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TECHNOLOGY AND ECONOMIC DEVELOPMENT*

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* Jorge M. Katz, IDB/ECLA/UNDP Research Programme on Scientific and Technological Development in Latin America, Buenos Aires, 1980. The present paper is intended to act as the first version of an overview summary of the research hypotheses and results of a four year long exploration into the Economics of Technological Change in various manufacturing industries in some of the major Latin American countries. The research Programme has been co-sponsored by IDB/ECLA and UNDP, whose longstanding support is hereby kindly acknowledged; obviously they are not to be held responsible for mistakes or personal opinions which normally come up during the course of exploration of this sort. The initial sections of the monograph have been prepared to be submitted at the Bar-Ilan University International Symposioum on Development and Cooperation in Latin America to be held at Ramat-Gan, Israel in May 1980. The present version has been presented at the Segunda Conferencia Internacional sobre América Latina y la Economía Mundial, organized by the Instituto Torcuato Di Tella with the sponsorship of the Organization of the American States, Buenos Aires, 26-29 August, 1980.

I. INTRODUCTION

Up until recent years the student of development economics was given to think that industrial firms opening up in developing countries would normally constitute a replica of more or less similar undertakings implanted a few years (or decades) back in more mature industrial societies. It was also taken for granted that the industrial organization -degree of vertical integration, patterns of subcontracting, etc.- associated to any particular manufacturing venture would also somehow replicate the industrial organization of the original undertaking.

The notion of the 'technology shelf' stocked somewhere in libraries and archives of universities and manufacturing firms of the developed world and just waiting to be used by any odd LDC was the standard idea with which economists approached the study of the industrialization process of developing nations. More frequently than not such view was also complemented by the assumption of an almost complete passiveness from the part of the recipient society, as if no domestic adaptation efforts worth taking into account could be expected to emerge during the process of industrial transfer. 1/

Very few people would today doubt that such a mechanical description of the industrialization process of LDCs leaves more unanswered questions than those that it helps to clarify. This is so for at least two different sets of reasons. On the one hand, the argument rests on a highly unrealistic perception of what a technology, and its associated industrial organization, actually are. On the other hand, such view of the process does not capture

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1/ Curiously enough such basic theoretical background was common to both, the neoclassical and the 'dependency' school. For either one of them 'technology' was something 'produced- by developed industrial nations, and all that was left to the developing countries was a 'correct' or 'incorrect' selection and negotiation for its purchase. It is now increasingly clear that both schools of thought have grossly missed a very important link of the story, i.e. the 'domestic component' involved in each and every action related to the incorporation of new technical knowledge in any given industry or society. One of the main lessons gained from our recent research is that the utilization of technical knowledge normally carries with it the need for the generation of additional technical knowledge.

the very large differences that prevail as between LDCs in terms of economic maturity in general and, more specifically, in terms of availability of domestic engineering and entrepreneurial skills which, in a gradual and steady way, adapt to the local environment the technological and organizational 'blue prints' received from abroad. We can intuitively perceive that such adaptation efforts, when they exist, can end up by giving birth to a new, rather different, and highly idiosyncratic, 'production function'.

Concerning the first of these topics, i.e. the unrealistic description of what a technology, and its associated industrial organization are supposed to be, economists have recently began to notice that: ..." to the extent that imitation is not trivial, the idea of an industry-wide production set the elements of which are accessible to all firms is a misleading abstraction" and that ..."to the extent that technologies are not well understood sharply defined invention possibility sets are a misleading concept and interaction between learning through R&D and learning through experience is an important part of the invention process". 2/

A similar kind of awareness concerning the rather idiosyncratic nature of the industrial organization fabric likely to develop in association with a given industry and, therefore, the likelihood of there being rather large inter-country differences in this respect, is also gaining ground in the profession. After studying the Taiwanese machine-tool industry A. Amsdem has writen: "...A striking feature of the structure of machine-tool production in Taiwan was and continues to be, a low degree of specialization and a high degree of vertical integration. The all-purpose nature of operations in the smaller firms has been very pronounced. Larger firms have engaged in even more activities with are ancillary to the production of machine-tools. In industrialized countries such activities would typically be sub-contracted'.3/

2/ R. Nelson: Innovation and economic development. Theoretical retrospect and prospect. Working paper N°31, IDB/ECLA/UNDP Programme of Research on Science and Technology. Buenos Aires, November 1978.

3/ A. Amsdem: The division of labour is limited by the type of market. The case of the Taiwanese machine-tool industry. World Development, 1977, Vol. 5, N° 3.

In other words: the standard text-book notion of the production function as an exogenoustly-given, completely-specified, easily-duplicable and internationally transferable set of engineering and organizational rules and 'blue prints' which tends to be rather similar across countries is now recognized to be an oversimplified tool of economic analysis which fares rather badly when we come to explore the actual evolution of the production fabric of any given society.

As far as the second topic is concerned, i.e. differences in industrial and technological achivements as between LDCs, it is becoming increasingly apparent that, pari pasu with the expansion of the share and complexity of the manufacturing sector, a group of developing countries -now frequently refered to as the NICs (new industrializing countries) - is attaining standards of industrial and technological sophistication which sets them quite apart from the LDCs group in general. Some of these countries have in recent years experienced a dramatic increase in their exports of manufactures -many of them of a fairly complex technological nature- and are nowadays claiming their initial significant successes as exporters of technology under the form of licenses, engineering services, sales of complete plants through 'turn key' operations, etc. 4/

As in other fields of contemporary economics some new thinking and a comprehensive body of new hard empirical evidence seem to be strongly needed in this field if we are to make further progress. In particular, the theory of innovation yet has to come to grips with the fact that important localized knowledge creation efforts are carried out in a number of developing countries. The rate and nature of such technological efforts as well as the role of micro and macro variables in shapping up entrepreneur's

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4/ Recent papers concerning technology exports by some of the developing nations have shown countries with so different an import-substitution strategy as Argentina, Korea, Taiwan and India attaining very impressive performances in this respect. See: i) J. Katz & E. Ablin: From infant industry to technology exports. The Argentine experience in the international sale of industrial plants and engineering works. Working paper N°14, IBD/ECLA/UNDP Programme on Science and Technology, Buenos Aires, 1976. ii) Y.W. Rhee & L.E. Westphal: A note on the exports of technology from the Republics of China and Taiwan. Paper presented at the seminar on Technology and Development organized by the IDB/ECLA/UNDP Programme on Science and Technology. Buenos Aires, November 1978. iii) S. Lall: Developing countries as exporters of technology and capital goods. The Indian experience. Mimeo, Oxford, June 1979.

behaviour in this respect should clearly receive priority in any research agenda concerned with the long term growth process. 5/ On the other hand, the theory of economic development needs to incorporate the fact that some of the developing nations have in the Post War period built up fairly strong industrial sectors many of which are nowadays reducing the technological gap which separated them from average international practices and are gradually gaining competitiveness in the world trade scenario not just on the basis of lower wages but also on the basis of an indigenously-generated and/or of a locally-adapted technology. The old 'infant industry' argument, as well as the whole debate concerning protection and the notion of dynamic comparative advantages seem to be calling for a fresh and careful re-examination. As in the previous case, this is a subject which has received insufficient attention in recent years. 6/

The purpose of the present paper is to explore two different sets of questions related to the technological performance of some of the largest Latin American countries. On the one hand, we would like to examine whether or not manufacturing firms in LDCs employ a technology -or production function- which closely resembles -i.e. is highly comparable to the one employed by firms producing similar commodities in more developed industrial societies. On the other hand, we would like to pose a somewhat similar question concerning not the technology itself, but its changes through time, i.e. the rate of technical progress. Is there any reason to believe that the pace, nature, etc. of technological change incorporated by firms or industries in LDCs somehow replicate those incorporated by comparable firms and industries in more mature societies?

Answering both such questions we expect to throw some new light upon various different territories belonging both to the theory of technological change of developing nations and to the broad field of Industrialization, Trade and Development.

5/ R. Nelson and S. Winter are breaking new and important ground in this territory on the basis of an ongoing research programme which has already produced most interesting results. See, for example: In search of a useful theory of innovation. Research Policy, 6 (1977) pag.36. Also: Simulation of Schumpeterian competition. American Economic Review, February 1977.

6/ It is interesting to observe how little atention the 'infant industry' argument has received in all of the large-scale research efforts carried out during the sixties by I.Little, T.Scitovsky, B.Balassa and others. A well taken critique of such neglect has recently been put forward by L.Westphal in: "The infant industry

During our examination of the previous questions we shall make extensive use of some of the research findings obtained in the course of a four year long exploration into the economics of technological change carried out by a team of economists and engineers. Individual firms, as well as industry-wide and macro studies were carried out in different Latin American countries in order to study: a. the rate and nature, and b. the determinants and consequences, of the observed technological changes incorporated by selected firms and industries through time. Some of the collected evidence comforms the empirical ground underlying the present paper.

Section II considers the first of the above-mentioned questions. Conventional theory has taken for granted that the answer is an easy one, i.e. that the technological package employed by manufacturing firms in LDCs constitutes a mere replica of the technical and organizational routines used at some prior point in history by industrial firms in developed nations. We shall argue throughout this paper that in most real life situations such view grossly oversimplifies the case and constitutes a wrong description of the manufacturing world. Production functions significantly differ as between firms and countries turning productivity comparisons, as well as growth accounting exercises, into rather misleading simplifications of what is actually going on.

