Economic Development and Innovation: Problem-solving in Scarcity Conditions

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Abstract

The aim of this paper is to contribute to the debate about innovation in developing countries. Innovation is not an unchanging element pervasive under all socio-economic conditions. We suggest that under the conditions of scarcity that prevail in underdevelopment—broadly understood as "not having enough" of inputs that are taken for granted in actual contexts characterized as industrialized—technological effort of a substantially different type emerges. Idiosyncratic innovative paths are followed; they may provide solutions for *otherwise unsolved problems*. We sketch a scarcity-induced innovation framework to give account of such paths; we suggest that this framework helps in understanding the specificity of "innovation under scarcity conditions" in developing countries. This understanding is critical for developmental purposes; we make a preliminary contribution.

Keywords: technological change, scarcity, problem-solving, innovation, economic development, local needs

JEL codes: O1, O33, Q55, B52

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1. Introduction: Recognizing the problem

This paper sketches a framework for thinking of economic development and innovation that focuses on the local relevance and application of varied types of technological effort particularly problem-solving, but viewed through a cognitive lens.[1]

We focus here on industrialization. "Development" in the form of industrialization is, at its core, an engagement of people with technology and certain types of production systems. This engagement, however, does not reproduce identically all the paths of technology incorporation present in contemporary developed/industrialized societies. Industrial dynamics and industrial structure evolve over long periods and are affected by day-to-day changes and challenges in the working environment. Cognitive, social, and economic factors, alongside technology, old and new, are present in these day-to-day challenges, shaping different types of specializations.

The contexts in which developmental processes take place are embedded in scarcities of various types that are not widely present in developed societies: this is a strong source of differentiation in technology incorporation. We are referring here to scarcity not in absolute terms but in comparative terms, and on what constitute a general ambience. Scarcity conditions thus include—without any pretension of a taxonomy at this stage—problems at the level of infrastructure that is missing or is not up-to-date, of access to materials and equipment of the required quality or accuracy, of institutional support for the building of endogenous capacities, of enough people with appropriate skills to run projects or discuss ideas, and of money to rely on well-known solutions. Even more importantly, we are talking about people that know that they live in a context shaped by scarcity, that is, who know that other conditions exist and other solutions exist as well elsewhere.

Under such conditions, cognition and problem-solving adapted to scarcity emerge. Some scholars might view this as a "temporary stage" along the way to technology homogenization, not deserving much attention. For example, the level of attention focused on the end outcomes and spectacular success in technology incorporation exhibited by some latecomer countries, particularly in East Asia, supports such a view. The peculiarities of the scarcities along the way are then primarily a story of means to an end, not of interest itself. However, in the wider context of the developing world, these economic success stories (such as East Asia) are the exception, not the rule. An immense number of countries with different intensities of industrialization exist. Thinking about such countries purely in terms of a long, linear march to the East Asian model (or other) distracts us from understanding how innovation occurs in other settings, or how such problem-solving may be well-suited to the conditions at hand. Specific forms of cognition and problem-solving adapted to scarcity conditions are thus one of the ways of technology incorporation in developmental processes: they are not competitive but complementary to the more classical ways of technology transfer. If properly understood and valued, they can affect, in the long run meeting local needs, production structures, forms of technological effort, and perhaps wider industrial dynamics.

2. Problem-solving by "doing things differently"

People that deal with technological issues in industrializing countries, be they researchers at the bench, engineers in productive endeavors, or those working with everyday machines of various types, often recognize that they learn and perform some of their activities differently from the "canonical" way. These differences have manifold expressions. Apparatuses can be calibrated

[1] We use the term industrialization to highlight problems of development. "Underdevelopment," of course, implies a value-laden concept. We use the term here not to refer to a comparative means of analysis with other countries, in some "catch-up" framework, but to highlight that countries are changing internally in their move towards industrialization. Other equally valid terms might be "industrializing countries," or countries of the "South."

following “idiosyncratic” procedures because the canonical requisites to do it “properly” include other apparatuses that are not available; devices can be invented or redesigned to produce specific outcomes, even if devices able to produce those outcomes already exist, because the latter are too expensive or have been designed to fit into contexts that do not work in local conditions; machines and materials can be used efficiently but differently from their original purpose. It is surprising to note the ease with which researchers and engineers that were educated or have work experience in industrializing countries acknowledge this “idiosyncratic” technological behavior; perhaps they have not thought much about this issue, but once it is raised they immediately recognize the pattern and confirm its occurrence with a variety of insightful examples. In other words, people working in such contexts instinctively recognize the expression “to innovate in scarcity conditions” as a telling way to describe how they overcome difficulties in problem-solving activities.

We now differentiate three broadly different situations associated with this expression, all related to “doing things differently”:

1. One implies searching for different solutions to problems that have been already solved because existing solutions are inappropriate or unaffordable, including the necessity of adaptation stemming from specificities of the natural endowment.
2. The second implies taking as a point of departure for innovative efforts the situation of prospective users that face scarcities of some type.
3. The third one implies developing specific “scarcity-driven” strategies to deal with well-identified but not yet solved problems.

As we discuss later, the cognitive dimension of our “scarcity” approach underscores the fuzziness that innovators may initially experience in conceptualizing the problem they wish to solve.

We now turn to why a new way of thinking of this type of innovation may be necessary.

3. A misguided quest for institutional uniformity in innovation?

A remarkable level of attention has been invested in studying innovation: how to do it better and more rapidly, why some do it better than others (including nations), and how to encourage some types more than others. Most of this has been driven, quite understandably, by the desire for economic growth fueled by technological change. While the original thrust for understanding innovation in the context of novelty arose from histories and case descriptions of advances in science and engineering (a la Lister or Edison), subsequent interpretations of innovation have rested almost entirely in the realm of the commercial and competitive possibilities of such advances. Not surprisingly, the field of economics presented some of the most compelling initial frameworks of novelty, learning, and commercialization.

