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Technological paradigms, patterns of learning and development: an introductory roadmap

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Abstract. This paper presents an evolutionary microeconomic theory of innovation and production and discusses its implications for development theory. Using the notions of technological paradigm and trajectory, it develops an alternative view of firm behavior and learning. It is shown then how these are embedded in broader national systems of innovation which account for persistent differences in technological capacities between countries. Finally, this "bottom-up" evolutionary analysis is linked with an institutional "top-down" approach, and the potential fruitfulness of this dialogue is demonstrated.

Key words: Technological paradigms – Technological change – Theory of innovations – National systems of innovation

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1. Introduction

Deep relationships of some sorts between technical change and economic development are now generally acknowledged in both economic history and economic theory. Still, their nature is matter of debate concerning the precise causal links. For example, it is quite intuitive that improvements in the efficiency of techniques of production or in product performances may be a determinant or at least a binding precondition of growth in per capita incomes and consumption. But, intricate

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debates concern "what ultimately determines what...": e.g. is it resource accumulation that primarily fosters the exploration of novel innovative opportunities, or, conversely, does innovation drive capital accumulation?; do new technological opportunities emerge mainly from an extra-economic domain ("pure science") or are they primarily driven by economic incentives?; should one assume that the institutions supporting technical change are sufficiently adaptive to adjust to whatever underlying economic dynamics emerges from market interactions; or, conversely, are they inertial enough to shape the rates and directions of innovation and diffusion?

Clearly, these and a few other, related, questions are at the core of many controversies regarding growth patterns: for example, is convergence the dominant tendency? How does one then interpret observed phenomena of forging ahead or falling behind? Is it legitimate to exclude from the analysis at least in a first approximation the specificities of institutions and corporate organizations? Even more so, all these questions and controversies underlie the political economy of development.

Obviously, one would not do justice to these intricate questions in a single paper even if one had achieved thorough answers (that indeed one is far from having). However, there has been over at least the last two decades a flourishing of studies on the sources, mechanisms and patterns of technological innovation. And, the opening of the technological blackbox has often gone together with important insights into innovation-driven market competition. Business historians have finally achieved some cross-fertilization with (some breeds of) economic theorizing. And the institutional understanding of the socio-economic fabrics of contemporary societies starts showing fruitful complementaries with other analyses stemming from the economists quarters.

Quite a few of these contributions have been proposed by scholars who would call themselves evolutionists or institutionalists. Many, others have come within different theoretical perspectives. Still, there is a sense that these diverse streams of research show a few common threads, highlighting – to paraphrase Richard Nelson the co-evolution of technologies, corporate organizations and institutions. These threads – linking evolutionary analyses of the microeconomics of innovation all the way to (daring) generalizations on some invariant features of the process of development – are the subject of this paper. Far from being a comprehensive survey, it is rather a sort of "roadmap" with an inevitable degree of idiosyncrasy.

We start by discussing the theoretical implications of what we know about the often patterned dynamics of innovative activities at a micro level. The notions of technological paradigms, trajectories (and largely overlapping ones such as dominant designs) entail a representation of technologies centered on the cognitive and problem-solving procedures which they involve.

Another major implication of this view is in terms of theory of production. It is rather straightforward to derive some sort of non-substitution properties, in the short-term, and, also in the long-term, technological asymmetries or gaps as permanent features across firms and, even more as, across countries.

Do these micro technological properties bear consequences at broader levels of observation, i.e. whole industrial sectors and whole countries? Or, putting it another way, can one identify invariances and patterns at sectoral or national level which can be interpreted in terms of some underlying specificities in the processes of collective learning, market selection and institutional governance of both?

This is the subject of the second part of the paper, and it is also where the roadmap inevitably bifurcates into different discourses. Some will be persued in reasonable detail and while others will only be sketched out, just flagging the elements of consistency with the rest of the argument. For example, there are sound theoretical reasons and a growing empirical evidence that the observed patterns of evolution of industrial structures are the outcome of specific modes of access to innovative opportunities and market selection mechanisms. However, we shall not dwell here on this aspect of the co-evolution between technologies and production structures. Rather more attention shall be devoted to the links between micro learning and economy-wide accumulation of technological capabilities and, in particular, to the existence of specific national system of production and innovation. The argument needs to be built through several steps. First, it follows from the microeconomics of innovation that firms are central, albeit by no means unique, repositories of technological knowledge. Hence, also their specific organizational and behavioral features affect the rates and direction of learning. Second, firms characteristics are not randomly distributed across sectors and across countries. On the contrary, particular traits tend to be reinforced through their interactions with the environment in which they are imbedded. Third, broad institutional mechanisms of governance of interactions further enhance the possibility of collective lock-in into particular modes of learning. Somewhat in analogy with the earlier microeconomic analysis we shall call these patterns as national trajectories.

Far from reviewing an immense historical evidence on these issues, we shall only draw from selected examples from developed countries and, in particular, from a somewhat archetypical comparison between the experiences of Latin America and the Asian Far East.