In what sense are we saying that 'production functions' are significantly different? Assume that we define 'technology' in a rather ample way so as to include all bits and pieces of technical knowledge or information indicating how to carry out a given economic activity. Such package of technical knowledge and information is related to at least three different aspects of the activity. They are: a. The design or specification of the product or service. b. The production process, or basic technology, to be employed and, c. The industrial organization -degree of vertical integration, patterns of subcontracting, etc.- most convenient to do it. 7/

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ment and the relation of trade policy to industrial strategy". Paper presented at the International Symposioum on Latin America held at Bar Ilan University, Ramat Gan, Israel, May 1980.

7/ When dealing with the concept of 'technology' economists normally think in terms of item b. of the above classification, wrongly leaving the other two items aside. H. Pack has recently shown that the lion share of productivity differentials between comparable industrial firms in developed and less developed countries is not to be explained by differences related to the basic production process, but rather by major differences in item c., i.e. industrial organization technology. Unfortunatelly, the profession has very little to say in this respect-. See his: "The capital goods sector in LDCs: A survey". Mimeo, Washington, April 1979.

For reasons which are examined in Section II -and which have to do, among other things, with the relative size of the market, with the availability (or lack of) a network of specialized subcontractors, with relative factor prices, with government-induced market distortions,etc. -manufacturing firms in LDCs will normally employ a technology which will substantially differ from the one employed by a firm producing a somewhat similar product in a developed society. The observed differences become all the more significant not in relation to the product design itself, but with respect to the other two items of the stated trilogy, i.e. the production process and the organizational technology of the production operation at large. 'Batch-like' discontinuous processes, of varying, but relativeely low, degree of automation, a high degree of vertical integration, a rather low level of subcontracting, etc. are all ubiquitous features of the Latin American manufacturing scenario. Contrarywise, continuous-flow processes of a much highly automated nature, low vertical integration, a great deal more of specialization and subcontracting, etc. immediately catch the eye when one examines comparable firms and industries in the USA, Europe or Japan. Put it succinctly: the whole 'mode of production' is sensibly different.

Having brought home the idiosyncratic nature of manufacturing technology in a LDC environment, and the rather important differences that obtain between such technology and the one that is employed by comparable firms in more developed nations, Section III of the paper proceeds to show that also technical change in a LDC industrial scenario is bound to be significantly different from the one incorporated by industrial firms in more mature societies. On the one hand, we should expect this to be so as a consequence of the observed differences concerning the production function itself. On the other hand, LDCs are characterized by peculiar features of their own -such as unduly high rates of tariff protection, acute raw material scarcities, market imperfections, bottlenecks affecting the physical design of manufacturing plants and industrial complexes, etc.- which continuously flash specific signals to the entrepreneurial community. Such signals induce particular and idiosyncratic patterns of technological response from the part of manufacturing firms. Summarizing in a very precise manner many of the research findings obtained during the course of our research, Professor Ch.Freeman has written: "...(Various) empirical studies of technical change in industry (he is refering to those carried out as part of the IDB/ECLA/UNDP Regional Programme of Research in Science and Technology) have demonstrated conclusively that firms do respond to changes in their environment by redirecting their efforts at technical change... It was discovered that the type of technical change which was sought and introduced varied both with

major changes in factor costs and with changes in the competitive environment. When one plant was the sole supplier the emphasis was on speed of output, but, when competitors entered the market and surplus capacity appeared, the emphasis changed to product quality. Changes in wage costs, material costs, etc. similarly led to re-direction and change of emphasis in technical effort. Such a response is more likely when the change is dramatic and therefore clearly perceived." 8/

In each one of the previously mentioned levels -product design, process engineering and industrial organization- the firm will normally search for incremental units of technical knowledge or information with which to upgrade its daily operation. Such technological search will not, however, be exogenously determined as most neoclassical growth models tend to assume, neither will it follow identical routes to the technological search process that takes place in a plant in a developed country environment. Rather, the specificity of each economic setup will provide a definite imprint of its own upon the technological efforts carried out at the firm level. We argue in Section III that the technological path of a given industrial plant is evolutionary in nature and should be studied as a time-dimentional process and not as a state or condition. The rate and nature of technical change, as well as the type of innovations and productivity advances to be sought for by a given enterprise at a certain point of time, strongly depend upon: a. strictly micro-economic forces emerging from the specific history of such firm; b. market variables describing the competitive environment in which the firm operates; c. macroeconomic forces characterizing the broad parameters of the system in which both the firm and industry are immersed and, finally, d. the evolution of the knowledge frontier, or 'state of the art' at a world -wide level-.

Finally, Section IV of the paper briefly deals with policy questions. Having shown that production functions significantly differ inter-country wise and that the rate, type and nature of technical change enjoyed by any given firm, industry or society are not exogenously given but rather result from the working of the overall economic system we proceed to explore the role and scope for public policy in this broad territory. Various important lessons concerning protection, the 'infant industry' argument, and industrial policy in general can be gained if we carefully evaluate the major research findings surveyed in this paper.

8/ Cr. Freeman: Technical change and unemployment. Paper presented at the Conference on "Science, Technology and Public Policy, an International perspective", University of New South Wales, December 1977. Mimeo, Sussex 1978.

II. Firms, technology and industrial organization in DCs and LDCs.

Let us start from a rather simple question: is there any reason on account of which to believe that a 'representative' firm in any given branch of manufacturing production in a LDC utilized a technology which somehow replicates the one employed by a comparable firm in a mature industrial society?. Or, in other words: is there any reason a priori to accept that manufacturing firms producing somewhat comparable goods in DCs and LDCs tend to use different factor intensities of a similar technology?.

Although observed differences in production functions as between firms in DCs and LDCs tend to be more significant in some branches of manufacturing than in others -this seems to be so, for example, in mechanical engineering industries as compared with process industries- we shall argue in this section that the answer to our question is a negative one across the industrial spectrum. Indeed, production functions significantly differ as between firms for reasons inherent, on the one hand, to the notion itself of technology as a package of technical information and, on the other hand, for circumstances emerging from the specificity of each particular social and physical environment in which a given technology is brought into operation.

Let us examine these two sets of reasons separately.

II.1 Irreplicability of the technical knowledge package.

The first major reason on account of which we cannot realistically expect any given manufacturing firm to have access to a package of technical information which is an exact replica of a similar package previously employed by somebody else, comes from the notion of knowledge itself as a factor of production. Unlike other factors, this one is frequently incompletely specified, i.e. it leaves room for ad hoc solutions and unforeseen procedures not completely described ex ante. As a consequence of this condition it cannot be entirely replicated. Neither can it be easily transfered. Knowledge accumulated through experience becomes an important part of the technical information package which conforms any identifiable technology.

In order to explore this point further we shall briefly deal with a central concept of production theory, i.e. that of the production posibility set.

Such concept, and its subset of efficient elements: the production function, constitutes one of the pilars upon which the theory of the firm has been constructed.

The production possibility set constitutes the domain of all the production activities which are technically feasible for a given producer. As Nelson and Winter put it: "In the conventional production set the boundary is the abyss of the unknown and the impossible". 10/ The notion of what is 'known' and 'technical possible', requires further examination.

Koopmans, Debreu and others have modeled the production set in terms of activities. An activity is 'a way of doing things', each one subject to fixed input-output coefficients, perfect divisibility and constant returns to scale. Intuitively we observe that an implicit assumption underlying the notion of an activity, is that each one of them is related to a certain body of knowledge or information -that is, to a certain routine or programme- which step-wise indicates how the activity is to be performed. Thus, underlying the notion of the production possibility set is the amount of knowledge or technical information an economic agent has at his disposal. 11/ Such information will determine: a) the subset of activities known to the agent and b) the routine or programme to perform them.

10/ R. Nelson & S. Winter: Organizational capabilities in a dynamic world. Chapter I. Mimeo, Yale University. Throughout the present section I shall draw rather heavily on this (to my knowledge) unpublished paper. I thank the authors for letting me have access to an early version of this most stimulating monograph.

11/ The notion of the production set admits of the creation of new technology. It does so, however, in a rather peculiar form. R&D has to be thought as one more activity belonging to the set. For such purpose we have to assume that "there is a discrete moment of time when R&D is completed and it springs forth like Minerva, into the production set. Unless this is assumed the sharpness of the model is broken". (Nelson & Winter, Op.cit.) There are obvious reasons to be worried with such a description of the knowledge creation process as a rather dichotomic phenomena in which the gradual resolution of uncertainty and successive levels of accomplishment are essentially absent.

The problem with this specification of the production possibility set is that it is much too clean. When technical knowledge or information is taken as yet another input to the production process, it does not seem realistic to specify such input in a dichotomic way, either as being there or not being there altogether. Rather, it seems only too natural to allow for learning and upgrading, that is, for a gradual and steady increment in the knowledge base inherent to any activity in the set, 'for a process, not a condition', as J. Hirschleifer has put it a few years ago. 12/ Nelson and Winter quite correctly argue that such a sharp distinction between the technically possible and impossible activities constitutes a legacy of modeling relatively static situations, i.e. optimal terminal points. 13/

The basic limitation of conventional theory for handling production situations in which technical knowledge and information become part of the story can now be intuitively seen. The boundaries of the production set cannot be taken as being sharp and clean. Rather, they should be thought as being blurred and uncertain. Activities might be known to a greater or lesser extent depending upon the complexity and sharpness of specification of the body of knowledge itself, as well as upon the initial knowledge base of the economic agent, its learning efforts, and the time span along which such efforts have been taking place.