The overwhelming dominance of innovations originated in developed countries had led to conceptualizations that tend to: (a) categorize all innovation to be of one universal “flavor” and (b) associate innovation with input resources of a specific kind, in contexts characterized by abundance. However, in “underdevelopment” in the industrial process, there is another logic related to innovation: rather than starting with available inputs, innovation often starts facing the lack, weakness, or inadequacy of inputs.[2]

These two characteristics of the current conceptualization on innovation have, by suggesting a universal class of innovations based in a common history, led to over-correctness in language of innovation research that assumes no overt differences in learning capabilities between North and

[2] While it is true that lack of certain inputs exists even in advanced industrialized countries, and in many high-tech, R&D laboratories, the ingenuity of the innovator under such circumstances can still be differentiated in qualitative terms, from the general ambience of scarcity in the conditions we are referring to.

South. Such differences exist, though (Adeboye 1997; Arocena and Sutz 2003). We are not implying that, in countries where scarcity conditions are the most common framework of problem-solving activities, all innovations are oriented by a "scarcity logic." What we claim is that this type of innovation is important in many respects, particularly for providing solutions to problems that otherwise would have remained unsolved i.e. technology's "local relevance." Whether or not it disappears when the country "develops" is an important question for future research on both economic and social change, as well as for innovation research.

Our aim here consists of highlighting real innovation practices that have in common some type of scarcity, as succinctly described before, as its driver. This line of reflection, focusing on the micro-level innovation process itself, may add to the understanding of the "larger" frameworks for studying comparative national innovation and economic histories, particularly those stemming from the National Systems of Innovation approach (Freeman 1987; Freeman and Lundvall 1988; Lundvall 1992; Nelson 1993). This is not attempted here, though, and much more research and reflection is needed to advance in that direction.

Overall, the literature on innovation and economic growth on the one hand, or innovation and economic development on the other, assume that the "innovation" in question is of one type. The explicit linking of innovation to economic development as a *process* of learning, *varied and dependent on the particular development environment*, has acquired some preeminence in the innovation literature mainly recently (see for instance Hobday 2002 and many of the works presented at the Globelics conferences). Studies that focus on learning and technological capabilities come closest to our attempt here (Katz 1987; Cohen and Levinthal 1990; Bell and Pavitt 1993; Kim 1997; Lall and Teubal 1998) to underscore the importance of how knowledge is articulated, utilized, absorbed, and exploited. Further, they draw a thread between firm-level capabilities and learning, to industrial-scale successes or failures. The learning environments of advanced industrialized and industrializing countries are significantly different in many ways; these differences lead to differences in skills, as it has been already acknowledged in some industrializing countries' literature. Moreover, literature coming from industrializing countries has since long tackled this issue (see for instance, Katz 1976), and the pioneering works on National Systems of Innovation already mentioned have contributed in that direction, too.

The articulation in the post-war years in the field of economics, of the idea that innovation arises from input resources of a specific kind was hugely influential. In the early literature, to the extent that such examples were greatly augmented by World War II and its post-construction phase, these innovations came to coincide not surprisingly with focused resources, ever-increasing in size. Universities, firms, government laboratories, many of which came into being earlier, were spurred on by the intent of innovation for the war effort for the national good. Industries such as chemicals, pharmaceuticals, and electronics were a greater source of innovations of this type. In the post-war years, depending on the country, institutional re-formation occurred to varying degrees, drawing on legal, educational, financial, agricultural, industrial, and health reforms that galvanized the inventive activity through the implicit linkage with economic growth and national need.

Indeed, even as critiques of neoclassical models appeared on the horizon, they drew attention of the reader to the inadequacies of the production possibilities frontier. Furthermore, the development of knowledge, through "learning by doing" described by Arrow (1962), focused on capturing the primary characteristic of the innovation, assuming that, more or less, *most* resource and institutional elements for the search and experimentation were satisfied. Later work by Nelson and Winter (1982) on routines further laid the basis for the translation of individual competencies into sustained organizational and institutional responses to knowledge absorption and generation. The dominant discourse today however, continues to be one where economic growth or development is equated with industrializing countries' trajectories or innovations becoming more like those of advanced industrialized nations, as various early "catch-up" arguments resting on "stages of growth" advocated. Indeed "latecomer" or "catch-up" models imply (even desire) that eventually the processes will look similar. Unlike these, our effort does not focus on convergence but is shifted away from comparison to contrast, directed at current underdevelopment, or semi-industrialisation, where learning has some unusual characteristics. The question of whether the *scarcity* situation of industrializing countries fosters special types of skills deserves more attention. We need ways of conceptualizing this and add to the intellectual toolkit some concepts that, even if not necessarily new, have not been so widely used for this purpose.

4. Scarcity and problem-solving

To use scarcity as a guiding concept, it is necessary to clarify the term.

First, scarcity is a constraint in landscapes that present difficulties in relying on available solutions to some problems or in following paths that are being pursued elsewhere: we shall take "underdevelopment" in the industrialization process as a proxy of such landscapes. This selection deserves many critics. Industrializing countries often display huge disparities in wealth between regions—Brazil and India being two well-known examples. They display as well huge social disparities, and so the inability to rely on modern technological solutions does *not* affect the whole population of persons and firms. For the well-off part of the population these can be perfectly adequate and affordable; for a vast majority of very poor people or for traditional small and medium enterprises, they probably do not count as solutions. However, given that underdevelopment is a consensual way of characterizing internal conditions of severe and diverse types of scarcities, we will assume this framework for analysis.