Along this *tour de force* from micro technological studies to the political economy of development, we shall on purpose raise many more questions than we shall able to answer. The major task here is to show that they can be consistently linked together in a broadly defined evolutionary interpretation.

2. The fundamental properties of technology

Technological paradigms and trajectories

A variety of concepts have recently been put forward to define the nature of innovative activities: *technological regimes, paradigms, trajectories, salients, guideposts, dominants designs* and so on. The names are not so important (although some standardization could make the diffusion of ideas easier!). More crucially, these concepts are highly overlapping in that they try to capture a few common features of the procedures and direction of technical change (for a discussion and references, see Dosi 1988). Let us consider some of them.[1]

The notion of technological paradigms is based on a view of technology grounded on the following three fundamental ideas.

First, it suggests that any satisfactory description of "what is technology" and how it changes must also embody the representation of the specific forms of knowledge on which a particular activity is based. Putting it more emphatically, technology cannot be reduced to the standard view of a set of well-defined blueprints. Rather, it primarily concerns problem-solving activities involving – to

[1] In the following, we shall stick to the categories of *paradigms* and *trajectories*, but the reader who is found of other names should still recognize familiar ideas.

varying degrees – also tacit forms of knowledge embodied in individuals and organizational procedures.

Second, paradigms entail specific heuristic and visions on "how to do things" and how to improve them, often shared by the community of practitioners in each particular activity (engineers, firms, technical societies, etc.), i.e. they entail a collectively shared cognitive frames (Constant 1985).

Third, paradigms generally also define basic models of artifacts and systems, which over time are progressively modified and improved. These basic artifacts can also be described in terms of some fundamental technological and economic characteristics. For example, in the case of an airplane, these basic attributes are described not only and obviously in terms of inputs and the production costs, but also on the basis of some salient technological features such as wing-load, take-off weight, speed, distance it can cover, etc. What is interesting is that technical progress seems to display patterns and invariances in terms of these product characteristics. Similar examples of technological invariances can be found e.g. in semiconductors, agricultural equipment, automobiles and a few other micro technological studies.

The concept of *technological trajectories* is associated to the progressive realization of the innovative opportunities associated with each paradigm, which can in principle be measured in terms of the changes in the fundamental techno-economic characteristics of artifacts and the production process. The core ideas involved in this notion of trajectories are the following.[2]

First, each particular body of knowledge (i.e. each paradigm) shapes and constraints the rates and direction of technological change irrespectively of market inducements. Second, as a consequence, one should be able to observe regularities and invariances in the pattern of technical change which hold under different market conditions (e.g. under different relative prices) and whose disruption is correlated with radical changes in knowledge-bases (in paradigms). Third, technical change is partly driven by repeated attempts to cope with technological imbalances which it itself creates.[3]

A general property, by now widely acknowledged in the innovation literature, is that learning is local and cumulative. Local means that the exploration and development of new techniques is likely to occur in the neighborhood of the techniques already in use. Cumulative means that current technological development – at least at the level of individual business units – often builds upon past experiences of production and innovation, and it proceeds via sequences of specific problem-solving junctures (Vincenti 1992). Clearly, this goes very well together with the ideas of paradigmatic knowledge and the ensuing trajectories. A crucial implication, however, is that at any point in time the agents involved in a particular production activity will face little scope for substitution among techniques, if by that we mean the easy availability of blueprints different from those actually in use, which could be put efficiently into operation according to relative input prices.

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[2] The interpretation of technical change and a number of historical examples can be found in pioneering works on economics of technical change such as those by Chris Freeman, Nathan Rosenberg, Richard Nelson, Sidney Winter, Thomas Hughes, Paul David, Joel Mokyr, Paolo Saviotti and others; see for a partial survey Dosi (1988).

[3] This is akin to the notion of reverse salients (Hughes 1992) and technological bottlenecks (Rosenberg 1976): to illustrate, think of increasing the speed of a machine tool, which in turn demands changes in cutting materials, which lead to changes in other parts of the machine...

Technological dominance, micro heterogeneity and non-substitution

The notion of paradigms contains elements of both a theory of production and theory of innovation. In short, we shall call it henceforth an evolutionary theory. Loosely speaking, we should consider such a theory at the same level of abstraction as, say, a Cobb-Douglas production function or a production possibility set. That is, all of them are theories of what are deemed to be some stylized but fundamental features of technology and, relatedly, of production process.[4]

In fact, one finds a few remarkable assumptions underlying conventional production theories. As already mentioned, technologies – at least in a first approximation – are seen as a set of blueprints describing alternative input combinations. Moreover, at any one time there must be many of them, in order to be able to interpret empirical observations as the outcome of a microeconomic process of optimal adjustment to relative prices. Information about these blueprints is generally assumed to be freely available (except those circumstances whereby they are privately appropriated via the patent system). Finally, one assumes to be able to separate the activities leading to the efficient exploitation of existing blueprints from those leading to the development of new ones (exogeneity of technical progress is its extreme version). Of course, this is only a trivialized account of a family of models that can be made much more sophisticated, by e.g. adding details on how blueprints are ordered with respect to each other (more technically, issues like continuity and convexity come under this heading). However, it still seems fair to say that the basic vision of production – also carried over in aggregate growth and development models – focuses on questions of choice among well defined techniques, generally available to all producers, who also know perfectly well what to do with all the recipes when they see them.

