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INNOVATION AND ECONOMIC DEVELOPMENT:
THEORETICAL RETROSPECT AND PROSPECT

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I. Introduction

The purpose of this paper is to discuss some theoretical issues latent in the basic ideas behind the IDB-ECLA research program in science and technology, and now being sharpened by the empirical findings that are emerging. The program presumes that manufacturing development in countries that are not technological leaders may involve significant elements of creativity and innovation. The empirical studies are finding this to be so. The technologies employed in Latin American manufacturing plants tend to be somewhat idiosyncratic and not easily describable as merely backwards. Further, technologies employed differ significantly among firms within the same country. Innovation, idiosyncrasy, and diversity, are not characteristics of manufacturing development highlighted by most formal development models, and indeed these characteristics are hard to reconcile with orthodox formal theory. Yet there they are, certainly interesting and probably important features of the development landscape.

What is it in prevailing orthodox theory that makes the empirical findings of this project seem heterodox? What kind of theoretical reformulation is necessary to square with the empirical facts that have been found? How can the concepts be formalized? What insights into the nature of effective development strategies are provided by a modified theoretical structure? There are the questions probed in this essay.

II. Technological Progress and Technological Backwardness in the Neoclassical Model

It seems useful to begin the discussion by stressing that contemporary formal neoclassical theory was not designed to deal with development type phenomena and problems, and that its implementation for these purposes has involved some ingenious but somewhat ad hoc add ons to the basic model. The question I want ultimately to explore is the adequacy of these add ons.

One of the consequences of the neoclassical synthesis and the focus on steady states that marked the main line of economic theorizing around the turn of the century was that attention turned away from one of the central concerns of classical economics - economic development. When in the early post-war era the attention of economists again turned to economic development much of the older classical wisdom had been forgotten. The theorizing about productivity was rested on the static neoclassical formulation of firm behavior that was used in contemporary price theory. But the neoclassical kit of concepts and perceptions lacked one idea that was prominent in the classical tradition: that innovation is an extremely important part of economic activity. And as a result the earlier attempts to analyze development within a neoclassical framework floundered.

The key presumption of the early post-war research was that changes over time in the output of a nation could be explained as movements along a production function, and differences in output at any time among nations could be explained as representing different points along a (common) production function. During the fifties a number of studies showed that only a small portion of growth (of output per worker) in countries could be explained by movements along a production function (increases in capital and other resources per worker). At roughly the same time economists,

to comprehend that differences in resources (capital) per worker could explain only a small fraction of the observed productivity differences among nations. If one preserves the production function language then clearly growth had to be understood largely in terms of shifts in production functions, and differences between rich and poor nations in terms of different levels of production functions.

Technological advance then became an important phrase in the vocabulary of growth and development theory. In high income countries this technological advance was viewed as the pushing forward of the frontiers of best practice. In less developed countries it was viewed as diffusion or (among engineers and natural scientists) technology transfer - the adoption of techniques that had been employed for some time in the more developed countries. One of the major functions of this IBD - ECLA project is to question the sharpness of this distinction. Anticipating, and exaggerating, conclusions, for the present I will talk of both kinds of shifts as innovation. During the late 1960s and into the 70s a considerable amount of attention began was paid to theorizing about innovation. There are three recognizable strands.

One of these, which might be called the simple neoclassical extension, views a firm as not merely choosing inputs and outputs within a given production set, but as choosing a production set. In the simplest versions, among the choices to be made on the basis of a profit maximizing calculus are various possible improvements in the production function (often characterized in terms of factor augmentations) that can be bought for different outlays of resources. For a firm at the frontiers of technology it is natural to call these outlays research and development. While to my knowledge this model has not been applied to firms not at the frontiers, it might be applied by considering investments in learning about and gaining access to the technologies used by other firms. As in the traditional

the process by which technological advance occurs, at least they specify a process - like doing R and D or engaging in technology transfer activities - that one can observe and describe. While in some of the verbal descriptions of learning there is some discussion of what is going on (see Hirsch for example) in the formal treatments there tends to be no discussion of what is learned by whom and how; there is no characterization of process. The learning by doing models must be recognized as logically incomplete.

As my discussion above has indicated, the phenomenon of a firm learning to do (something like) what other firms have been doing has been not carefully considered in any of the traditions concerned with innovation. I have suggested ways in which it could be treated as an investment in learning what others are doing, or as a special kind of search. But these characterizations of the process, as their analogue characterizations of the creation or discovery of new technology, do not come to grips with the groping uncertain nature of the technology transfer process and with the obvious fact that a mix of special transfer activities and learning by doing is involved.