A second necessary clarification is that we deliberately move away from traditional factor scarcity frameworks used in economics, because for innovation purposes they appear to mislead considerably. Factor scarcities—in the sense of strict inputs—disguise two basic realities in contexts of industrialisation: first, that *institutional* scarcities do matter, and second, that innovation may occur despite (and as we show below, sometimes *because of)* factor scarcities in the economic sense. Thus, in terms of induced innovations, the strict microeconomic model's requirements of articulating a well-defined choice set, the maximizing choice rationalization and the use of the factor substitutions *may not be necessary* to analyze the types of innovations we describe below. The evolutionary economics model (Nelson and Winter 1982) highlights some elements that are important for our framework, like local search, certain degree of imitation, and satisfying behavior. However, even these elements emerge differently in practice of innovation in the preliminary framework we develop (see Ruttan 1997 on induced innovation approaches, many of which rest on factor scarcity).

A third clarification relates to the differences between adaptation efforts and the capacities to innovate in scarcity conditions. Adaptations have some of the ingredients of innovation in general, particularly because they often rely on different ways of combining already known issues. Moreover, the need for adaptation often arises from scarcity conditions. But we are talking here of innovations in the strict technological sense of the term: new and different ways of solving problems, not only adapting pre-existing devices and procedures to a given context.

We can describe this then as scarcity-induced innovations (SII) emerging from at least three important characteristics.

The first one is of a *cognitive,* twofold type: the canonical set of solutions can be relatively obscure and often even absent from the mental landscape of the innovator, or the innovator, even being aware of such set, is unable to use it and faces the need to address the problem differently.

The second one is structural/institutional—*institutional or physical*: lack of supporting organizations, laws, and technical instruments.

The third characteristic is *socio-economic*: as already mentioned, when problems affecting developing societies have not been tackled at all, or the solutions available are unaffordable, new searching avenues need to be pursued. All this changes the micro-process of technological effort and innovation.

From a "developmental" point of view, though, there is a dynamic that deserves special attention and may be a manifestation of the previous three: SII usually do not *"scale up."* Individual capabilities do not translate into appreciable transmissible means of knowledge (possibly equated with routines). SIIs are, more often than not, "encapsulated" innovations. They can be "locally strong" capabilities but they remain isolated, precisely due to the difficulties on cognitive, structural, institutional, and socio-economic dimensions (Srinivas 2005).

We shall fix ideas on scarcity, referring to industrializing countries with i) restricted access to possibilities that are to a good extent abundant in highly industrialized countries, and ii) demands that have been to a great extent already solved there. This implies, on the demand side, unsatisfied basic needs related to health, food, shelter, transportation, sanitation, and water supply; on the problem-solving side this implies, importantly although by no means exclusively,[3] lack of resources, particularly financial resources, to adopt already known solutions.

Some part of the innovation that occurs in underdeveloped countries is a strange animal, hard to recognize, at least in part, because we usually look for innovations with theoretical insights that unwittingly leave the strange animal to continue in darkness. We rarely ask the question "why?" regarding the initial environment for innovation as it affects the *micro-characteristics of the innovation process itself*, a question which answers require various perspectives. Which of these are ours? Our reflection stems in part—and hopefully can contribute to—the field of industrial dynamics and innovation studies, because we identify a special set of innovations. It can thus be related to studies on development, because we suggest that it deserves the design and implementation of specific hybrid innovation and development policies—including skills-focused and educational policies—to capture the differentiated technological effort and local relevance inherent within SII.

It is important to stress that scarcity as a potential source of innovativeness should not be reified, because extreme scarcity can be a serious obstacle for innovation and development.[4] Nevertheless, with the caveat stated, scarcity as a source of a peculiar and very central type of innovation deserves considerable attention. Innovation theory acknowledges various forms of experienced-based learning leading to innovation, which are seen as varied forms of a universal set. Our analysis un-packages another member of this set, scarcity-induced innovation, mainly present in developing countries. SII is a member of this set and not just a collection of scattered anecdotes. It is not easy to

[3] Scarcity includes important educational issues: quality of primary and secondary schools and, particularly, extension of technical education.

[4] At least some research (most familiarly in the environmental field) leads to this conclusion, as the following statement suggests: "Resource depletion and degradation in poor economies may have their most inimical effect not by directly constraining growth but by indirectly affecting the potential of these economies to innovate…" (Barbier and Homer-Dixon 1996).

recognize as such, that is, as a category in its own right, probably because it does not fit well in the theoretical framework with which we usually approach technical change and innovation. As Rosenberg (1969, 3) earlier suggests, “Perhaps what is needed is to break out of an excessively restrictive competitive framework and to approach the problem of technological change from different vantage points.”

A main contention of this paper is that scarcity conditions are at the source of an idiosyncratic way of defining and solving problems in industrializing countries. The “defining” part has to do with needs, wants, demands, and constraints; the “solving” part, with ways of addressing them.

Innovation in isolation, if it ever existed, is a rare event: innovation is not only contextual in the sense of being, eventually, specific to a context, but in the sense that the process of innovation takes place within a context. Globalization, as well as linking technologies in information communication realms, has enormously enlarged the context in which ideas and artifacts for innovating activities originate. They have not, however, homogenized the contexts where concrete innovations take place; moreover, they probably have accentuated already existent asymmetries, particularly between highly industrialized countries and underdeveloped ones.

The term “idiosyncratic” is used tentatively, without any pretension of differentiating good from less good designs, or efficient from less efficient performances. It is used to stress the existence of different approaches to solving problems that are not totally independent—in which case the term idiosyncratic would not make sense. Given a determined problem, a “canonical” approach or solution can be conceptualized as one that is well-known, has wide acceptance in the market, and can be accessed in a relatively standardized way. In face of the same problem, an “idiosyncratic” approach or solution is one that shares some features of the canonical way of addressing the problem but differs from the canonical solution more or less radically. Furthermore, interpretation about the place of a “canonical” solution in a pantheon of known solutions or attempts is an extremely contextual exercise.