Once we leave behind the neat distinction between the technically possible and not possible activities, we venture into a world in which there are differences -small or large- in the quantity and quality of the package of technical information commanded by any two producers performing the same activity, i.e. firms have to be thought as accomplishing an essentially comparable job but following different engineering routines. Each one of the routines will have an unspecified component of ad hoc technical knowledge 'produced' by its user in order to fulfill all those steps of the routine which were not completely specified ex ante.

12/ J. Hirschleifer: Where are we in the theory of information. American Economic Review, Vol. 63, N°2, May 1973.

13/ R. Nelson & S. Winter: Op.Cit. pag. 4.

Consider now a second set of reasons on account of which production functions in DCs and LDCs are likely to be significantly different. These ones relate to environment differences which make it technologically impossible or economically unprofitable to replicate in a LDC environment the technological package of a more mature industrial society.

II.2. Differences in environmental and operating conditions as between developed and less developed countries.

1. Plant size and choice of technique

With very few exceptions most industrial firms operating in LDCs are just a tiny fraction -between 1-10%- of the size of their counterparts in developed nations. For example, a 'representative' Latin American firm producing automobiles could turn up anything between 20 and 100 thousand units per annum. A machine tool manufacturer would produce from 100 to 500 lathes per year, whereas a petrochemical plant producing polyethylene would operate anywhere between 10 and 120 thousand tons per annum. 15/ Only in very recent years some Brazilian firms seem to be moving up in order to reach internationally competitive scales. (This is however, certainly more the exception than the rule throughout the region). Industrial firms producing similar commodities in mature industrial societies would normally be five to ten (or more) times larger.

We shall argue here that such differences in plant size induce very many differences in the way in which products are actually produced. The present point has been recently made by S.A. Morley and G.W. Smith after studying a sample of Brazilian manufacturing firms, "When we looked closely at the way products are actually produced we could see why production methods may be insensitive to relative factor prices. It seems clear that economies of scale and technical considerations dominate technical choice almost regardless of factor prices". 16/

15/ Evidence in this respect can be obtained from various different sources. See, for example: a) J. Baranson: International Transfer of automotive technology to developing countries. Unitar Research Reports, N°8, New York, 1971. b) S. Watanabe: Technical cooperation between large and small firms in the Filipino automobile industry. World Employment Programme Research, ILO, Geneve, 1979. c) J.D. Mitra: The capital goods sector in LDCs. A case for state intervention? World Bank Working Papers N°343. Washington, July 1979, etc. etc.

16/ See: Samuel A. Morley and G.W. Smith: Adaptation by foreign firms to labour abundance in Brazil; In: Technological progress in Latin America. The

Continuous flow, highly automated technologies which would normally be the technology of choice for a new industrial undertaking in a developed country environment, are frequently ruled out right from the begining by firms operating in LDCs. This is so for at least two different reasons. On the one hand, such technologies normally envolve a rate of output which is well beyond the size of the local market. On the other hand, such plants frequently embody a level of operational and maintenance complexity which can not be handled by the locally available engineering and technical skills.

Instead of such option LDCs manufacturing firms usually settle for a discontinuous technology, and for a much lower degree of automation, than the one looked for by DCs firms. The choice of a discontinuous, not highly automated technology, certainly has a major impact upon such aspects as: 1. Plant 'lay-out-, 2. Type, cost, etc. of the equipment and machinery to be installed, 3. Overall organization of production (degree and patterns of subcontracting, etc.) 4. Overall number of workers, as well as the proportion of direct to indirect labour which will be economic to employ, etc. Such choice will also affect the size of the economies of scale which can eventually be captured by the firm as well as the rate and nature of the various technological changes that the manufacturing plant can incorporate through time.

In other words: not only will the physical configuration of the plant be rather different, but also the sources of efficiency growth (possibilities for capital/labour substitution, economies of scale, rate and nature of technical progress, etc.) will be dramatically at variance from those underlying the operation of a countinuous flow manufacturing unit.

In spite of the fact that almost any dichotomic classificatory schemme -continuous vs. discontinuous processes, automated vs. non-automated technologies, etc.- is bound to create some difficulties when we use it to examine a distribution which in fact is organized along a continuum, we shall try to develop the argument of the present section by comparing two polar cases: on the one hand that of a highly automated, continuous flow technology and, on the other hand, the alternative option of a discontinuous, less automated design, for the production of a somewhat comparable commodity.

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prospects of overcoming dependency. (Ed. J.H. Street and D.D. James), Westview Press, Boulder, Colorado, 1979.

Obviously most real life situations are not as clear cut cases as the two extreme options to be examined here. Discontinuous technologies in which partial sections of the plant have been transformed for continuous operation, or manufacturing plants which, in spite of being of a discontinuous nature yet produce a similar commodity with very different degrees of automation, have been found in our exploratio of the Latin American manufacturing scenario. However, and for the sake of argument, we shall examine here two 'stylized' extreme situations. Consider first the case of a continuous flow production unit.

Manufacturing plants of this sort frequently are product-specific, i.e. their 'lay-out' is organized following a sequence or order imposed by the various technical transformations that have to be carried out for the purpose of producing a given product. The sequence of technical transformations is always the same and this is what decides the factory 'lay-out'. In manufacturing units of this sort the rate of output is usually rather large as it frequently happens that continuous flow technologies are employed to produce massively commercialized products. Common features of a plant of this kind are:

1. The pre-production planning of the 'line' is extremely detail and complete. There is low ex-post flexibility concerning both the product design and the production process.

2. Activities and technical transformations sistematically follow one after the other along a 'direct' route, thus minimizing delays and downtime. The production cycle is minimized as the production 'line' is balanced and activities have to be individually coordinated to the level of the micromovement.

3. Handling of raw materials and stocks of work in progress is also minimized. Inventories as well as storage spaces have to be balanced in conjunction with the overall production 'line'.

4. The product tends to be highly normalized and most of the equipment has a rather specific nature, i.e. is specially designed to fulfill particular tasks or combination of tasks.

5. There is relatively little 'on-the-job-decision-making', thus direct labour skills and supervisory requirements are relatively less important than in discontinuous production units.

In spite of its various potential advantages -in particular concerning economies of scale and minimum production cycle- a continuous flow production technology is not always and necessarily the cheapest available way of production. On the one hand, plants of this sort normally involve relatively large investment outlays. Unit capital costs tend to be rather large if the equipment is less than fully utilized. On the other hand, a stop anywhere along the 'line' can bring the whole of the line into a halt; thus, unplanned delays tend to be rather expensive. On account of both reasons a continuous flow technology can become far from economic in situations in which a steady rate of full capacity utilization is not guaranteed.

Contrary to the previous picture discontinuous process plants are very different animals indeed. The plant 'lay-out' is organized in 'shops' whose order is by no means unique, let alone constant through time. Such factories are frequently related to the production of goods or services in small runs or in response to individual orders. Various different products can be simultaneously produced, and it is now the product the one that has to proceed from one 'shop' to the next moving aroung the factory, i.e. the plant is not designed following the succesive technical transformations demanded by the product, but rather by 'groups' of somewhat similar machines.

Frequent features of a manufacturing plant of this sort are some of the following:

1. The capital equipment is less expensive and of a more general nature than the one required by a continuous flow technology. There is less need for 'back-up' equipment (which is normally kept idle for replacement purposes in continuous flow production units).

2. There is a great deal of flexibility in the way in which a given job is being performed. Given that all of the machines of a certain type can perform a particular task the actual work load is assigned to whatever machine happens to be available. Also, similar transformations can be performed with different machines.

3. Transport of raw materials, components, subassemblies, etc. between 'shops' becomes an important part of the production process. It is, also, a significant source of bottlenecks, waiting periods and other forms of slack. The production cycle is not minimized and there is ample room for actually reducing it by carefully re-arranging the physical distribution of jobs in the plant.

6. Given that the product is not highly standardized, on-the-job-decision-making is relatively important. 'Custom-ordered' changes are normally admitted. Workers skills in setting up the machines, preparing jigs and tools for the job, etc. and in actually carrying out the task, become very important indeed. The same tends to be true of supervisory skills.

From both previous descriptions we notice that continuous and discontinuous technologies correspond indeed to very different 'production functions'. This is so regardless of the actual degree of automation embodied in a given plant design. In either case a production unit can be designed embodying a relatively high or relatively low degree of automation, depending upon the specific conditions of a given environment i.e. -relative factor prices, availability of electronic process control skills, etc.- Independently of the degree of automation, however, we can intuitively perceive that both the physical configuration and the modus operandi of continuous and discontinuous technologies will differ quite substantially.