I believe that a serious model of innovation must admit uncertainty in a way more fundamental than contained within the contemporary search models, and must recognize a range of interacting activities that contribute to innovation including specially directed ones like research and development and others connected with operating experience. Obviously I need now to support and elaborate these propositions. Let me do so by exploring how and why the neoclassical formalism evades them.

III. Implicit Assumptions Behind the Orthodox Models

It is useful to look both at the surface structure of these models, and at some implicit assumptions that seem to lie behind the surface structure. On the surface, these models (excepting the learning by doing models which seem logically incomplete) almost invariably have three major components. The first is a sharply defined production set which characterizes what a firm can do at any time. The second is an "industry" production set which contains the existing sets of all the firms in the industry and which is viewed as depicting all the points that are in some sense or other accessible to any firm at that time through "technology transfer". Finally there is an invention possibility set which extends beyond the prevailing industry production set and includes all the points that are achievable through research and development; research and development outcomes within this set may be regarded as stochastic (with known distribution) or determinate. These components have proved analytically convenient for modeling. It well may be, however, that models based on them tend to obscure, and are incapable of illuminating, certain important features of the economic development process.

While in most models these components simply are assumed with little or no discussion to justify them, I propose that behind the scenes is a set of deeper notions, occasionally explicit but almost always implicit, that economists hold about production capabilities, technology transfer, and invention. The key organizing idea is that there is something called "technology" which lies behind each of these sets -- the smaller set technology "known" to a firm, the middle size set technology "known" to the industry, the larger set technology "known to be achievable" by engineers and scientists. Technology is regarded as being describable by a set of blue prints, or a recipe, or a set of instructions, which if followed precisely, will lead to a specified result. In the earlier post-

war literature, the blueprints implicitly were assumed to be contained within a giant library, accessible to all. Subtly the idea of access changed, and property rights and private libraries became the metaphors. Thus a firm at any time is viewed as possessing and being able to work with a particular set of blueprints (instructions) that in general do not include all the known (by somebody) blueprints. A firm (or engineer) who possesses a particular blueprint is viewed as being able to give or sell that blueprint (perhaps along with other kinds of instruction) to another firm who then possesses and can use the technology. Scientists and engineers are viewed as being able to visualize quite precisely blueprints and instructions not yet drawn up, and as being able to prepare and make available these blueprints through an activity called research and development. At a still more abstract level of description, technology is viewed as explicit and articulated, imitable and teachable, and imbedded in a broadened body of understanding which permits previously unused variants to be reliably readied for use.

I maintain that if not exactly these, closely equivalent assumptions are needed if one were to deduce or justify the way the major components of orthodox models are specified. But surely there is a considerable tacit element in what is required to operate many technologies, particularly if a considerable division of labor and a command and control system are involved in their undertaking. A firm will not be able to know with certainty all the things it can do, and certainly will not be able to articulate explicitly how it does what it does. For this reason and others, the technologies operated successfully by one firm may not be easily imitated or taught. And the result of a "technology transfer" process is likely to be a set of procedures that differs in certain important respects from the template. In many technologies there is little understanding of why certain things work and others not, and hence considerable vagueness regarding what new techniques can be developed easily. These uncertainties often are not resolvable fully in the laboratory

or pilot plant but require actual operating experience. Even if they are resolvable in a laboratory, teaching and learning problems may require that learning by doing supplement learning by experiment and engineering design efforts.

To the extent technologies are tacit, firm production sets are fuzzy around the edges. 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. To the extent that technologies are not well understood, sharply defined invention possibility sets are a misleading concept and interaction between learning through R and D and learning through experience is an essential part of the invention process.

These aspects - tacitness, inimitability, and low level of understanding - clearly are not orthogonal but well may go together. I have used the term "tacit" to refer to uncertainty regarding the range of available techniques for production, and "low understanding" to indicate lack of a reliable R and D activity; the phenomena here are very close and not readily separable in practice. Difficulties in imitation can stem from lack of explicitness about what is being imitated or lack of understanding to enable the imitator and teacher to distinguish essential from inessential elements; these aspects sound different but may be close to the same thing. However, I propose that for modeling purposes it is useful to think of three different dimensions in characterizing particular technologies -- explicitness, imitability, degree of understanding. The neoclassical innovation model can be viewed as a special case in which polar assumptions are made about all of these variables. I would propose that for some technologies and for some problems, these polar extreme assumptions may be a convenient first approximation, but for other technologies and inquiries it is extremely important to pay attention to tacitness, inimitability, weakness of understanding.