Well, to put it very strongly, the theory of production based on paradigms develops on nearly opposite theoretical building blocks. And indeed many of the latter yield empirically testable hypotheses.

Here, we shall argue that a paradigm-based theory of technology may perform the same interpretive tasks, at the same level of generality, and do it better, in the sense that it is more in tune with microeconomic evidence and also directly links with theories of innovation. Our theory would predict the following.

a) In general, there is at any point in time one or very few best practice techniques which dominate the others irrespectively of relative prices.
b) Different agents are characterized by persistently diverse (better and worse) techniques.
c) Over time the observed aggregate dynamics of technical coefficients in each particular activity is the joint outcome of the process of imitation/diffusion of existing best-practice techniques, of the search for new ones, and of market selection amongst heterogeneous agents.
d) Changes over time of the best practice techniques themselves highlight rather regular paths (i.e. trajectories) both in the space of input coefficients and also in the space of the core technical characteristics of outputs (see the earlier example on aircrafts).

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[4] Few believe that a production possibility set literally exists. Many would however probably maintain that such a notion enhances the understanding of the observed technical coefficients in the economy and also how they change over time. We claim the same for the evolution theory.

A representation of production and technological activities

Let us further illustrate the previous points with a graphical example.

Start from the notion that each technical coefficient observed at the microlevel is the outcome of codified information (something resembling blueprints), but also of more tacit and firm specific forms of knowledge. Suppose that, for the sake of simplicity, we are considering here the production of an homogeneous good under constant returns to scale with two variable inputs only, x_1 and x_2.[5]

A paradigm-based theory of production predicts that, in general, in the space of unit inputs, micro coefficients are distributed somewhat as depicted in Figure 1. Suppose that at time t the coefficients are $c_1, \ldots, c_n$; where $1, \ldots, n$ are the various techniques/firms labelled in order of decreasing efficiency at time t. It is straightforward that technique/firm c_1 is unequivocally superior to the other ones no matter what relative prices are: it can produce the same unit output with less inputs of both x_1 and x_2. The same applies to the comparison between c_3 and c_n, etc....

Let us call this property *technological dominance*, and call some measure of the distribution of the coefficients across heterogeneous firms as the *degree of asymmetry* of that industry (for example, the standard deviation around the mean value C).

The first question is why doesn't firm n adopt technique $c1$? To simplify a more articulated argument (see Freeman 1982, Nelson and Winter 1982, Dosi 1988 and Dosi, Pavitt and Soete 1990), the answer is "because it does not know how to do it...". That is, even if it is informed about the existence of c_1, it might not have the capabilities of developing or using it. Remarkably, this might have little to do with the possibility for c_1 to be legally covered by a patent. The argument is much more general: precisely because technological knowledge is partly tacit, also embodied in complex organizational practices, etc., technological lags and lead may well be persistent even without legal appropriation. The opposite also holds: if the two firms have similar technological capabilities, imitation might occur very quickly, patent

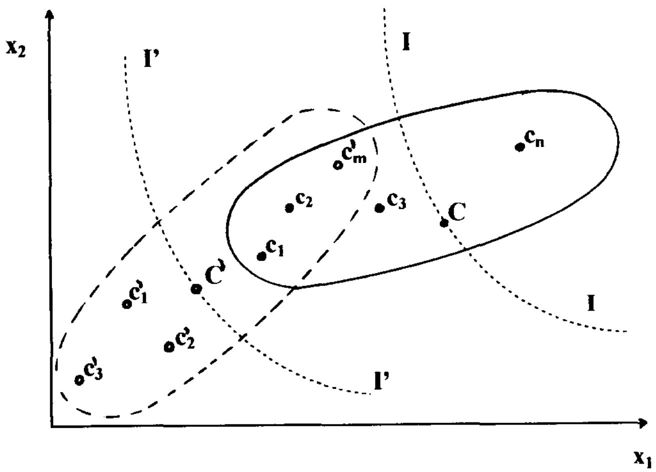

Fig. 1. Microheterogeneity and technological trajectories

[5] Note that fixed inputs, vintage effects and economies of scale would iust strenghten the argument.

protection notwithstanding, by means of "inventing around" a patent, reverse engineering, etc..