Solutions are always relative: they are such for some people in a given circumstance and can be no solution at all for some other people or in different circumstances. This is so because problems are solved within a determined set of conditions, restrictions, or constraints. If the “unit of adoption” of a solution for a given problem is immersed in a set of conditions or restrictions sufficiently different from the one in which a canonical solution to that problem or type of problems was designed, the latter can fail to be a solution for that adopter. Moreover, the set of conditions suggests, to some extent, the path to search for solutions. If a certain ensemble of technological inputs can be used to design a performing solution, without constrains of access or cost, designers will probably identify it and use it. If this set of inputs is out of reach, for any reason, designers will search in other directions (assuming a minimal set of supportive conditions). The result of that search can be that some inputs are replaced while the overall logic of the original design is maintained; such design can also result totally transformed. In either case—or in any of the intermediate ones—different sets of conditions gave rise to different paths for searching, leading to different solutions.

Many problems that have proved to be solvable in developed landscapes frequently have solutions that are out of reach in the developing ones, due to a diversity of reasons that can be put under the common label of “scarcity” or “resource-constrained” conditions. This, along with the fact that only a tiny part of all world research effort is devoted to problems mainly present in poor countries, limits severely the possibility of finding ready-made and performing solutions to fulfill innovation needs in those countries. “Not having enough” prevents in many cases the easier ways of technology transfer, mainly technological imports; it may stimulate, though, new patterns of creativity.

The contexts where the appearance of idiosyncratic solutions can be found usually differ significantly from those where canonical ones are present, but they share a common framework of thought, making use of modern knowledge to solve problems. In this sense, solutions belonging to ancient or traditional knowledge are not idiosyncratic but simply different. Is an idiosyncratic solution an innovation? Even if some of such solutions can be not sufficiently new to be accepted for patenting, they can be understood as innovations, both in Schumpeterian terms—they imply a new process, a new product, or a new combination of already known processes and products—and in subjective terms: "An innovation is an idea, practice, or object that is perceived as new by an individual or other unit of adoption" (Rogers 1995, 11).

Searching and designing processes are influenced by "input side" and by "demand side" conditions. The latter include the spending capabilities of the prospective adopters of the outcomes to be achieved through those processes. The input side is also powerful in delineating the landscape where searching and designing occurs. "…Search is distinguished by what we may term its *contingent* character. Real search processes take place in specific historical contexts and their outcomes clearly depend in part on what those contexts contain in the way of problem solutions that are available to be "found." What there is to be found consists in large part of the fruits, by-products, and residues of information-producing activities elsewhere in the society" (Nelson and Winter 1982, 172).

Roughly speaking, the input side and the demand side conditions configure "technological universes," where people search for and design solutions. One of such technological universes, mostly present in industrializing countries, is characterized by scarcity, as already referred to. To innovate or to solve problems there requires the development of a series of skills—learnt by doing, by searching, by interacting, by solving—that are idiosyncratic: we term them *capacities to innovate in scarcity conditions*.

Given the preeminence of advanced industrialized countries in technological outputs in relation to the rest of the world, it is commonsensical to conceptualize the ensemble of processes and artifacts developed there as canonical. They are well known, have wide acceptance in the market, and can be accessed in a relatively standardized way: not surprisingly they are usually the first try to solve problems in any industrializing country. In some occasions, though, they are not appropriate; this lack of appropriateness is sometimes addressed by idiosyncratic solutions, in the sense explicated before. The eventual inappropriateness of some canonical solutions derives from differences in the input side as well as in the demand side in advanced industrialized and industrializing countries. In a general way, these differences can be expressed as the contrast between a technological universe characterized by abundance and a technological universe characterized by scarcity. The common sense of the designers of solutions evolves differently in both technological universes. Engineers, researchers, medical doctors, agronomists, and architects, acquire, respectively, a "common sense related to abundance" and a "common sense related to scarcity" that usually give rise to different heuristics to solve problems.

We present now some of the reasons that lead us to analyze the issue of "capacities to innovate in scarcity conditions," as well as to explicitly state what we do not want to mean by that. These reasons justify as well why we understand that this concept is worth exploring.

i) It is not possible to solve problems in underdeveloped countries relying exclusively in the capacity of problem-solving accumulated elsewhere.
ii) This is so because, in the first place, some problems are idiosyncratic enough for not having been faced elsewhere and so there is no solution available for them; secondly, some solutions can turn out to be no solutions at all when applied to a context

sufficiently different to the one where they were successfully designed and applied; this is why even adaptation of existing technologies is always difficult to judge.

iii) The capability to solve problems is an important part of the self-esteem, at nation level and for individual people; self-esteem is fundamental to start a problem-solving process, particularly because it is always uncertain.

iv) Being able to solve problems relying on own forces is important not only for the technical achievement per se but for the enhancement of self-confidence that it brings about; this is said without any pretension of autarchy, for an intelligent problem definition and solving ability would include, at some level, the ability to recognize when to make, when to buy, when to combine.

v) Solving problems in contexts where even simple things, available everywhere in the advanced industrialized world, are missing or are too expensive to be part of a solution, implies a challenge that must be faced with high doses of creativity; this creativity must be allowed to be deployed: in principle, nobody knows ex-ante how to solve problems in ways that differ from the canonical ones; moreover, nobody knows how to solve problems that are categorized as challenges for the first time; often, it can even not be known where there is a canonical sense or not, thus even if solutions might exists that are "transportable," they may not be recognized as such.

vi) The creativity needed to "innovate in scarcity conditions" should be recognized, studied, praised, and gain theoretical status as a way to enter, finally, in the realm of policies.

vii) Specific policies are needed to make the best of this type of creativity, for it is fragile and almost socially invisible, being for that reasons particularly vulnerable; "invisibility" is important not only in relation to self-confidence, but also because even if large numbers of problems might have been solved in a country, policy-makers, founders, etc. can be oblivious to this, due in part to the fact that what constitutes innovation can be incorrectly evaluated and valued; and inputs into innovation are misunderstood, thus, the vicious circle is reinforced.

Finally, we *do not* imply any of the following statements:

i) The only thing that counts in underdevelopment countries are "appropriate technologies" (defined as the opposite of modern, western, high-tech, or whatever other denomination).

ii) Innovations made under scarcity conditions are "appropriate technologies" in the sense defined above.

iii) The capacities to innovate in scarcity conditions are related almost exclusively to the problems of the poor and the less educated part of the population.