We can now close the present section briefly summarizing its central point. Due to large differences in market size manufacturing plants operating in LDCs frequently tend to do it on the basis of discontinuous flow technologies, and of a relatively low degree of automation. As a consequence of this, both the physical configuration of the plant -its 'lay-out', the number and nature of the machines actually employed, etc.- as well as the modus operandi of the firm - its forms of industrial organization, patterns of subcontracting, etc. will all be significantly different from those employed by firms in DCs which operate on the basis of continuous flow manufacturing units. It is rather misleading to think that both techniques are different factor intensities of a similar production function. A fairly different, 'mode of production' is embodied in each one of them and straightforward comparisons among them should be handled with extreme care.

2. 'Roundaboutness', skills and further technological differences between developed and less developed countries.

Throughout last section we have argued that due to large differences in size we should a priori expect firms in developed and less developed countries to operate with different production functions and not just with different techniques emerging from the same function, i.e. different factor intensities of a given

technology.

So far then we have looked at one possible source of differences among manufacturing firms in DCs and LDCs -size-. We shall now examine yet another set of reasons on account of which the technological modus operandi of manufacturing firms in DCs and LDCs is likely to be significantly different. We refer to the degree of vertical integration and to the extent and nature of subcontracting employed in either case.

The empirical evidence on this account is scanty but rather conclusive. It shows that: 1. Manufacturing firms in LDCs make much less use of subcontracting than their counterparts in DCs. i.e. they chose to operate with a much higher degree of vertical integration than the one normally chosen by comparable firms in DCs. 17/ 2. The degree of subcontracting seems to increase over time, but not at a very fast pace. 18/ Quite on the contrary, the time span needed for a reasonably efficient network of subcontractors to emerge and develop in any particular branch of manufacturing seems to take the better part of two (or even three) decades. In such respect the experience of LDCs does not seem to be significantly different from the earlier one of England, the USA and, more recently, Japan. 19/

17/ Besides A. Amsden's research results which illuminate this point in relation to the Taiwanese machine-tool industry (see note 3, page 2), a similar pattern is suggested by H. Pack when he writes: "Despite efforts to foster subcontracting in the late 1960's the larges Indian machine tool producer purchased only 10% of its inputs externally whereas for one Western European collaborator the comparable number was 40%. See: H. Pack. Op.Cit. page 17. Identical results have been found in various of the studies carried out in Latin America. See, for example: A. Castaño, J. Katz and F. Navajas, Etapas históricas y conductas tecnológicas en una planta metalmecánica argentina. Mimeo, Programa BID/CEPAL/PNUD en Ciencia y Tecnología, Buenos Aires, 1980. See also: S. Watanabe, Technical cooperation between large and small firms in Philippine Automobile industry. World Employment Programme Research, ILO, Geneve, March, 1979.

18/ Research now in progress in the metalmechanic industry of Argentina, Brazil, Venezuela, etc. indicate that the subject of subcontracting is becoming an important one at the present time. See in this respect: A. Castaño, J. Katz, F. Navajas, "Etapas Históricas y conductas tecnológicas en una planta argentina de máquinas-herramienta". Mimeo, Buenos Aires, June 1980.

19/ See, for example: G.C. Allen: British Industries and their organization. Longman, London 1970.

3, Subcontractors tend to grow out of the very fabric of large industrial firms. Our studies have shown that former technicians and workers of large manufacturing firms frequently settle down as independent subcontractors for such companies, on the basis of second-hand equipment and technology obtained from them. 20/

So much for the empirical evidence. At the conceptual level the subject of subcontracting -which is, of course, central to the classical view of the long term development process- has not received a great deal of atention in the modern literature.

H. Pack has recently revisited some of the basic economics of subcontracting. He shows that, in principle, it is to be expected that a given entrepreneur "will not engage himself in subcontracting unless the marginal cost of internal coordination of production exceeds the marginal cost of external coordination minus the difference between the marginal cost of internal vs. external production. That is, he will not opt for subcontracting unless:

$$C_i > C_e - (P_i - P_e)$$

Where: C_i, C_e - Marginal cost of internal and external coordination of production respectively.

P_i, P_e - Marginal cost of internal and external production.

In other words: the difference in production costs due to external, rather than internal, production should exceed the (presumably) higher cost of coordinating external suppliers, for the entrepreneur to be attracted by the prospect of subcontracting.

The trouble with this general formulation of the problem is that it does not carry us very far in the understanding of the actual problems which underlie the subcontracting decision.

20/ An interesting example of such development can be seem in: J. Katz et.al. "Productivity, Technology and Domestic Efforts in Research and Development". Working Paper N° 14, IDB/ECLA/UNDP Programme of Science and Technology. Buenos Aires, July 1978.

Classical economics teaches us that the cost of external production should in principle be lower than that of internal supply in all those cases in which a large enough market permits to capture the benefits of specialization and dynamic economies of scale. Clearly this constitutes the core of A. Smith's contention that the degree of 'roundaboutness' employed in production is a direct reflection of the size of the market. Large enough markets permit further division of labour and this, in turn, allows for a group of complex processes to be transformed into a succession of simpler processes, some of which lend themselves to the use of specialized machinery. Such machinery in itself is also an outspring of the expansion of the market in as much as the existence of a large market induces innovative efforts in the development of new capital goods. In Smith we find not just economies of scale in the static sense, but rather a mixture of economies of scale and 'learning by doing', in a dynamic framework. His view of the problem comes up quite clearly when he writes: "This great increase in the quantity of work, which, in consequence of the division of labour, the same number of people are capable of performing, is owing to three different circumstances; first, to the increase in dexterity in every particular workman; secondly, to the saving of time which is commonly lost in passing from one species of work to another; and lastly, to the invention of a great number of machines which facilitate and abridge labour and enable one man to do the work of many. 21/

Thus, we notice that in the classical formulation the division of labour, resulting from the expansion of the market, brings about: a. An enhancement of skills, b. savings of time and c. the development and introduction of specialized machinery.

For various reasons such formulation of the problem does not seem to convey the complete story. The available evidence seems to indicate that it is not exclusively on the basis of straightforward cost differentials that entrepreneurs make decisions concerning subcontracting. Rather, questions of quality of supply (indeed of

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21/ A. Smith, Wealth of Nations, Book I, pag. 7.

stability of quality standards) as well as considerations of uncertainty in delivery, fare very highly indeed among the reasons frequently quoted by large industrial firms in LDCs for maintaining a high rate of vertical integration, i.e. a low level of subcontracting. 22/ 23/

Now, quality standards and reliability are not easily obtained in societies in which engineering and entrepreneurial skills are in very short supply. The fact that such talents require a rather long gestation period is what probably explains why even in those few LDCs which do have large enough domestic markets of their own -such as for example Brazil or India-, the growth of subcontractors has proceeded at a very low pace indeed nowhere reaching levels comparable to those prevailing in mature industrial societies.

Comparing India and Japan, and trying to explain why subcontracting has not proceeded at a comparable pace, J. Baranson has written: "The following are some of the outstanding reasons on account of which India has not been able to develop an infrastructure of subcontractors comparable to the Japanese one:

a. Shortage of engineers and technicians experienced at adapting techniques to the available equipment and raw materials.

b. Lack of skilled personnel capable of operating the equipment and of maintaining minimum standards of industrial discipline.

c. Absence of an industrial organization flexible enough to make room for the efficient utilization of small firms as complementary to modern industrial

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22/ Questions of quality and uncertainty of supply could be explicitely incorporated into H. Pack's framework. We would then have a probabilistic model comparing the expected cost of internal vs. external supply, this last one weighted by the probability of failure due to low quality and by the likelihood of subcontractors not meeting required deadlines.

23/ Exploring the magnitude and problems of subcontracting in the Philippine automobile industry S. Watanabe has recently written: "Anywhere in the developing world, and even in industrialised countries, parent firms in subcontracting almost invariably face three major problems: high cost of production, inadequate quality of work and unreliable delivery", Technical co-operation between large and small firms in the Filipino Automobile industry, WEP 2-22/WP 47, Technology and Employment Programme, ILO, Geneva, March 1979.

complexes.

d. Limited size of the local market and small rates of growth". 24/

Thus, and coming now full circle from the classical argument, we notice that in spite of the fact that skills and industrial organization are bound to improve with the division of labour and the expansion of the market, their initial shortage might very well start by constituting a major barrier to a further division of labour. In other words: even if it is perfectly possible that in the long run engineering and entrepreneurial skills would improve pari pasu with the expansion of the market, in shorter periods of time -and here we might well be speaking of a few decades- lack of certain skills may blockade the expansion of a suitable network of subcontractors and therefore foreclose the possibility of large manufacturing firms collecting as big a package of economies of scale and specialization as the one normally captured by industrial firms in developed nations.

Summarizing: two major sets of reasons force large industrial firms in LDCs to operate with a much higher degree of vertical integration, i.e. with a lower degree of subcontracting, than the one normally chosen by comparable firms in DCs. Such reasons are: a. Smallness of the domestic market, and, b. Structural deficiencies in the supply of engineering and entrepreneurial skills. On account of both reasons manufacturing firms in LDCs are likely to have both a manufacturing and an organizational technology which will significantly differ from the one employed by comparable firms in DCs.