We are prepared to push the argument further and suggest that even if firm n were given all the blueprints of technique c_1 (or, in a more general case, also all the pieces of capital equipment associated with it), performances and thus revealed input coefficients might still widely differ. Following R. Nelson, it is easy to illustrate this by means of a gastronomical metaphor: despite readily available cooking blueprints and, indeed, also codified rules on technical procedures, unavailable in most economic representations of production ("... first heat the oven, then after around ten minutes introduce some specified mixture of flour and butter,... etc."), one obtains systematically asymmetric outcomes in terms of widely shared standards of food quality. This applies to comparisons among individual agents and also to institutionally differentiated groups of them: for example, we are ready to bet that most eaters randomly extracted from the world population would systematically rank samples of English cooks to be "worse" than French, Chinese, Italian, Indian,... ones, even when performing on identical recipes!!. If one accepts the metaphor, this should apply, much more so, to circumstances whereby performances result from highly complex and opaque organizational routines (Incidentally, Leibenstein's X-efficiency rest also upon this widespread phenomenon).

Suppose now that at some subsequent time t' we observe the distribution of microcoefficients $c'_3, \ldots, c'_m$. How do we interpret such a change?

The paradigm-based story would roughly be the following. At time t, all below-best-practice firms try with varying success to imitate technological leader(s). Moreover, firms change their market shares, some may die and other may enter: all this obviously changes the weights (i.e. the relative frequencies) by which techniques/firms appear. Finally, at least some of the firms try to discover new techniques, prompted by the perception of innovative opportunities, irrespectively of whether relative prices change or not (for the sake of illustration, in Figure 1, firm-3 succeeds in leapfrogging and becomes the technological leader while firm-m now embodies the marginal technique).

How do relative prices fit into this picture?

In a first approximation, no price-related substitution among firm-known blueprints occurs at all. Rather, changes in relative prices primarily affect both the direction of imitation and the innovative search by bounded-rational agents. However, the paradigm-based story would maintain that, even if relative prices change significantly, the direction of innovative search and the resulting trajectories would remain bounded within some relatively narrow paths determined by the nature of the underlying knowledge base, the physical and chemical principles it exploits, the technological systems in which a particular activity is embodied. Still more importantly, persistent shocks on relative prices, or, for that matter, on demand conditions, are likely to exert irreversible effects on the choice and relative diffusion of alternative technological paradigms, whenever such an alternative exists, and, in the long term, focus the search for new ones.

In a extreme synthesis, a paradigm-based production theory suggests as the general case, in the short term, fixed-coefficient (Leontieff-type) techniques, with respect to both individual firms and industries, the latter showing rather inertial averages over heterogeneous firms. In the longer term, we should observe quite patterned changes, often only loosely correlated with the dynamics of relative prices.

In fact, the available evidence – admittedly scattered, due also to the economists propensity to avoid disturbing questions – is consistent with these conjectures: there appear to be wide and persistent asymmetries in efficiency among firms within the same industry (cf. for a survey and discussion Nelson 1981). This applies to developed countries and, more so, to developing ones. Moreover, persistent asymmetries appear also in profitability (Geroski and Jaquemin 1988, Muller 1990). Finally, several industrial case studies highlight technology-specific regularities in the patterns of technical change hardly interpretable as direct responses to changes in relative prices and demand conditions: in this respect, the case of the semiconductors (Dosi 1984) is only an extreme example of a more general phenomenon.

Let us now expand the space over which technologies are described and include, in addition to input requirements, also the core characteristics of process and artifacts, hinted earlier: e.g. wing-load, take off weight etc. in airplanes; circuit density, processing speed in semiconductors; acceleration, fuel consumption in automobiles; etc. The conjecture is that also in this higher-dimension space, trajectories appear and that discontinuities are associated with changes in knowledge bases and search heuristics. Indeed, the evidence put forward by e.g. Devandra Sahal and, more recently, by Paolo Saviotti at Manchester University show remarkable regularities in the patterns of change within the space of core product characteristics: for example, in commercial aircrafts, one can observe a well defined trajectory leading from the DC-3 to contemporary models. (Interestingly, models which turn out to be technological or commercial failures often happen to be far from the trajectory itself).

These findings bear implications also for the economic analysis of the relationship between supply and demand dynamics. Start from a Lancasterian view of final demand (i.e., consumers demand characteristics which satisfy their "needs"). With rising incomes and heterogeneous preferences, one might have expected product variety to grow and be distributed over the whole space of characteristics. In fact, one obviously observe an enormous product variety. However, at a closer look, it appears that product innovation explore only a minor sub-set of such a space. Putting it differently, the nature of each paradigm appears to be a powerful factor binding the variety in the technical features and performances of observed products.

Technical change, international asymmetries and development

Naturally, there is an alternative interpretation of all the evidence discussed so far drawing on standard production theory. Let us consider once more Figure 1. Take for example the average technical coefficient C at time t by reading it from published industrial statistics. *Assume* by definition that C is the equilibrium technique (whereby average and best practice techniques nearly coincide). Relatedly, draw some generic *and unobservable* downward-sloped curve through C (say, in Fig. 1 the II curve) and also the observed relative price ratio. Do the same with point C' corresponding to the average values at t', and again with the subsequent average observations. Next assume a particular functional form to the unobserved curve postuled to pass through $C, C', C', \ldots$, etc. and call it the isoquant of a corresponding production function. (The same method can be applied, of course, over time or cross-sectionally). Then, run some econometric estimates based on such postulated function, using data derived from the time-series of relative prices and $C, C', \ldots$ Finally, interpret the relationship between the values of the estimated coefficients in terms of elasticities of substitution (i.e. some notional movement along the II curve, as equilibrium responses to relative price changes), and attribute the residual variance to a drift in the technological opportunity set, as represented by the movement from II to I'I', etc..