5. The "ambience" for innovation

It has been said that necessity is the mother of invention; this could have been said about scarcity or resource constraints as well, since scarcity fuels necessity of a particularly urgent and vulnerable variety. Economic historians have described how specific constellations of resources, some scarce and some abundant in relation to the context in which first innovators operated in industrialized countries, gave rise to different solutions to similar problems. The work of Nathan Rosenberg comparing the design of machine tools in England and the United States in the XIX Century is quite telling in this respect (Rosenberg 1963). Moreover:

> "…Differences in the resource endowments and demand conditions of an economy go a long way towards determining what kind of inventions—with what kinds of products characteristics and factor-saving biases—it will be profitable to develop and exploit. (…) We need to distinguish here between

> invention and adoption. It is obvious that only those inventions which are compatible with a country's needs will be widely adopted. I am making here a stronger assertion that a high proportion of the *inventions made* will reflect the particular needs of the economic environment in which they are developed. (Rosenberg 1995a, 111, italics in the original, underlined text our emphasis).

Economic historians from the future, looking at innovations in today's highly industrialized countries will probably state that abundance, much more than necessity arising from scarcity, is the mother of invention. This includes an abundance of money to develop innovations, of highly trained people to fuel innovation processes, and of customers able to pay for the achieved outputs in the midst of a generalized culture of eagerness for the new just because it is new: to innovate in such a landscape is different from how it was in the past for today's industrialized countries and, for sure, from how it is now in underdevelopment.

Some regions affected in the past by huge scarcities, like Scandinavia, were nevertheless able to develop into highly industrialized societies, well integrated into the world market and making extensive use of knowledge and innovation. The scarcities that affect many countries in Africa, Asia, and Latin America today, however, are immersed in "underdeveloped conditions" that have shown a remarkable resistance to structural and social change. We are not attempting here to go further in analyzing such divergences in development paths, a challenging problem for economic historians. We simply want to put forward that scarcity conditions in contemporary underdevelopment do not appear to belong to the same species of scarcity that existed in early stages of today's highly industrialized countries, especially because conceptualizing scarcity exclusively related to strict factor inputs can considerably mislead with regard to innovation in today's development.

Yet, even in the literature profiling the histories of advanced industrialized countries today, there are some vestiges of a debate of scarcity. However, these are almost entirely histories of factor input scarcities, in the economic sense, not broader institutional ones. The basic premise in economics is that the subject is about the study of scarce resources and their allocation. From this framework, innovation (institutional, scientific, and technological) would appear to be something that society has to value and agree upon before resources are allocated to the process; i.e., innovation, it is presumed, is something that occurs when resources are thrown at the problem. In fact, most used metrics for measuring innovations rest on R&D spending and on numbers of skilled workers with higher education and physical infrastructure that is often state-of-the-art. The one field or sub-field within economics that explicitly devoted attention to development (development economics), while differing on multiple dimensions from the rest of mainstream economics, drew significantly on the idea of resources and allocation in the face of development. Ironically, it dwelt primarily on appropriate allocation, without dwelling on the special attributes that scarcity itself might make evident. After all, resources are not "given." They are created, interpreted, differentially applied, and spread by people, institutions, and technologies. The divergence of technological *outputs* between industrializing and advanced industrialized countries has been far greater analyzed than has been scarcity and its manifestations in technical change at the micro-level. But without analyzing scarcities and the differentiated efforts arising from them, the divergence of *outputs* is hardly surprising.

Thus, overcoming scarcity in contexts where some fundamental resources for innovation are in place, even if a "punctual" scarcity appears, differs from attempting the same aim in contexts where such resources are lacking. The case of the production of insulin in Denmark can illustrate this point. Denmark got involved with insulin production as early as 1925, through a firm, Novo

Nordisk, that exists until today and represents at present a fair share of the world market for this product. Two reasons explain this feature: the first was the early awareness of the 1920 Danish Nobel Prize, August Krosh, of the isolation of insulin and its extraction from animal pancreas. The second reason was "…the abundant (at least in the beginning) availability of raw material in Denmark in the form of calf, ox, and pig pancreas. These were all by-products in the predominantly agricultural country Denmark" (Laursen 1996, 1125). This abundance lasted until the Second World War, when Denmark's insulin production was severely affected by scarcity of pancreases. The situation was aggravated by the fact that another important industrial product of the firm, the *trypsin* enzyme, was also obtained from pancreases: "According to conventional theory, insulin and enzymes could not be extracted from the same glands. Nonetheless, the scarcity induced Novo to research on this topic; perhaps the theory was wrong?" (ibid.). This was in fact the case, and the answer was the development of fairly sophisticated equipment that allowed the company to extract enzymes from the remainder of the gland after extracting insulin. This way of producing insulin became obsolete in the early eighties with the development of a method to produce human insulin, a breakthrough obtained almost simultaneously by Novo and the American firm Eli Lilly, even if through different methodologies: pancreases scarcity was no more a restriction. A fundamental point that can be derived from Laursen's analysis is that in Novo's process of innovation regarding insulin, both scarcity and abundance played a role. Scarcity of raw material and abundance of accumulated experience, high-level R&D activities, and strong market position: it seems that "scarcity" was incidental and "abundance" was able to neutralize it. Argentina, that was a main provider of animal insulin through the local branch of Ely Lilly given its especially rich cattle endowment, was not able to pursue a comparable pattern of innovation. The country's production came to a halt when human insulin replaced animal extraction. This situation, which had serious consequences for the economy as well as for the well being of its insulin-dependent citizens (Bisang et al. 1986), can be traced to a "wrong" combination of abundance and scarcity—abundance of raw materials and, to only mention one of various scarcities, weakness of institutional negotiation power vis-à-vis multinational pharmaceuticals.