3. Other sources of technological differences as between developed and less developed countries.

Size and initial lack of qualified subcontractors are two of the main reasons on account of which manufacturing firms in LDCs will normally find it technologically

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24/ See: Jack Baranson, Manufacturing problems in India: the Cummins Diesel Experience, New York, Syracuse University Press, 1967, pp. 68-69. It is interesting to notice here that, as economists, we probably miss a very significant factor in our comparative history studies when we fail to take into account the very peculiar 'shaibatzu' system which has characterized the Japanese case during its early years of capitalist expansion.

imposible and economically unprofitable to replicate the technology employed by firms in DCs. They are by no means the only explanations that can be found of the fact that firms in LDCs will normally operate on the basis of a highly idiosyncratic technological package, clearly different from the one exployed by comparable firms in more advanced industrial societies. Other explanations, some of them of the sort that can be derived from conventional price theory, can be found as well. Let us briefly consider them.

Substitution effects.

Various different substitution effects play an active role inducing firms in LDCs to adopt different production techniques than those normallv employed in more developed countries. Substitution effects could be policy-induced -government intervention being in this case a major source of relative price distortions which ultimately influence technological choice- or of an 'autonomous' nature, i.e. derive from differences in resource endowments or other such 'natural' sources.

Under the heading of 'policy-induced' substitution effects we include all those forms of substitution between different types of machinery and/or raw materials, etc. -particularly among those of a local vis a vis imported origin- which result from tariffs on imported goods, quotas, distorted exchange rates, outright prohibition of access to certain imputs, etc. all of which have been shown seriously to affect choice of technique by Latin American industrial firms. 25/

As far as 'autonomous' factor substitution is concerned relative price differentials as between capital and labour is probably the major source of technological

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25/ See, in this respect: a) A.Canitrot: Method for evaluating the significance of macro-economic variables in the analysis of technology incorporation decisions. Working Paper N°12, 1977; b) S.Teitel: Notes on technical change induced under condition of protection, distortions and rationing, Working Paper N°34, 1979. Various case studies of the IDB/ECLA/UNDP Programme present empirical evidence confirming the fact that choice of technique seems to reflect factor price differentials as between countries. Among them: a) J. Lucángeli & J.Fidel: Cost-benefit of different technological options in the context of a differentiated oligopoly: The case of the Argentine cigarette industry. Working Paper N°18, 1978; R.Pearson: Technology, innovation and transfer of technology in the cement industry; Working Paper N°9, 1976; F.Sercovich Design engineering and endogenous technical change. A Microeconomic approach based on the experience of the Argentine Chemical and Petrochemical industries, Working Paper N°19. 1978. All the Working Papers mentioned in this footnote belong to the IDB/ECLA/UNDP Programme on Science and Technology.

differences between firms in LDCs and DCs that needs to be taken into account.26/

A much lower degree of automation -implying more universal machines, manual rather than electronic process control devices, etc.- a more labour intensive transportation system within the plant , a less sophisticated maintenance technology, etc. are all standard features of the Latin American manufacturing escenario. The available empirical evidence clearly shows that choice of technique has been, and still is, highly sensible to factor price differentials of the king hereby mentioned.

Physical bottlenecks and other technical constraints.

The literature of recent years, from N. Rosemberg 27/ to P. David 28/ , including various different industry and individual plant studies carried out in Latin America 29/ , unanimously indicates the extent to which a given original engineering design places a set of technical constraints upon potential expansions and plant modernization schemmes. The examples single out steel mills and petrochemical complexes as particular cases in which unbalanced sectional expansions as well as previous technical choices, seriously affect the range of technical options from which manufacturing firms have to choose.

26/ This is, of course, the standard case examined by A. Sen in his fammous 1960's book The Choice of Techniques. Cambridge University Press, England.

27/ N. Rosemberg: The direction of technical change: inducement mechanism and focusing devices. Economic Development and Cultural Change, October 1960. Also: Perspectives on Technology. Cambridge University Press, England 1978.

28/ P.A. David: Technical Choice, Innovation and Economic Growth: Essays on American and British Experience in the 19th. Century. Cambridge University Press, 1975.

29/ For an introductory general survey see: J.Katz: Technological Change,Economic Development and Intra and Extra Regional Relations in Latin America, Working Paper N°30 1978. Also J.Lucángeli & R.Cibotti: "El Fenómeno Tecnológico Interno", 1980, Mimeo , IDB/ECLA/UNDP Programme on Science & Technology.

We can now close the present section by briefly re-stating its central point. Size, lack of subcontractors, policy-induced and autonomous substitution effects, physical bottlenecks emerging from prior technological history, etc. all seem to play a role in making DCs technological packages -i.e., product designs, production processes and patterns of industrial organization- far from replicable in LDCs environments. Rather, manufacturing firms in LDCs build up their operation on the basis of highly idiosyncratic technologies which reflect the nature and intensity of local market imperfections, prevailing physical scarcities, factor price differentials, degree of development of the network of subcontractors, size of the market, etc. Rather than assuming identical production functions across countries it becomes all the more urgent for the profession to continue exploring the actual production fabric of individual societies in order to be able to come up with a more substantive explanation of international productivity differentials.

Having looked at choice of technique, let us now turn to changes of technique through time, i.e. technical progress.

III. The 'production function' for new technical knowledge.

1. 'In-house' engineering activities.

If production functions significantly differ across firms then the introduction of changes in the engineering routine of any given firm will normally involve a certain amount of 'custom-ordered' specificity. This being so there is reason to expect firms to engage in technological search activities the purpose of which would be that of generating additional technical information useful within the plant.

In this section of the paper we examine the evolutionary nature of such knowledge-generation process. We would like to throw some light upon questions such as:
a. Which sections or activities within the plant will have as their major task that of 'producing' new technical information?. How would the size and nature of such activities be influenced by company-specific as well as by market and general macroeconomic forces?. etc.

Consider first the question of knowledge-generating activities performed at the individual firm level. Three broadly defined categories of engineering and technical activities have been previously identified. They are: 1. Product design, 2. Process engineering and 3. Industrial organization of production.

It should be noted that we are talking about technical activities which might or might not be performed by formally organized departments or sections within the firm. The same set of technical functions will be present even if a formal structure is absent. They are carried out by the entrepreneur himself in small family enterprises and are gradually des-centralized and covered by specialized personnel when the firm adquires larger size and complexity. It is the nature, time sequence of their individual development, specific input requirements, different forms of output they normally turn out, etc. what we look at in the next few pages.

In dealing with 'in plant' knowledge generation activities it becomes important once again to separate between firms employing a continuous flow production process as against those operating with a discontinuous technology. Also, it is important to know whether we are examining an homogenous product produced for stock or, on the contrary, if we are looking at firms which produce 'custom-ordered' goods or

services. Very significant differences prevail in these cases in terms of stability of product design, flexibility of the production process and industrial organization of production at large.

Let us first consider each of the three technical functions on an individual basis before bringing up their mutual interdependencies.

a. Product design and specification.

Being responsible for answering the question of what to produce the Product Design Department -or the design function, whenever a formal department is not organized within the firm- constitutes the very first technical function that needs to be fulfilled by any given enterprise. The Product Design department employs different design techniques -building of prototypes, pilot plant experimentation, etc.- with the aim of attaining a final product design which minimizes engineering complexity, input content, etc.

The engineering knowledge generated by this department takes the form of 'blueprints', formulaes, etc. specifying different aspects of the commodity to be produced. Also, this technical department has as a standard job that of generating incremental units of technical information on the basis of which to upgrade, improve or modify the original product design.

Economic, as well as technical considerations, influence the technological search efforts carried out by design personnel. On the one side, product differenciation and/or cost-reduction needs imposed by competitive presure can be frequently traced back as underlying the activities of the product design personnel. On the other hand, newly received technical information -coming up either from the Service Department statistics, or from trade journals, academic publications, and the like- could point out towards the need of re-designing specific parts and components and/or of producing them with different raw materials or under different physical conditions. Typical of the technical efforts carried out by product design engineers are: a. product simplification studies, b. standardization and normalization of parts and components, c. substitution between raw materials, etc. As we shall later on see many of these technical efforts envolve a great deal of interaction between product design officers and members of the process engineering and industrial organization departments.

b. Process engineering.

The process engineering section of the firm is responsible for answering questions such as how, by whom, where, etc. should the product be produced For such purpose it has to choose both the equipment and the labour force -size and skills of the crew- as well as the type of raw materials, components, etc. to be used in production.

It also has to work out detail instruction sheets indicating the engineering routines to be followed, the tolerance limits and other technical parameters to be watched for, etc.

It is this group within the plant the one that has to study the production cycle in order to reduce it whenever possible. Also, it will explore all potential 'output-stretching' capabilities embodied in the existing equipment,30/ as well as the relationship between raw materials and the production process itself. Pilot plant experimental work as well time and motion and job evaluation studies constitute some of the technological search efforts carried out by this engineering department. There is a great deal of cummulative learning underlying the functioning of this office. It gradually has to adquire capabilities for registering and interpreting technical parameters describing the behaviour of the production process under different operative circumstances. The adquisition of such capabilities constitutes a very major step in terms of organizational structure, incorporation of electronic equipment for the collection and processing of technical information, and skills enhancements associated to the understanding of the production process.

c. Industrial Engineering: planning and control of the overall production operation.

A third technical department with a major role on technical affairs is the one responsible for Planning and Control of the overall production operation. This technical section of the plant -normally called Industrial Engineering Department- is the one that has to issue a formal production plan stating when each

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30/ See: P.Maxwell, Implicit R&D Strategy and Investment-linked R&D. A Study of the R&D Programme of the Argentine Steel Firm, Acindar S.A., Working Paper N°23, IDB/ECLA/UNDP Programme on Science and Technology, March 1979.

action should be performed, in which machine or equipment using what externally-adquired part and components, etc.