For the purpose of this argument, one can neglect whether such a drift is meant to be an exogenous time-dependent dynamics – as in Solow-type growth models –, or is in turn the outcome of some higher level production function of blueprints – as in many new growth models. In any case, if – for whatever reasons – relative prices present some intertemporal regularity and so do pattems of technological search (for example because they follow paradigm-driven trajectories), then one is likely to find a good statistical fit to the postulated model, even when no causal link actually exists between distributive shares and factor intensities. This is a well established point, convincingly argued in different perspectives by F. Fischer, R. Nelson, L. Pasinetti, A. Shaikh, H. Simon. Even if the evolutionary microdynamics described above were the true one, one could still successfully undertake the standard statistical exercise of fitting some production function. But the exercise would in fact obscure rather than illuminate the underlying links between technical change and output growth.

Take the illustration of Fig. 1 and suppose that the evidence does not refer to two distributions of micro-technical coefficients over time within the same country, but instead to two countries at the same time: after all, paraphrasing Robert Lucas, we only need informed tourists to recognize that most countries can be ranked in terms of unequivocal average technological gaps. With some additional assumptions on the nature of production function, one can still claim that C, C', etc. remain equilibrium realizations of country-specific allocation processes. Conversely, in the context of an evolutionary approach, one would suggest – as we do – that optimizing choice among technical alternatives commonly shared by all agents in the two countries have little to do with all this, and that one should rather look for an explanation of such inter-national differences within the process of accumulation of technological competence and also within the institution governing market interaction and collective learning. The contrast between (imperfect) *learning vs optimal allocation of resources* as the fundamental engine of development has indeed been repeatedly emphasized among others by Kaldor, Pasinetti and earlier by Schumpeter, but to our knowledge, no-one has yet fully explored its consequences for the theory and policy of development. Needless to say, we are dramatizing the differences. After all, learning is intertwined with the process of resource allocation. Still, it is useful to distinguish between what is assumed as having first order or second order effects.

All this has also an empirical counterpart: indeed, the economic discipline has undertaken far too few exercises at the highest available disaggregation on international comparisons among sectoral technical coefficients. Our conjecture is that, at this level, one could observe a good deal of evidence conflicting with the standard theory of production: less developed countries may well show higher utilization of all or most inputs per unit of output and perhaps even higher relative intensity of those inputs that the theory would consider more scarce (that is, some loose equivalent of what euphemistically the economic profession calls in international trade the Leontieff paradox). Conversely, an evolutionary interpretation is straightforward: unequivocal technological gaps account for generalized differences in input efficiencies. Moreover, if technical progress happens to involve also high rates of saving in physical capital and skilled-labour inputs, one may also observe less developed countries which do not only use more capital per unit of output but also more capital per unit of labour input as compared to technological leaders (Figure 1 illustrates a similar case: compare for example, techniques c'_3 and c_n).

Some important implications emerge from this approach.

First, the theory would predict persistent asymmetries among countries in the production processes which they are able to master (this of course also shows up in terms of different inputs effficiencies: see Dosi, Pavitt and Soete 1990). Thus, at any point in time, one can draw two major testable conjectures: (i) different countries might well be unequivocally ranked according to the efficiencies of their average techniques of production and, in the product space, of the (price-weighted) performance characteristics of their outputs, irrespectively of relative prices, and (ii) the absence of any significant relationship between these gaps and international differences in the capital/output ratios. Wide differences apply also to the capabilities of developing new products and to different time lags in producing them after they have been introduced into the world economy. Indeed, the international distribution of innovative capabilities regarding new products is at least as uneven as that regarding production processes. For example if one takes international patents or the number discrete innovation as a proxy for innovativeness, the evidence suggest that the club of the innovators has been restricted over the whole past century to a dozen developed countries with only one major new entry, Japan (more on the evidence in Dosi, Pavitt and Soete 1990).

Second, the process of development and industrialization are strictly linked to the inter- and intra-national diffusion of "superior" techniques. Relatedly, as already mentioned, at any point in time, there is likely to be only one or, at most, very few "best practice" techniques of production which correspond to the technological frontier. In the case of developing economies, the process of industrialization is thus closely linked with the borrowing, imitation, adaptation of established technologies from more advanced economies. These process of adoption and adaptation of technologies, in turn, are influenced by the specific capabilities of each economy.[6]

In this context, we suggest that evolutionary micro-theories are well apt to account for the processes by which technological gaps and national institutional diversities can jointly reproduce themselves over rather long spans of time. Conversely, in other circumstances, it might be precisely this institutional and technological diversity among countries which may foster catching-up (and, rarely leapfrogging) in innovative capabilities and the per capita incomes. Rigorous demonstrations of these propositions would indeed require many intermediate steps, linking the externalities and positive feedback mechanisms based on technological learning with the institutional context in which microeconomic agents are embedded, and also the economic signals they face. We shall briefly come back to this issue later on. Here let us just emphasize that systematically different rates of learning may have very little to do with "how well markets work". Rather, the incentives and opportunities which agents perceive in a particular context are themselves the result of particular histories of technologies and institutions.