On the other hand, the situation in industrializing countries differs. Scarcity does not imply that technological capabilities do not exist in the industrializing world, quite to the contrary, as many scholars from North and South have shown (in the tradition of White 1962, McNeill 1963, Barraclough 1964, Alvares 1991). In fact, problem solving surrounded by endemic scarcities showcases ingenuity at its best, even if this process is under-researched. While it is certainly the case that even today's advanced industrialized countries face scarcities in the innovation environment, we suggest that these latter cases are "incidental scarcities," where most other elements of the innovation environment are in place and the specific instance of scarcity can be remedied relatively systematically. Contrasting with this, industrializing countries witness more "systemic scarcities": this covers a whole range of issues, from material ones to the most diverse types of institutional ones, even, arguably, a scarcity of self-confidence. So, scarcity in actual industrializing countries, particularly regarding innovation, is more an "ambience" than a well-delineated and encapsulated "incident" such as the lack of a specific input or the absence of a particular market at a point in time.[5]

[5] It can be argued that every country faces the problem of not having a thorough understanding of the whole knowledge needed to solve problems. In this sense, "developed" and "developing" countries alike face an important type of scarcity. However, the tools that each type of country has to tackle with it are overwhelmingly disparate.

6. Examples of innovation in conditions of scarcity

Scarcity conditions should not be equated with "low intensity of modern and formal knowledge" nor with "reverse engineering." In some cases, mainly associated with problem-solving activities undertaken by communities living in subsistence conditions, be them rural or urban, the modern knowledge input to the solutions found may be negligible. But in many other cases, all types of scarcity of resources coexist with rather high knowledge based capabilities in sectors from pharmaceuticals to motorcycle parts and assembly to wood stove design. In those cases, modern and formal knowledge can be used as profitably as in contexts marked by plentiful conditions, even if probably following different paths.

Discussions of technological advance in industrializing countries are often in the same breath as "reverse engineering." There is no doubt truth to this description—many indeed do work backwards from a known prototype, working primarily from a wage advantage, to produce clones in some cases and "creative" imitations in others. Moreover, the attempts of solving any of the problems described in this taxonomy can include to some extent "reverse engineering" processes. Overall, though, this characterization of innovation from industrializing countries hides as much as it reveals. What does it mean to reverse engineer given one does away with the idea of a perfect production possibility frontier and inserts scarcity, risk, and uncertainty at the heart of the debate? More specifically, how does one reverse engineer if one cannot know what the prototype looks like, or even whether such a prototype exists in the world? Certainly, our experience is that a notable variant of innovation from many industrializing countries is that, despite the scarcity and uncertainties (or because of?), novel ways of creating the "routines" so highly stressed by Nelson and Winter (1982), and in previous writing, take on new forms. For example, the following discussion shows three varied productive outcomes arising from an ambience of scarcity.

6.1. Science and scarcity: "Implementing the laboratory by yourself"

In many industrializing countries a discrepancy can be found between the quality of the scientific publications achieved and the modest, old-fashioned, and sometimes odd infrastructure in which the research work was accomplished. The latter is not at all surprising. As Eva Harris put it, "Technology is the bedrock of scientific investigation, and numerous frustrating—and at times amusing—obstacles arise when performing experiments under 'resource constrained conditions'—the latest in an endless series of euphemisms used to describe the difficult environment found in most industrializing countries' laboratories" (Harris 2004). Harris has the great merit of stating and describing an "everybody knows" situation that is rarely made explicit.

> "Making scientific tools available in such situations necessitates a fundamental analysis of the technical requirements, which then leads to clever adaptations of equipment, the use of alternative techniques, simplification of protocols and reliance on recycling. The impediments we encounter range from the mundane to the sublime, and foster the most ingenious innovations imaginable."

A fundamental point she made is the following: "By breaking down technology and reconstituting it on site, one can often achieve what at first seemed impossible, and find simpler ways of performing experiments in the process. *The key, however, is to understand the principles behind the technique, as well as its limitations*" (italics added). It is not "pure" inventiveness but its blend with a sound comprehension of the fundamentals of whatever techniques are being used that allows one to find a path to achieve equivalent results with totally different procedures. The perception from a Californian researcher working for fifteen years with industrializing countries' biological research laboratories is that "many of these adaptations lead to methodologies that cost less and are also environmentally friendlier" (Harris 2004).

"Scientific instruments may be usefully regarded as the capital goods of the research industry" (Rosenberg 1995b, 251): "idiosyncratic" ways of designing these capital goods may be the only way of participating in such an industry in industrializing countries.

6.2. Pursuing similar outcomes through different ways: Process innovations

An example of a technical solution where the actual cost makes it not available for a great part of humankind is the high quality surgical set needed to perform a procedure to remove cataracts, an affliction conducive to blindness, particularly severe in industrializing countries. The challenge is posed in the following terms: "…to invent a surgical set of equivalent quality, priced around $10, and to distribute these sets to the surgeons throughout the S.E.E. (Surgical Expeditions International, www.seeintl.org) network and other channels, who are desperately waiting for them. By discovering a way to produce high quality, inexpensive sets for cataract surgery, we may also develop an innovative, low cost solution for many other types of medical instruments" (Gresser 2003). The team assembled to tackle the problem, following specific and new technical strategies, seems to have reached a feasible prototype within the desired cost parameters, even though the cost of part of the machinery needed for production is fairly high. Anyway, this is an example of explicit recognition that to resolve problems already solved when substantially fewer resources are available implies a true process of innovation.