For example (while the studies coming out of this project are rocking me even regarding this) I would have presumed that certain chemical process technologies, mostly wrapped up and embodied in particular pieces of equipment, could safely be regarded as explicit (in the sense that one could specify accurately the program for running the plant), imitable and teachable (the technology transfer metaphor ought to work here) and embedded in a strong enough body of general understanding so that certain redesigns and modifications could be attempted with some confidence of success. In contrast, various crafts clearly are not characterized by an explicit and articulated technology; indeed each piece of a craft output is likely to be in some ways unique. Crafts are imitable and teachable only in a very broad sense involving a considerable amount of apprenticeship resulting in a skill by the learner that differs in essential respects from that of the teacher. And one of the reasons for the lack of significant innovation in many craft technologies is that understanding is so weak that the batting average for attempted modifications from prevailing custom is very low.

Consider the implications for thinking about the process of manufacturing development in less developed countries of recognizing a considerable element of tacitness regarding a firm's prevailing capabilities, considerable difficulty in imitating what another firm is doing and with technical transfer more generally, and limited understanding of why things work the way they do and what would happen if something else were tried. One would expect to find exactly what the empirical studies in this project are finding. Idiosyncratic firms, differing significantly among themselves in capabilities, even when evolving under roughly the same economic conditions. Nervousness on the part of firms about departing too far from their established practices. A blend

of attempts to learn from other firms and engineers, to do engineering design studies (research and development), and learning by doing, in augmenting capabilities.

I have not yet mentioned an obviously important factor behind difficulties of technology transfers, and a key source of the idiosyncrasies of technologies used by certain firms in certain countries - unavailability of certain particular inputs or local conditions that make it impossible, not merely uneconomic, to employ a technology used successfully elsewhere. I have not because I suspect that this aspect of the problem may easily be overweighted in quick simple explanations of the phenomena in question, and thus initial attention to it may deter looking further to see the kinds of factors I have discussed above. Further, I propose that to a considerable extent the idiosyncratic inputs and special requirements problem may be the result of the idiosyncratic technology phenomena as much as a cause. Certainly there can be peculiarities of locally available raw materials. But consider the courses of idiosyncrasies of locally manufactured intermediate inputs - one would suspect idiosyncratic technologies employed would be at least as important as peculiar local raw materials. And to what extent are particularities of the local market that require special designs of product related to particularities of complimentary products or systems that employ the product as an input? I don't know, but I suspect that there are a number of cases where this is important. For example, the inability to adequately maintain roads calls for cars with especially durable axles.

Whatever the chicken and whatever the egg, there clearly are fascinating dynamics involved in a system where technologies are somewhat tacit, difficult to imitate precisely, and require learning by doing as well as by R and D. There is firm specific as well as industry and technology general knowledge. Product differentiation may emerge as a result of that, at

least initially, rather than being the result of any carefully thought through marketing strategy. In a competitive environment selection pressures would be exerted to weed out firms with high cost technologies and inferior products. Responses to these pressures, even by an alert active management, would not inevitably be successful if technology transfer and R and D both were not particularly reliable activities. In less competitive environments one would not be startled to see certain very idiosyncratic and uneconomic enterprises continuing to survive.

I suspect that there is at once a considerable amount of agreement among scholars of the manufacturing development process regarding this characterization, together with considerable nervousness that what I have been describing must be regarded as empirical complexities and not as elements for theoretical reasoning. I think the concern is misplaced. Economists have got so used to theoretical formalism based on well defined firm and industry production sets and invention possibility sets that the proposal to back off from these is seen as anti-theoretical. This is not so. I am pointing to a problem in a particular theoretical formulation, not in theorizing in general.

I will not argue that the theoretical reconstruction I propose will be easy. But I maintain that there are a number of building blocks around for beginning the attempts at reconstruction.

IV. How Might The Ideas Be Formalized?

I propose that there are two roughly separable problems here. One is the formalization of the ideas at the microscopic level of the individual firm, innovation, or case history. The other is formalization that enables one to analyze behavior at the level of the sector or economy. Let me deal with this latter aspect first. I think that the models being developed jointly by Sidney Winter and myself provide some strong clues as to how some of these ideas might be formalized at the level of analysis of an industry or sector. Indeed these models already have build into them in a stylized abstract way a number of a necessary features.