The importance of the institutional dimension for evolutionary theories of production and innovation should come as no surprise, supported by a growing evidence from both micro and macro patterns of technological change. After all, at the micro level, technologies are to a fair extent incorporated in particular institutions, the firms, whose characteristics, decision rules, capabilities, and behaviors are fundamental in shaping the rates and directions of technological advance. In turn,

[6] Abramovitz notion of differentiated "social capabilities" is quite consistent with this view, Abramovitz (1989).

firms are embedded in rich networks of relations with each other and with other institutional actors – ranging from government agencies to universities etc...[7]

But how did particular technologies come into exist existence in the first place? Let us turn to this question.

Economic and social factors in the emergence of new paradigms

It is useful to separate the genesis of new paradigms from the processes leading to the dominance of some of them. Let us first consider the emergence of new potential paradigms; that is, the generation of notional opportunities of radical innovation involving new knowledge bases, new search heuristics, new dominant designs.

In the literature one find quite different interpretative archetypes. A first class of models entails a lot of "techno-scientific determinism": advancements in pure science determine advancements in technological opportunities which in turn determine realized technological achievements. In fact, in order to find the most naive literature along these lines one should mostly search in the archives of defunct socialist countries. There, one is likely to find plenty of examples of Engels-type vulgata on the simplest linear models from science to technology to production.

The interpretation that students of economics find in textbook production is more sophisticated although basically of the same type. It maintains the basic linear sequence from science to technological opportunities to production but it claims that science only generates those notional blueprints discussed earlier, while some optimizing microeconomic algorithm selects among them. Proper economic analysis begins indeed by stating some daring assumptions on the nature of such blueprints which maintain in principle an empirical nature albeit little empirical micro support (e.g. on continuity, convexity, etc.). From then onward, production theory is generally presented as an application of methods of constrained maximization which intends to capture the purposed behavior of the *homo economicus* facing alternative allocative choices, and most often, also the aggregate properties of industries or whole economies.

Yet more sophisticated recent modelling on new-growth, new-trade theories, while attempting to endogenize the generation of blueprints themselves, push further upstream that same notional process of optimizing allocation involving some sort of production function for the blueprints themselves. This is not the place to discuss the (rather important) achievements and the (equally important) limitations of such theories. What we simply want to emphasize is the persistence across ample streams of micro and macro literature of two basic ideas: first, the linear representation of the innovative process, running from science to technology to production; and second, the focus upon an explicit deliberation, equivalent in every respect to an allocative choice, by supposedly rational agents.

[7] In this co-evolutionary perspective on technologies, corporate organizations and institutions (Nelson 1994), it is straightforward to acknowledge also a bi-directional relation between market structures (as proxied by measures on the distribution of different characteristics such as firm sizes, innovative competences, ownership, persistent behavioral traits, etc.) and patterns of technological learning. Different rates of learning influence the ability of firms to survive and expand and thus affect industrial structures. Conversely any particular structure – with its associated distribution of corporate features – influences and constrains what and how fast firms are able and willing to learn. Formal applications of this general idea are in Nelson and Winter (1982), Winter (1984), Dosi, Marsili, Orsenigo and Salvatore (1993).

However, as Chris Freeman, Nathan Rosenberg, and others have convincingly shown, historical evidence rules out the general applicability of linear models of innovation. One can find plenty of counter examples. First, the lag between scientific advancements and their technological application can vary between a few months (as in case of the transistor) to centuries. Second, technological innovation may actually precede the scientific discovery of the general principle on which those very technologies work (as in the case of electric lamps). Third, scientific advancements may actually be based on the invention of new machinery and not the other way round (think of the importance of the electronic microscopes for the subsequent scientific discoveries in biology).[8]

As regards the behavioral foundations of innovative decisions, we are quite skeptical about their reduction to deliberate allocative choices. As emphasized not only by evolutionary economists by also by rational choice theorists like K. Arrow, almost by definition innovation concerns the generation of something new and at least partly unexpected. Relatedly, the genesis of exploratory ventures into novel paradigms is more the domain of institutional and organizational inquiries on the conditions fastering entrepreneurial activities rather than rational choice models.[9]

Indeed, there are good reasons to believe that one will not be able to find anything like a general theory of the emergence of new technological paradigms. However, what might be possible is a) an analysis of the necessary condition for such emergence; b) historical taxonomies and also appreciative models of the processes by which it occurs; and c) taxonomies and models of the processes of competition amongst different paradigms and their diffusion.