Also, it is the Industrial Engineering personnel the one that decides on size of 'batch', loading programme for the available machinery, degree and patterns of external subcontracting, level of inventories, etc. Moreover, it is also this technical unit the one that has to integrate into the overal operative network the functions of plant maintenance, raw materials purchasing, quality control, etc.

Given the central role fulfilled by the Planning and Control department it has a rather large scope for introducing changes in the engineering routine followed by the plant.

In actual facts such department operates on the basis of a long term plan, a short term action programme and a control function which monitors whether the current operation is proceeding as expected.

Contrary to the other two technical-sections which have very precise knowledge-generating activities whose output can be explicitly identify as a set of 'blue-prints', production instruction sheets, etc. the Planning and Control Department has a less obvious knowledge-generating function but, nonetheless, an important one. It is this section the one that has to issue -on a daily, weekly, etc. basis- the production plan of the firm. Far from performing a static allocative excercise this section fulfills a dynamic role, constantly adjusting the plant's operation to the everchanging signals emerging from the market place.

Having answered the first of the previously stated questions: i.e. which kind of technical activities are knowledge-generating activities within a plant, let us now examine both the inputs and outputs of such activities and their mutual interdependencies.

As stated before, the nature of the production process -whether a continuous flow operation as opposed to a discontinuous process-, as well as the type of product -an homogeneous commodity produced for stock as against an individually-ordered 'tailor-made' good or service- will both influence the role played by the above mentioned technical departments as well as the specific inputs and outputs associated to them.

In the case of an homogeneous commodity produced in a continuous flow 'line' -as it is the case with the production of automobiles, petrochemical products, etc.- we have a rather inflexible product design as well as a tightly specified production process. None of them can be significantly modified. The pre-production engineering efforts, related to both product design and process specification are very detail and so is the overall planning of the plant's operation. A great deal of 'ex ante' technical effort is put into balancing the production line and the time and motion studies required for such purpose are very precise and come right down to the level of the micromovement. Given such a degree of pre-specification of the production routine the amount of preparatory work for each position in the 'line' is rather large whereas the actual working time involved in each one is relatively less significant. Time and motion specialists, programmers, and other such skilled personnel is employed in order to specify ex ante each activity.

Contrary to such picture, discontinuous technologies -frequently related to the production of goods and services in response to individual orders- tend to be organized in 'isles' or 'centers' rather than in 'lines'. Such production areas organize around a specific type of machine, lathes, drills, etc. The production of airplanes, shipyards, as well as the ubiquitous activities of stamping, forging, machining, belong to this type of industries.

In most of these cases the product is not tightly specified and admits ad-hoc changes. So does the production equipment which, in general, is more of a universal nature than in the previous case. Production planning is done almost every other time a given product is produced. There is significant scope for reducing the duration of the production cycle which is now highly dependent on the amount of time which is employed in 'transport' operations as well as waiting in between 'isles'. Contrary to the former case ex ante preparation time is relatively smaller than actual working time.

Keeping in mind the present dichotomy between continuous and discontinuous technologies let us now take a new look at the 'in house' knowledge-generating activities. It can be intuitively perceived that the three previously described technical departments will have different responsibilities and will fulfill different roles.

In the case of a continuous flow plant product design 'blue-prints' as well as production routines are spelled out in great detail and on an ex ante basis. Almost each and every other part, component, or production subroutine is treated with equal thoroughness. Both, product design and process engineering efforts take a very different form in discontinuous process industries. Following what engineers call the 'ABC method' careful attempts are made at designing some 20-30% of the total number of parts and components which belong to a given product design, leaving the remaining 70-80% of the total list of parts and components relatively less attended. 31/

Thus, in a discontinuous process plant there is a lot more of 'ad hoc' decision making done at the shop level. This introduces a set of skill requirements at the actual machine level which significantly differs from those tipically demanded by a continuous flow operation. Skillful craftmen with decades of experience in the actual technical secrets of each particular job substitute job programmers and time and motion specialists.

Also, the Industrial Engineering department of continuous and discontinuous plants carry out rather different activities. In the latter case such office is responsible for issuing a Machine Loading Programme the purpose of which is that of minimizing waiting periods as between jobs and capacity underutilization emerging from inbalances as between stations. By definition of continuous flow operation the production 'line' is balanced ex ante, the production cycle is minimized as from the begining, and no such similar job, i.e. Machine Loading Programme, needs to be done at all.

31/ Parts and components of a given product design, as well as the respective production routines, are classified according to their relative weight in total cost. It is then observed that only a small proportion -usually less than 20% of the total list- accounts for close to 80% of total cost. Those items are classified as 'Category A' and are the ones that receive the most attention as far as design and production methods are concerned. There is a second 'Category B' usually conformed by an additional 20% of the total list of parts and components which absorbs yet another 10-15% of the product's cost. Some of these items, but not all of them, receive individual attention from the product design and process engineering teams. The remaining items, -a rather large number, but accounting only for a minute fraction of total cost- is called 'Category C'. Standard versions of them available in the market -nuts, bolts, screws, etc- or rather unsophisticated 'in-house' designs, are employed in this case. See: Introducción al Estudio del Trabajo, ILO, Geneve 1966. Also: Tools and Manufacturing Engineers handbook. Me Graw Hill Book Co., USA, 1949.

Before closing the present section let us briefly consider the mutual interdependencies between the previously described technical departments.

In most real life situations the design of a given product, the substitution of one raw material for another in its production, etc. is far from independent from the way in which such product is to be produced. And viceversa, various different parameters of the production process - speed, etc. are strongly correlated with the product's quality, reliability and general performance. Thus, it is frequently observed that 'in-house'-knowledge-generating efforts demand mixed groups in which product design engineers, personnel from the process engineering department, and members of the Production Planning Office interact rather strongly jointly to develop a new product design and/or production engineering routine. Normally, one of the three departments will take the lead of the technological search effort -which one depending on whether the search entails a new product, a new production method or a change in the organization of production- but there seems to be consensus around the idea that succesful technology generation normally involves a combined effort from all three of the above-mentioned technical offices of a given firm.

The last section in this paper examines further the nature of the 'in-house' knowledge generation process likely to obtain in any given firm or industry.

2. An 'Evolutionary' metaphor of the 'in house' technology generation process.

Firms, markets, macroeconomic systems and technologies are dynamic entities which change through time and therefore call for a frequent re-stating of their mutual interdependencies.

Let us briefly look at them from the perspective of received theory before we present a rather simple verbal metaphor describing various aspects of firm behaviour as far as 'in house' knowledge generation efforts is concerned. 32/

A. Firms.

Research in the field of technology has clearly taken a microeconomic strand over the last decade. The old paradigm in which technological change is exogenously given to the firm has now given way to a new micro theory in which companies have an endogenously determined "technological search path" Various different authors 33/ have in recent years examined what an 'optimal' "search path" would be like under conventional profit maximizing assumptions explicitly showing that the direction of technical change will be in accordance with factor scarcities as perceived by the entrepreneur. Assuming technical change to be exclusively of the cost-reducing variety and being the Innovation Possibility Frontier (IPF) 34/ given and constant it is not surprising that companies

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32/ It should be noted that the overall rate of technical progress attained by any given enterprise includes both technical knowledge generated externally to the firm by equipment and raw material suppliers, as well as technical knowledge produced' in-house by its own technical staff. The present section deals exclusively with 'in-house' technology generation efforts therefore covering only part of the firm's technological history.

33/ The decade of the 1960's has been rather rich in research efforts concerning the theory of induced innovation. For example, S. Ahmad in: "On the theory of induced invention. Economic Journal, June 1966, Ch. Kennedy (see following footnote), W. Fellner: Two propositions in the theory of induced innovations. Economic Journal, 1971 In contrast with the previously-mentioned authors the contributors of the 1970's have been interested in the dynamic extension of the notion of induced search. H. Bingswagner: A microeconomic approach to induced innovations. Economic Journal, December 1974, as well as L. Evenson and G. Kisler in "Agricultural research and productivity" Yale University, New Haven, 1975, have been some of the outstanding contributors to the debate.

34/ The concept of the IPF (innovation possibility frontier) has been used by

would push their search efforts in any one direction up to the point where marginal return from such efforts equals marginal cost. 35/ In spite of the fact that there is quite a lot to be learnt from this sort of modeling of the innovation process, yet a fair number of unresolved questions remain. 36/ Furthermore, different authors have pointed out the rather stringent nature of some of the assumptions which underlie the basic paradigm. 37/

Leaving on one side the standard profit maximization metaphor other micromodels of the search process have been discussed in the literature. Nelson and Winter do not particularly quarrel with the idea of ..."the quest for profit being a good first approximation of a firm's objectives, but rather with the formalization of behaviour as profit maximization". 38/

They argue that..."maximization of profits presumes that the choice set is given and that the firm knows this set and the profit consequences of choosing any element". Rather, they prefer to assume that at any given time firms operate with technologies as good as any they know about, but that they dedicate research and imagination to searching for better things to be doing ".... in particular, it must not be presumed that the process is so effective that the full set of alternatives can be explored cheaply and quickly" 39/

Ch. Kennedy in his fammous 1960's article as an analitical tool with which to explore 'induced' technological search efforts. See: Induced bias in innovation and the theory of distribution. Economic Journal, September 1964.