The models presume that at any moment of time firms have only a limited range of techniques among which they can choose reliably. The models contain two different kinds of search activities, one directed toward exploring theoretical possibilities (one can think of this as R and D), the other focusing on what other firms are doing. The outcome of these search activities are stochastic and not predictable in advance in any detail. The firms compete with each other in a market, some do well and grow and others do badly and decline. The overall model provides a vehicle for exploring at the level of the industry or the economy the implications, in terms of a time series of variables like output, inputs, and prices, of such a collection of idiosyncratic, groping, and competing firms.

The explicitness, imitability, and degree of understanding associated with a technology can be interpreted within these models in quite natural ways. In the earlier discussion, explicitness was associated with the presence of a set of blueprints which a firm could follow reliably so as to be able to do things significantly different from what it presently is doing. In most of the specific models we have run, we have assumed that at any time a firm only knows one technique - in the language coined above this

is an extreme assumption about "implicitness". But, as a monotonic function of explicitness, that set might be augmented to include technologies that the firm has used in the recent past, some that it never has used, and some that no firm has ever used. (The latter situation would correspond to the full blown available production set assumption of contemporary orthodoxy.)

It pays to dwell a moment on theoretical issues relating to a firm's production set, and connections between today's production set and yesterday's R and D (or other forms of learning). Main line price theory evades the issues by never asking where the production set comes from. Most of the standard induced innovation models presume that successful R and D creates not just a new technique with a given input proportions and output attributes but a wide range of available new production choice options (e.g. labor is augmented at every possible capital-labor rates). In the language employed here this seems to presume that new techniques are explicit. They come out of R and D ready to use, and there is no need for fumbling trial and error in actual practice. Further, what comes out of R and D is a book of related techniques. The search models also presume an explicitness about the new techniques that come from R and D, in that no learning by doing seems required after "invention", but the invention is of a single technique not a book of them. Atkinson and Stiglitz, in their note, propose that technical change is local; in our language in their model an R and D project results in a single blueprint not a family of blueprints. If technical change is local, and past R and D is limited, then even if technological knowledge is explicit today's production set may be quite small. But if technological knowledge is tacit it is almost bound to be. Even if there are sets of blueprints for unused techniques, they are not usable without a lot of trial and

learning by doing. On the other hand with explicit articulated technical knowledge, if R and D results in packages of blueprints, prevailing production sets may have that textbook scope.

In several of the models we have put together we have variables which determine the costs of trying to identify the technologies of other firms, the likelihood of identifying various other technologies, and the extent to which imitation when it is attempted results in a technique identical to or close to that employed by the imitated firm. The characterization of the degree of imitatability contained here strikes me as rather rich.

The degree to which a technology is well understood might be modeled, within the above theoretical structure, in terms of the ability of a firm to point its research and development activity (search) reliably in one direction or another, in the sense that it can achieve with a reasonable degree of confidence what it tries to achieve at predicted cost. The neoclassical models employing an innovation possibility frontier represent one extreme of understandability, some of our models where the firm has no ability to point research and development in one activity or another and the consequences of search amount to the results of a random draw represent the other extreme.

The models under discussion clearly are a significant distance removed from grip on the details of firm behavior and innovation being explored in the empirical work of the research program on science and technology. They involve a drastic compression and simplification of what is going on at the level of the individual firm and of the characteristics of the individual innovation and sequences of innovation. The advantage of this simplification and compression is that one can see the implications of the kind of behavior of firms built into the model at the level of the industry or the economy. And most economic analysis, as contrasted with organization analysis, or management consulting, proceeds at the level of the industry or the economy, not the individual firm. But the difficulties with the traditional theory

discussed above reveal sharply the importance of understanding of what really is going on at the microscopic level. "As if" theorizing is a dangerous thing unless disciplined by such an understanding.

At the more micro-cosmic level, I propose that the ideas in behavioral models of firm actions (Cyert and March) are appropriate as building blocks. It is obvious that, in deliberating innovation and trying to solve problems, while firms may try to do as well as they can, they should not be viewed as maximizing over a well defined choice set with the implications of any choice well understood probabilistically. The firms in the Nelson-Winter models described above are "behavioral" in the sense that they follow rules of thumb and search for improvements in a manner that, while perhaps sensible, is not the result of any global optimizing calculations on their part.

I suspect that the most fruitful modeling goal at the micro-cosmic level is not so much to understand the behavior of particular firms in considerable detail, but to understand better the character of the key processes involved in innovation. Clearly these are "problem solving" processes. While there has been some progress recently in modeling problem solving (see for example Newell and Simon) the models have tended to be of single person problems isolated in time - as a human being trying to play a winning game of chess. Two striking aspects of innovation, widely noted in the general empirical literature as well as in the studies under consideration here - are that it is a cumulative process with today's problems growing out of yesterday's solutions (like the moves in a chess game), and that it is a social process involving interaction among people and information flow.