A wealth of examples of incremental process innovations created at firm level and induced by scarcity conditions came from case studies in industrializing countries (for Latin America in general see the work of Katz 1986; and for Brazil, Cassiolato et al. 2003). A typical statement of this type of studies is the following, related to a Brazilian firm producing machinery for cereal processing:

> "It must be stressed that the firm's productive process followed its own trajectory, fairly independent of what was going on in this same sector in countries with advanced technology. The restrictions imposed by the level of development of the industrial infrastructure, the type of labor force available, the relative prices of diverse raw materials and products, and the restrictions related to equipment imports, called for singular solutions in each opportunity."
> (Nogueira da Cruz 1986, 194, our translation from Spanish)

The scarcity perspective has some value even in more "high-tech" sectors such as pharmaceuticals, where product R&D may be considered too expensive a proposition, or where source technologies for product development are unavailable for geopolitical reasons, such as India's access to key pharmaceutical technologies in the 1950s, some of which were sourced from the former Soviet Union, others through the US or Japan. Thus, although privileged in terms of abundance of inputs through more formal R&D systems relative to their compatriots, and larger budgets for search and experimentation, many of these public and private sector firms were forced to find innovative ways to proceed—ranging from cognitive, institutional, and geopolitical pressures to do so. This initial scarcity led not only to pharmaceutical policy shifts at national-level, but also substantially different search and experimentation routines at firm-level. An Indian generic drug company with significant export markets today and a dominant position as a speedy developer and manufacturer stated the situation succinctly, "We couldn't afford products, so we chose processes" (cited in Srinivas 2004). The standard explanation of Indian process capabilities has been the process patent regime, which, while undoubtedly highly important, could be interpreted as being itself shaped by scarcity considerations and the national goal of upgrading capabilities in the absence of various resources and challenges to conventional learning (ibid.). The process patent regime then emerged as an institution to protect local firms and circumvent these challenges. The firm-level implications are complex and diversely manifested in both pharmaceuticals and newer biotechnologies, despite the fact that some Indian firms now look very similar to Western ones.

6.3. Targeted innovations for resource-scarce users

A third important way in which innovation can arise is the search for social adaptation and "lateral" uses of technologies. An article in the *Financial Times* of September 24, 2004, begins that way: "It is often assumed that innovation requires abundant resources, but as companies from developing countries have shown, creativity and a commitment to solving customer problems can be just as powerful a force." (Sull and Ruelas-Gossi 2004) The common challenge that innovative firms face in those countries is that they "must eke out a profit while serving customers with little money to spend on their products," that is, they have "to innovate on a modest budget." From the common strategies followed by these very different firms, two are particularly interesting: "they live with their customers" and "they systematize non-technological innovation." The latter means that what users do and value must be taken on board as key clues for design, as in the case of Chinese farmers, who use normal washing machines not only to laundry clothes but to wash vegetables. Innovations thus result from a mix between technical solutions and social understanding. In other words, "What these companies and others like them share is a distinct approach to innovation: they strategically exploit an intimate knowledge of their customers' mindsets, they innovate around (rather than through) technology…" (Sull, Ruelas-Gossi, and Escobari 2003).

7. Proposing the "SII framework" for scarcity-induced innovations

As a group of often quoted scholars stated: "Perhaps the highest-level characterization that is safe to make about technical innovation is that it must involve synthesis of some kind of need with some kind of technical possibility" (Langrish et al. 1972, 57). When resources are scarce, existing resources (and skills) are parsed out sparingly; the "technical possibility" frontier, in the textbook sense, meets a grave demise in such situations, for the frontier is variable, not absolute or context free. It is of little help to know that some need has encountered a technical possibility if in a given situation this possibility is, for a series of reasons, impossible to implement. Perhaps a more "development-friendly" way of rephrasing the initial approach to the concept of innovation could be "the encounter between a need and some kind of technical possibility available in a framework of constrained resources," controlled by market size, that is, a reasonably expected payoff for the effort and investment committed to foster the encounter. So, to innovate in scarcity conditions implies the capacity to find solutions to perceived problems, or to actual or potential needs, that are feasible within a certain set of technical, economic, and even cultural constraints—use-inspired, as Stokes would say (Stokes 1997).

A possible taxonomy of the kind of problems referred above is the following:

- i) Problems that have been identified as such worldwide but without actual solution whatsoever;
- ii) Problems posed and identified in industrializing contexts that do not drive worldwide attention;
- iii) Problems that had already been solved but where the solution(s) found need changes if they are to be adopted as innovations in a given context;
- iv) Problems that had already been solved but where the solution(s) found are for different reasons of no use in the context in which the problem is present;
- v) Problems of replacement: how to build a known device replacing some of its components, or the machines used in its manufacturing, by other components or instruments, obtaining similar performance.

To build on the different types of problems and their solutions described above, we attempt a schematic presentation in matrix form to describe varied technological innovations. AIC refers to advanced industrialized countries and ICs to developing/industrializing countries.

Figure 1: A Scarcity-induced Innovation Framework

	Problems for which solutions have been found in AICs	Problems for which solutions have not been searched or found in AICs
Problems for which solutions suitable for ICs conditions exist	The vast majority of solutions acquired through technology transfer (eventually with minor modifications)	Solutions to problems mainly posed in ICs and developed locally
Problems for which solutions suitable for ICs conditions do not exist	"Canonical" solutions exist, but for different scarcity reasons they are not suitable for ICs conditions	No solutions (yet) Typically health issues

Local research and local technological efforts are needed in the four quadrants to obtain efficient solutions in ICs; these efforts are, though, of different natures and strengths.

In the upper left-hand quadrant, where solutions exist and solutions suitable for local conditions exist as well, different kinds of adaptation efforts are necessary in the majority of cases. The industrialization and technological change literature captures many of these. A wealth of minor innovation stems from these efforts, which have a twofold importance: firstly, to allow machines and procedures to work properly and, secondly, to allow a process of technical learning for which accumulation is central to further improvements and for innovative capacities. Neglected diseases and some other not-yet solved or not-yet-researched problems of development fall into the lower right hand quadrant. These are cases where new technologies with truly public benefits of one type or another may be needed. Simultaneous attempts need to be made by policy at national and international levels to ensure that innovating environments within ICs also have these public benefits in terms of access to technologies and the ability to share information, people, and skills. Simply put, it is unlikely that outputs can have public benefits without some of the inputs having the same features.