35/ An excercise of this sort was also examined by the present author. See: Importación de Tecnología, aprendizaje local e industrialización dependiente. Fondo de Cultura Económica, México 1976.

36/ See, for example, the note by W. Nordhaus: Some skeptical thoughts on the theory of induced innovation. Quarterly Journal of Economies, 1973.

37/ See, for example: R. Nelson and S. Winter. Neoclassical vs. evolutionary theories of economic growth. Critique and prospectus. Economic Journal, December 1974.

38/ R. Nelson and S. Winter. Firm and industry response to changed market conditions. Institution for Social and Policy Studies, Yale University, Working Paper N°788, May 1979. (Mimeo).

39/ R. Nelson and S. Winter. Op.Cit. Mimeo 1979.

March and Cyert 40/ as well as N. Rosemberg 41/ have argued that the search process is 'problem-oriented', i.e. "My primary point is that most mechanical productive processes throw off signals of a sort which are both compelling and fairly obvious. Indeed, these processes when sufficiently complex and interdependent involve an almost compulsive formulation of problems. These problems capture a large proportion of the time and energies of those engaged in the search for improved techniques" 42/

None of the previously mentioned authors, however, gets into details concerning the type of engineering search efforts likely to be carried out by manufacturing firms under different micro and macro circumstances. Neither do they specifically have in mind cases in which market distortions, physical scarcities, protection, etc. are as extreme as they have been shown to be in most Latin American manufacturing industries.

Given the above we have considered it useful to begin by presenting a verbal exposition of some observed patterns. We feel that such 'pre-theoretical' approach might clear up the ground for future theoretical efforts.

Industry and individual firm studies seem to indicate that an 'evolutionary sequence' tends to prevail as far as 'in house' technological search efforts are concerned. Such sequence appears to begin with search efforts in the area of product design, being followed later on by process engineering search activities. Third in the sequence, and in many cases a good number of years along the line 43/ production

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40/ Cyert, R. & March, J.: A Behavioural Theory of the Firm. Prentice Hall, 1963.

41/ N. Rosenberg: The direction of technological change. Inducement mechanisms and focusing devices. Economic Development and Cultural Change, October 1969, Vol.18, Part I.

42/ N. Resenberg: Op.Cit., 1969, Vol.18, Part.I.

43/ Two different studies of individual firm technological behaviour in the context of Argentina showed that it was only at a late point during the second decade of production activities that both companies could confidently handle industrial organization and production planning questions of rather large technological implications. Both firms could tackle product engineering efforts much before that. Among the series of IDB/ECLA/UNDP studies the reader can consult: J.Katz et.al., Productivity, Technology and Domestic Efforts in Research and Development, Working Paper N°13, 1978 and A.Castaño, J.Katz & F.Navajas, Etapas Históricas y Conductas Tecnológicas en una Planta Argentina de Máquinas-herramienta, Mimeo , 1980. A similar pattern emerges from a case study concerning a Mexican chemical firm. See: L.A.Pérez & J.Pérez Aceves, Análisis Microeconómico de las Características del Cambio Tecnológico y del Proceso de Innovaciones. El caso de Furfural y Derivados, S.A. México, Working Paper N°20, 1978.

planning and industrial engineering search projects are considered. The above mentioned sequence seems to be significantly affected both by micro and macro variables such as the size of the firm and its rate of growth, the diversity and sophistication of the product mix, the continuous or discontinuous nature of the technology, the extent and type of competition, the level of engineering skills available in plant, etc.

Let us examine the sequence in some more detail. The very first thing a firm must have is a clearly defined product with which to approach a given market. Most products produced by Latin American firms are not new, i.e. they were previously produced elsewhere by firms in more developed societies.

By the time these products are brought into production in any of the Latin American markets one, two (or even more) decades have already passed from the product's first world wide introduction. In the meantime the original version has gone through a number of 'maturity stages' which are associated with: 1. Design simplification, 2. Standardization of production methods, 3. Dissemination of technical information, both among producers and consumers, etc.

It is precisely the fact that such dissemination of technical information takes place what explains that in a fair number of cases -which range from foodstuffs and textiles to agricultural and transport equipment- succesful local immitations have been arrived at by skilful craftmen or technicians. 44/ Licensing and product design transfers within the framework of MNCs constitute the other major channels through which access is being obtained to the original product designs which conform the starting point of the industrialization process of most of the Latin American manufacturing markets.

In spite of such externally-conditioned origin, technological search efforts in the area of product design seem to appear rather early in the technical history of many of the examined manufacturing firms. Only a few years after start up

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44/ A large number of locally-designed products can be identified in the Latin American manufacturing escenario. The ingenious combination of available separate pieces of technology frequently constitutes the basis of an indigenous technological design. For example, a horse-powered harvest machine and the power plant of a passangers vehicle provide fertile soil for an imaginative local mechanic to design a complex agricultural machinery. Creative sequences of such sort, based on the assembly of already available pieces of technology, are rather frequently found in the largest Latin American countries.

firms seem to begin developing 'in house' technical skills related to product engineering. On the basis of such skills they, first, adapt and improve the original design and, second, start playing product differenciation strategies as part of their competitive behaviour. The 'life-cycle' of industrial products -consumer durables, pharmaceuticals, and very many other manufacturing goods seem to exhibit life cycles which, roughly, oscilate between four and eight years- 45/ as well as the relatively low incentive to search for cost reduction innovations, given the rather extreme protection granted to industrial firms, appear as major explanations of the fact that product design engineering capabilities seem to develop at a somewhat earlier stage. We have observed that firms engage in such search efforts much before they can exhibit significant technical strenght in other areas. Prototypes and pilot plant experimentation for product design purposes seem to appear on the stage way before time and motion studies or other such tools of production engineering are employed by 'in house' technical personnel.

The previous statement should not be taken to mean that technological search in areas related to process engineering are entirely absent during the initial years of firm's life. Rudimentary forms of search are almost invariably present during the 'start-up' period. 46/ Also, substitution of one raw material for another, the introduction of new or improved products, etc. are activities which necessarily call for some limited amount of search efforts concerning both the production process and the organization of production.

We have noted, however, that a certain discontinuity frequently obtains in the technical history of firms as far as search efforts are concerned in the fields of process engineering and production planning. Such discontinuity seems to be associated to a major change in attitude towards questions of quality control, limits of tolerance, preventive maintenance, and other such technical matters. In many cases such change of attitude seems to be related, both to a significant re-organization of the firm's administrative structure, with the creation of a number of new departments such as Quality Control, Research and Development,

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45/ The duration of the 'life-cycle' in pharmaceutical products has been examined by various authors in: (Ed.) J.D. Cooper, The economics of drug innovation. The American University, Washington 1970.

46/ M.E. Clark, E.M.de Forest and L.R. Stechely. Aches and pains of plant 'start-up'. Chemical and Engineering Progress, Vol.67, December 1971.

Tooling, etc. and, to a major increase in the size and complexity and/or in the degree of sophistication of the commodity produced. Both such changes call for a rather different way of handling Purchasing and Inventories, Machine Loading Programmes, plant space, Quality control, etc. Process engineering and organizational skills adquired in an informal way during the initial years of company operation are found to be insufficient at that point, this flagging the need for a radical change in departamental organization, data gathering and interpretation efforts, etc. A whole new approach towards engineering efforts frequently sets in after such discontinuity in the firm's technical history, being noticeable a drastic increase in the ratio of indirect to direct personnel.

B. Markets.

As much as individual firms have been argued to undergo changes through time both in organizational structure and in the rate and nature of the technological search efforts they commit themselves to, also markets seem to experiment significant changes both in structure and in competitive atomosphere. Two 'stylized' cases outstand from the various case studies undertaken in Latin America. In both cases market structures evolve endogenously through time. In 'case I' due to the granting of an exclusive import license or to the early entrance of a large enough plant capable of catering for all (or most) of the domestic market, the prevailing market structure at the industry's starting point is that of a monopoly. Automobiles, the production of chemical and petrochemical products, etc. tend to reflect cases of this sort.

On the other hand, 'case II' describes an entirely opposite situation, i.e.a starting point characterized by the existence of many small undifferenciated competitors. Such situation has been shown to be a fair description of different branches of the Metalmechanic sector, Residencial construction, etc. 47/

47/ See: A.Castaño, J. Katz & F. Navajas, Op.Cit.

48/ See: G. Vitelli, Competition, Oligopoly and Technological Change in the Construction Industry. The Argentine Case, Working Paper N°3, IDB/ECLA/UNDP Programme on Science and Technology, 1976.

Both models' do, in due time, evolve into situations of an oligopolistic nature. The case of the protected monopolist does so as a consequence of new entry induced by abnormaly high profits. 48/ That of the atomistic undifferenciated competitors is somewhat more complex. We have observed that either a financial and/or a technological advantage determines that at some point in the market's history one of the firms outgrows its fellow competitors, eventually becoming a market leader.