The connected nature of much of technical advance has been discussed by Rosenberg (on a big canvas) and Hollander (in a smaller frame). In a recent paper of mine I have tried to formalize what is going on in the context of a model of search where what is found today provides part of the basis for devising ones search tomorrow. And here the question of how various things

are found or found out about clearly is crucial. Perhaps one can think of an R and D activity, or an activity studying another firm's technologies, as providing not explicit blueprints or new technical capabilities ready to use, but information and plausible hypotheses about what will work in practice, to guide changes in what a firm tries to do. In turn, experience in doing feeds back to influence the next round of the more separate and cognitive learning processes.

The fact that innovation involves information flow among people and the marshalling of appropriate expertise is well recognized, but not adequately treated theoretically in any place that I know of. Many facets are involved. For one thing, externality and public goods aspects are involved in information generation. Economists have recognized this, but mainly in the context of treating a newly invented technique as explicit information. But to the extent that techniques tend to have significant tacit aspects and are difficult to teach and learn, the question of what are the public aspects of technical knowledge has to be seen as more complex than the simple "public technical knowledge" models presume. The question of how information flows, is sent and received, and mastered, become critical issues. This is what the technical transfer discussion is all about. But economists have hardly begun to model these aspects.

V. Implications Regarding Thinking About Manufacturing Development

Presume that much of manufacturing technology is characterized by a considerable element of tacitness, difficulties in imitation and teaching, and uncertainty regarding what modifications will work and what will not. What differences would this make, compared with the presumption of explicitness, imitability, and predictable innovation, to thinking about manufacturing development?

One implication is that the "technology choice" issue is much more complex and subtle than is implied by the orthodox discussion thereof. There doesn't exist a well defined set of "technological options" out there that a firm can scan and assess easily and reliably. This is not to deny that there isn't a wide range of choice, and that finding out about the options and thinking about the choices isn't important. However, it is likely to be a far more difficult matter than generally assumed for a firm to be able to judge how a particular technique employed by another firm would operate for it. Its own version of the technique invariably would involve a variety of idiosyncracies, some intended and some not. Invariably there would be teething problems, and a need to learn by doing, and perhaps by "researching".

Second, neither the old fashioned Hecksher-Ohlin, nor the newer fangled "product cycle" theories of trade can adequately come to grips with evolving comparative advantage in less developed countries. This isn't to say that relative factor endowments don't matter, or that the most advanced countries don't have a broad economic advantage in industries where technical change is very rapid. But it is to say that manufacturing firms in countries not at the frontiers inevitably are going to be working with techniques that are different from, and not merely outdated versions of, the techniques used in the firms in the countries at the technological frontiers. And they will be producing products of somewhat different character. These techniques and products may

be better suited for purchase and use in countries with comparable economic environments than those produced and used in the more advanced countries. And where this is so, it is highly likely that a certain amount of purposive innovation has gone on in the relevant company.

Third, success in manufacturing development may depend to a very considerable extent on the creation and strengthening of an indigenous innovative capacity. I am not familiar with the details of what has been happening in manufacturing industry in those countries which have experienced the most striking success in manufacturing development over the last decade -- Korea, Taiwan, Singapore, Mexico. I would conjecture strongly, however, that what has been happening can not be adequately explained merely in terms of growth of capital, and technology transfer. Rather, what has been happening has involved a considerable creativity. The case studies prepared under this project of the more successful firms reveal this sharply.

Fourth, to the extent that this is so, inquiry needs to be redirected to the kinds of developmental questions that so concerned the classical economists, but which dropped out of attention with the ascendancy of neoclassical formalism. There is a high premium to be placed on focusing theoretical attention on issues of innovation, entrepreneurship, dynamic competition and the role of education, banking institutions, and government policies more generally in these processes. It is not that serious scholars of the development process have not paid attention to these variables. But they have paid attention to them in an atheoretical way.

Indeed, it appears to me that there has been a growing gap between what sensible development economists know about development processes, and the theoretical structures available to give coherence and power to research. There is a strange notion that floats about among economists that theory should lead and empirical research should follow and test theory. This is much too asymmetric a view of fruitful relationship between theory and

empirical work. One of the really important accomplishments of this project may be that the phenomena that it is documenting so well will shock theorists into paying attention.

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