released in September 2002 the communication entitled "More research for Europe: towards 3% of GDP", a wide consultation with several actors, including firms, was launched. "Industry reaction to 'More research for Europe' showed unambiguously that the main factors considered by firms when deciding whether and when to invest in research are the availability of abundant and excellent researchers and research personnel, a vibrant, world class public research base, improved public financial incentives…" (Commission of European Communities, 2003: 12).

[xiv] A different approach to these issues can be seen in Bértola et al (2004).

[xv] The following categorization of procurement policies has been proposed:

"*(1)* *Creative* procurement policies: procurement in which the purchaser conceives the idea, identifies potential users for it, and puts out to contract the development and production of the final product;

(2) *Constructive* procurement, in which the purchaser specifies the desired product, but leaves the detailed product design to the suppliers, with detailed discussion taking place with each potential supplier before a formal competitive tender exercise takes place; and

(3) *Tactical* procurement, involving the pursuit of immediate short-term objectives by the purchaser without regard of longer-term implications e.g. pursuit of lowest purchase price without regard to product life-cycle costs or future security of supply." (Hutton and Hartley, 1985: 206)

[xvi] This instrument, as well as some others included in this text, was considered in Arocena and Sutz, 1998.

[xvii] "In innovative circuits we often witness the relevant role of "technological tailors", that is, teams or firms capable of elaborating a knowledge-intensive solution "tailored" to the specific aspects of the problem under consideration, its scale and available resources. Solutions of this type, particularly when the problems are posed in small peripheral countries, are not usually available in the international technological market. Consequently, those problems may induce innovations and learning processes with a strong national dimension." (Arocena and Sutz, 2002).

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The graph on the cover, generated by means of fractal geometry model, simulates a pattern formed by three ring vortices playing catch up with one another (also called 'chaotic leapfrogging').

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