Technological search efforts are clearly influenced, both, in their rate and nature, by the dynamics of the market's competitive atmosphere. Protected monopoly has been seen to be relatively more associated to technological search efforts of the 'output-stretching' variety than to cost-reducing and/or quality improvement innovations. By the time the monopolistic advantage evolves into an oligopolistic confrontation, product-differenciation search efforts, as well as a relatively stronger interest for cost-reducing innovations, are likely to develop as well. Contrarywise, other things being equal, more competitive environments have been observed to lead to cost-reduction technological search efforts as well as to product-differenciation strategies.

Summarizing: There are reasons to expect product design search efforts to develop at a rather early stage in a firm's history. More competitive environments are likely to induce a stronger drive in this direction. On the contrary, monopolistic market situations enhance the search for output-stretching innovations rather than for quality improvements and/or product differenciation.

Obviously we should not take the above-mentioned 'trends' in a restrictive way, as indicating that always, and as a matter of logical necessity, firms behave as hereby suggested. Similarly, there is nothing compulsory leading monopolistic firms into output-stretching innovations and more competitive ones into product differenciation efforts. Cases can be found where such 'tendencies' do not obtain, and yet our generalization seems to be supported by various different individual case studies.

48/ A model of this sort has been recently presented by R. Nelson and S.Winter in: 'The Schumpeterian Trade off revisited'. Working paper N°834. Institution for Social and Policy Studies, New Haven, May 1980, Mimeo.

C. Macroeconomic variables.

It can be scarcely surprising to know that firms react to changes in macroeconomic variables by modifying their behaviour. Magnitude of the change and company's degree of perception seem to be rather crucial in determining patterns of reacion.49/

Consider the following list of observed behavioral relations:

a. An increase in the cost of new capital equipment -which obtains, for example, as a consequence of a higher rate of interest or of a currency devaluation, etc.- induces entrepreneurs to postpone major investment decisions. Simultaneously, the advantages of output-stretching technological search efforts are enhanced.

Conversely, subsidies to capital expenditure -such as, for example, those that emerge from a cut in taxation, or from the granting of an import license at a preferential exchange rate- increase the internal rate of return of a given investment project, thus reducing the likelihood of the firm adopting an output-stretching strategy. Socially unjustifiable overextensions of the life cycle of outmoded equipment, as well as equally unjustifiable unticipated plant scrap decisions have both been detected during the course of our field work. The former one can be interpreted as a rational private choice on the face of the observed relative prices of skilled engineering labour vis a vis new capital equipment. 50/

b. In the same fashion as above, a rapid rate of demand expansion -obtaining for example, form various different policy actions related to aggregate demand management- will most probably induce favourable expectations among entrepreneurs and therefore induce optimistic investment programmes in new plant and equipment. Such expantionaty business 'climate' will reduce the likelihood of search efforts of the output-stretching variety, making it more probable the erection of new production facilities.

49/ H. Schwartz, from the IDB, has recently examined the subject of perception coming up with a very stimulating monograph on a topic which has thus far been given much too little attention by economists. See: Perception, judgement and motivation in decision making. Hypothesis suggested by a study of metalworking enterprises in Argentina, Mexico and the United States.(Mimeo), Washington, November, 1979.

50/ See: J. Fidel & J.Lucángeli, Op.Cit.1978 and A.Canitrot, Op.Cit. 1977.

c. The rate of interest -in as much as it represents the cost of time- also has a rather strong influence upon firms' technological behaviour. An increase in the rate of interest, other things being equal, can be expected to induce search efforts directed towards the reduction of the production cycle. Such efforts could be of the product engineering sort -simplification of design standardization, etc.- but will most likely be related to process engineering aspects (for example: reduction of transport operations in between 'stations' of a discontinuous process plant) -or to production planning matters- (such as, say, a more adecuate management of inventories of raw materials and components).51/

d. Tariffs also seem to play a role in determining the direction of search followed be a given company. Sheltered from external competition local firms feel some what less compelled to improve their product's quality. Obviously there is still some incentive coming from domestic competition but this one is not necessarily a perfect substitute for the former. Output-stretching innovations are more likely to obtain in such market regime than product-improvements.

e. Other features of the macro-economy -besides tarriffs, the rate of interest, the rate of expansion of G.D.P., the level of taxation, subsidies to capital expenditure, etc.- will also influence micro-economic technological behaviour. Two conditioning forces of major importance should he mentioned at this point. First, availability and cost of skilled personnel, including here long term macro-economic efforts in education, retraining, etc. of the labour force. Second, all those measures of direct support to individual company's research efforts, such as tax incentives to R&D expenditure, direct public participation (through universities, public research laboratories, etc.) in technology generation programmes, etc. 52/

A final set of forces influencing firms' technological behaviour is related to events of a scientific and technological nature taking place at the industries knowledge frontier. Let us briefly examine it.

51/ After experiencing for large decades a negative rate of interest the Argentine economy has in recent years passed to a regime of a rather high and positive value of such variable. Various different firms under study carried out search efforts of the sort indicated in the text, being it noticeable that the production cycle could be reduced by as much as 30% in some cases.

52/ Almost every other government -both of the developed and less developed world- is presently involved in heavy subsidization of R&D expenditure. The decision of interfering in the 'knowledge' market is a clear reflexion of the fact that market forces can not be expected to induce an adecuate alocation of resources to the creation of new technology.

D. Movements in the technology frontier.

It is frequent in the field of technology to hear about the existence of 'science-based' industries which are defined as those in which ..."latent productivity evolves over time at a rate determined by outside forces (i.e. advances in fundamental physics or biology, etc. resulting from research at universities)". 53/ 54/

Both, the rythm of expansion of the 'best practice' frontier and the ease of imitation -both, technical and legal- of the rapidly evolving technology, are crucial aspects of the competitive atmosphere prevailing in such industries. There seems to be consensus in the literature concerning the fact that 'science-based' industries are characterized by rather elastic demand functions, and by a product design and a production process which are both relatively flexible and therefore admit quite significant ad-hoc changes. Product engineering efforts are of fundamental importance even though standardization and normalization activities only take place after a few 'generations' of the original product design have passed the market test. Process engineering and production planning efforts also tend to be rather flexible, as the experience indicates that frequent changes have to be introduced both in the equipment -which is of a more universal nature- and in the organization of production.

Obviously 'science-based' industries are a far cry from being accesible fields for LDCs firms. Quite on the contrary, innumerable branches of manufacturing exhibit a much slower technological pace, conformed by cummulative improvements around a basically stable technological paradigm. The likelihood of LDCs firms 'catching up' with average international practices is considerably greater in these industries than in the former ones.

53/ R. Nelson & S.Winter: Op.Cit., 1980.

54/ There is a certain 'cross-fertilization' effect which needs to be mentioned at this point and which comes from the recent dramatic expansion of the electronic industry. Microprocesors and electronic process control equipment of all sorts are presently being adopted with great success by sectors as different as Foodstuffs or Textiles, thus making it possible for some of the advances in one of the 'science-based' sectors to penetrate into the production fabric of 'non-science-based' industries. Effects of this sort can also be found in other areas of manufacturing.

'In-house' technology generation activities will no doubt reflect in various different ways the relative distance between an industry's technology and the basic knowledge pool from where such industry draws the scientific and technological principles that underlie its operation. An example in this respect is the extent to which mechanical engineering firms producing, say, machine tools, have been forced to introduce changes in the skill composition of their product design and process engineering departments in order to 'catch up' with the rapidly evolving trend into numerically-controlled machine tools which seems now on the making in the machine tool sector as a consequence of contemporary developments in the electronic front. 55/

We are now in a position both to summarize our discussion concerning the determinants of 'in-house' technology generation efforts, and to return to the basic question addressed in this section of the paper, i.e. is there any reason on account of which we should expect the pace, nature, etc. of technological change of any given firm in a LDC environment to be a close replica of that introduced by comparable firms in more developed industrial societies?

As we have seen, an evolutionary sequence seems to develop at the level of the individual firm as far as in-house knowledge generation efforts is concerned. Such sequence involves search, trial and error, and above all, learning, in a much more fundamental way than the one presently contained in the received theory. Product design capabilities, followed in due time by process engineering and production planning skills, seem to develop in a sequencial order, absorbing the best part of one (or even two) decades of company technical history.

The market's competitive atmosphere, the changing package of macroeconomic parameters and the exogenously-given pace of advance of the knowledge frontier, will permanently flash out specific technical and economic signals inducing firms periodically to re-state their technological search strategy. Obviously the answers firms come up with are unlikely to be an exact replica of previously attained answers, as there is a

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55/ A research venture in this respect is presently being undertaken within the framework of the IDB/ECLA/UNDP Programme on Science and Technology. See: S.Jacobsson: Technical change, skill requirements and intervention policies in the machine toolsector. The case of Argentina. (Outline for a research piece intended as a doctoral dissertation for the University of Sussex, England.) Mimeo, March 1980.

great deal of specificity in the questions firms address themselves to. Company histories, as well as market relations and macroeconomic forces, significantly differ across countries and individual firm search strategies will no doubt reflect such differences.

A final word on research methodology. Our discussion of previous pages has shown how complex the problem is of formalizing microeconomic behaviour in the field of technology. Further exploratory work in each one of the four interacting fields hereby described seems to be needed in order to overcome the pre-theoretical stage in which the profession still dwindles as far as understanding technology-generation efforts.