Regarding the first heading, one is like to find that the existence of some unexploited technological opportunities, together with the relevant knowledge base and some minimum appropriability conditions, define only the boundaries of the set of potential new paradigms: those which are actually explored within this set might crucially depend on particular organizational and social dynamics. So for example, there is good evidence that the micro e lectronics paradigm as we know it (silicon-based, etc) was shaped in its early stages by military requirements (Dosi 1984, Misa 1985). David Noble argues that the NC machine-tool paradigm – although he does not use that expression – has been influenced by power considerations regarding labour management (Noble 1984). In the history of technology one finds several examples of this kind. The general point is that various institutions (ranging from incumbent firms to government agencies), social groups and also individual agents (including, of course, individual innovators and entrepreneurs) perform as *ex ante* selectors of the avenues of research that are pursued, the techno-economic dimensions upon which research ought to focus, the knowledge base one calls upon. Thus, they ultimately select the new paradigms that are actually explored.

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[8] See Rosenberg (1991)

[9] Of course this is not to say that the economic variables governing the incentives and penalties to entrepreneurial endeavours are irrelevant. The point is that the former tend to set only some lose incentive-compatibility constraints. Given these constraint, explanations of willingness of incubent firms to explore new paradigms, of the rate of the birth of new start-up firms, etc. requires a much more detailed understanding of specific corporate and institutional histories. Working backward from observed outcomes to some rational expectations model does not do the trick: on the contrary, there is evidence that in many new industries, had entrants rational expectations of their future profit streams, entry would not have occurred at all! (this seems to emerge also from a research, in progress. by Don Lovallo and Giovanni Dosi).

There is a much more general theoretical story regarding the development, diffusion and competition among those (possible alternative) paradigms that are actually explored. It can be told via explicit evolutionary models (as in Nelson and Winter 1982 or in Silverberg, Dosi and Orsenigo 1988), via path-dependent stochastic models (as in Arthur 1988, Arthur, Ermoliev and Kaniovski 1987, Dosi and Kaniovski 1994 and David 1989), and also via sociological models of network development (as in Callon 1991). The basic ingredients of the story are i) some forms of dynamics increasing returns (for example in learning); ii) positive externalities in the production or the use of the technology; iii) endogenous expectation formation; iv) some market dynamics which selects ex post amongst products, and indirectly amongst technologies and firms; v) the progressive development of standards and relatively inertial institutions which embody and reproduce particular forms of knowledge and also the behavioral norms and the incentives to do so.

3. Learning and trajectories in the process of development

Techno-ecnomic paradigms or regimes: from micro technologies to national system of innovation

So far, we have discussed paradigms, trajectories or equivalent concepts at a micro-technological level. A paradigm-based theory of innovation and production – we have argued – seems to be highly consistent with the evidence on the patterned and cumulative nature of technical change and also with the evidence on microeconomic heterogeneity and technological gaps. Moreover, it directly links with those theories of production which allow for dynamic increasing returns from A. Young and Kaldor to the recent and more rigorous formalizations of path-dependent models of innovation diffusion, whereby the interaction between micro decisions and some form of learning or some externalities produces irreversible technological paths and lock-in effects with respect to technologies which may well be inferior, on any welfare measure, to other notional ones, but still happen to be dominant – loosely speaking – because of the weight of their history (cf. the models by B. Arthur and P. David). However, paradigms are generally embodied in larger technological systems and in even bigger economic-wide systems of production and innovation.

The steps leading from a microeconomic theory of innovation and production to more aggregate analyses are clearly numerous and complex. A first obvious question concern the possibility of identifying relative coherence and structures also at these broader levels of observation. Indeed, historians of technology – T. Hughes, B. Gilles and P. David, among others – highlight the importance of technological systems, that is in the terminology of this paper, structured combinations of micro technological paradigms (see for example, the fascinating reconstructions of the emerging system of electrification and electrical standards in David 1992).

At an even higher level of generality, Freeman and Perez (1988) have suggested the notion of techno-economic paradigms as a synthetic definition of macro-level systems of production, innovation, governance of social relations. So, for example, they identify broad phases of modern industrial development partly isomorphic to the notion of "regimes of socio-economic Regulation" suggested by the mainly French macro institutionalists literature (see Aglietta 1976, Boyer 1988a and b).

In an extreme synthesis, both prospectives hold, first, that one can identify rather long periods of capitalist development distinguished according to their specific engines of technological dynamism and their modes of governance of the relationships amongst the major social actors (e.g. firms, workers, banks, collective political authorities etc), and, second, that the patterns of technological advancement and those of institutional change are bound to be coupled in such ways as to yield recognizable invariances for quite long times in most economic and political structures. Just to provide an example, one might roughly identify, over the three decades after WW II, across most developed economies, some "Fordist/Keynesian" regime of socio-economic "Regulation", driven by major innovative opportunities of technological innovation in electromechanic technologies, synthetic chemistry and relatively cheap exploitation of energy sources, and reproduced by some specific forms of institutional governance of industrial conflict, income distribution and aggregate demand management. Analogously, earlier in industrial history, one should be able to detect some sort of archetype of a "classical/Victorian Regime" driven in its growth by the full exploitation of textile manufacturing and light engineering mechanization, relatively competitive labour markets, politically driven efforts to expand privileged market outlets, etc..