The upper right-hand quadrant comprises extremely diverse needs and examples of success in the application of local capabilities. The following reflection gives an accurate idea of the technological approaches that to a great deal fall in this category:

> "For those whose idea of what an engineer is, is restricted by the role of the engineer in highly industrialized societies, what comes now may seem difficult to accept. (…) The economically insecure man in the Southern nations is (…) engaged in the task of survival, but this time, primary survival. Considering the range of odds against which he must struggle and his experience thus far in using all his wits about him to remain alive, he comes very close to being an engineer *par excellence.*" (Alvares 1991, 16–17).

In this upper right-hand quadrant are also included problems present mainly in ICs for which solutions are not available in the world technological supermarket and which have been solved in ICs exploiting the Western technological system. An example of this is the solution found to the problem of transforming dirty water into drinkable water in places where the heavy infrastructures needed for this task are not available (see United Nations 2005, Box 2.3, 24).

Finally, the lower left-hand quadrant contains particularly clear examples of "idiosyncratic" solutions. It includes the points iv) and v) of the proposed typology. A telling example of the iv) point of a truly "idiosyncratic" solution is the synthetic vaccine against the Haemophilus influenzae type B bacterium. A vaccine was developed in the USA, a biological vaccine, that dramatically dropped the incidence of this illness in advanced industrialized countries. "Few infections now occur in the industrialized world, but Hib still kills 600,000 children each year in developing countries" (Kayser 2004). The cost of the biological vaccine made it unaffordable for a public health campaign; the reason was the strategy to obtain its core compound through fermenting the pathogenic bacteria. An alternative strategy would be "fashioning from scratch" the needed compound—a chemical synthesis approach—leading to a purer vaccine and to a far cheaper production process. However, "…because this kind of chemistry is so dauntingly complex, nobody has developed and clinically tested a synthetic carbohydrate-based vaccine until now" (Kayser 2004). After fourteen years of research, a joint team of Cuban and Canadian researchers finally arrived to a synthetic vaccine that is far easier to produce and, thus, significantly cheaper than the current one. The news was widely released only in 2004, after all the clinical trials were finished; during that year a million doses of the vaccine were administered to Cuban children.

The HoneyBee network in India, to give another example, has been attempting to catalogue an enormous number of innovations at the grassroots. These and other such efforts may throw more light on the dynamics of the innovation process and limits to "scaling up."

The SII framework also provides a means by which both cooperative and competitive technological efforts can be analyzed in terms of problem classes and corresponding "capability classes." In the realm of biotechnology and human health, for instance, big countries like Brazil and India, medium countries like Argentina, or small countries like Cuba have proved to be able to obtain good results. More systematic data collection in lower income countries is necessary. The upper right-hand quadrant and the lower left-hand quadrant represent potential opportunities for such industrializing countries to build technological capabilities and to innovate in truly substantive ways; the lower right-hand quadrant holds the same potential, particularly if international cooperation is put in place, including the potential for exporting such innovations back to industrialized countries.

Besides trying to capture a "fact of life," that is, bringing to the forefront an idiosyncratic way of solving problems widely present in developing or industrializing countries, the aim of the SII framework is to facilitate the understanding of the difficulties and limitations faced by this type of innovations. Another way of characterizing these differences relates to systems of innovation. "Mainstream" innovation studies, with all their richness, need to be complemented by new approaches to fully understand SII. This is so because both intellectual efforts are directed to different objects, as depicted in Figure 2. Mainstream innovation studies analyze innovations that occur in fully fledged innovation systems, while SII usually take place in fragmented, weak, and incomplete innovation systems (compared to the former) and cannot be analysed in the same ways as simple modifications, or necessarily earlier "stages," of the former.

Figure 2: Mainstream vs. Scarcity-induced Innovation

"Mainstream" innovation studies draw on relatively well-structured landscape of :	Scarcity-induced framework refers to:
* Ideas * Institutions * Channels of knowledge transmission	*Individuals less well connected to their surroundings * Cognitive emphasis * Embedded in a landscape of relative scarcity

Any process of development must be supported by local strengths in knowledge and innovation. A good deal of these strengths in industrializing countries relate to SII. However, to transform these strengths into a developmental tool, the roots of the difficulties and limitations referred above need to be better understood.

8. Final remarks

The tentative SII framework presented above was developed to address problems that fall squarely in the ambit of technological change, innovation, and development and are grounded in micro-processes of problem solving and innovation with both cognitive and institutional dimensions. We hope it can also provide some insights into other problems of industrial dynamics with an international facet, such as different technical standards or the impact of intellectual property regimes in countries, regions, or sectors with specialisation in any quadrant or shifting from one quadrant to another. We would like to suggest that the framework elaborated here of problem-solving and innovation capabilities is close to developmental reality. More research is necessary on the cognitive and institutional elements of the problem-solving process in conditions of underdevelopment and scarcity, just as detailed histories of advanced industrialized countries have been carried out. Such an effort to conceptualise scarcity and its impact on problem-solving may provide answers to why many problem-solving and technological skills, visible in entrepreneurs and small and medium enterprises in industrializing countries, do not appear to "scale up" or lead to more robust economic development and locally relevant technologies. Such emphasis on detailed micro-processes of innovation may push studies away from "catch-up" frameworks, suggesting quite different ways in which productive technological capabilities are embedded in society, or whether certain "stages" are even necessary or desirable in economic development. There is also a need for more studies on how theories of the firm relate to industrializing countries and the nature of path dependency in problem-solving varieties.

Development, according to Hirschman (1958), depends not so much on finding optimal combinations of productive factors and resources as on using—for development tasks—resources and capabilities that are hidden, scattered, or badly utilized. Consequently, underdevelopment is essentially a state where important potentials for development are often neither used nor sufficiently exploited. We hope to have been able to convey the idea that the capacity to innovate in scarcity conditions is one of those crucial potentials and has important implications for both industrial dynamics and structure.

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