These general conjectures on historical phases or regimes are grounded on the importance in growth and development of specific combinations among technological systems and forms of socio-economic governance. The approach can be applied also to the analysis of the differences and similarities of development patterns in the late-industrializing countries. One has focused for example on the interplay between the modes of governance of the labour market and the pattern of technical accumulation, showing how the specificities in labour market institutions originate virtuous or vicious circles of development in different historical periods.[10]

As an intermediate step toward the identification of national socio-economic regimes let us consider the anatomy and development of particular systems of innovation and production at national level, embodying distinctive mechanisms and directions of learning, and grounded in the micro theory of production and innovation sketched above.

Even if micro paradigms present considerable invariances across countries, the ways various paradigms are combined in broader technological systems and, more so, in national systems of production and innovation highlight – we suggest – a considerable variety, shaped by country-specific institutions, policies and social factors. The hypothesis here is that evolutionary microfoundations are a fruitful starting point for a theory showing how technological gaps and national institutional diversities can jointly reproduce themselves over rather long spans of time in ways that are easily compatible with the patterns of incentives and opportunities facing individual agents, even when they turn out to be profoundly suboptimal from a collective point of view.

In order to detail this hypothesis, however, one requires to analysis of the composing elements and properties of these national systems which in the recent literature have been referred to with a variety of largely overlapping concepts, such as global technological capability of each country, national innovation systems, national technological capabilities and national systems of production.[11]

In our view, the major building blocks in an evolutionary account of the specificities of national systems of production and innovation are following.

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[10] See Aboites (1988) Boyer (1993), Cetrangolo (1988a), (1988b), Cimoli (1988), (1990), Coriat and Saboia (1987).

[11] See Cimoli and Dosi (1988), (1990), Chesnais (1993), Ernest and O'Connor (1989), Lall (1984), (1987), (1992), Lundvall (1992), Nelson (1993), Zysman (1994).

First, there is the idea that firms are a crucial (although not exclusive) repositories of knowledge, to a large extent embodied in their operational routines, and modified through time by their higher level rules of behaviors and strategies (such as their search behaviors and their decisions concerning vertical integration and horizontal diversification, etc.).

Second, firms themselves are nested in networks of linkages with other firms and also with other non-profit organizations (such as public agencies etc.). These networks, or lack of them, enhance or limit the opportunities facing each firm to improve their problem-solving capabilities.

Third, national systems entail also a broader notion of embeddedness of microeconomic behaviors into a set of social relationships, rules and political constraints (Granovetter 1985). Even at a properly micro level, the momentum associated with single technological trajectories is itself a largely social concept: "it points... to the organizations and people committed by various interests to the system, to manufacturing corporations, research and development laboratories, investment banking houses, educational institutions and regulatory bodies" (Misa 1991: p. 15). And, in turn, these interests and institutions are sustained by the increasing-return and local nature of most learning activities. Even more so, at a system-level, the evolutionary interpretation presented here is consistent and indeed complementary with institutional approaches building on the observation that markets do not exist or operate apart from the rules and institutions that establish them and that "the institutional structure of the economy creates a distinct pattern of constraints and incentives", which defines the interests of the actors as well as shaping and channeling their behaviours (Zysman 1994: pp. 1–2).[12]

Paradigms, routines, organizations

A locus classicus in the analysis of the profound intertwining between technological learning and organizational change is certainly Alfred Chandler's reconstruction of the origins of the modern multi-divisional (the M-form) corporation and its ensuing effects on the American competitive leadership over several decades (Chandler (1990), (1992a) and (1993)). And, as Chandler himself has recently argued, there are strict links between story and evolutionary theories (Chandler (1992b). While it is not possible to enter into the richness of the Chandlerian analysis here, let us just recall one of the main messages:

> [...] it was the institutionalizing of the learning involved in product and process development that gave established managerial firms advantages over start-ups in the commercialization of technological innovations. Development remained a simple process involving a wide variety of usually highly product-specific skills, experience and information. It required a close interaction between functional specialists, such as designers, engineers, production managers, marketers and managers [...]. Such individuals had to coordinate their activities, particularly during the scale-up processes and the initial introduction of the new products on the market [...]. Existing firms with established core lines had retained earnings as a source of inexpensive capital and often had specialized organizational and technical competence not available to new entrepreneurial firms (Chandler 1993: p. 37).

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[12] Note incidentally that the second building block – i.e. networks, etc. – in so far as it is equivalent to an externality or to some economy-wide mechanism for the generation of knowledge, is also captured in a highly simplified form by the new growth theories. (More on the general spirit of the latter in Romer 1994a and b). Conversely the first and third are distinctive of evolutionary/institutionalist analyses. These represent also a major point linkage between evolutionary theories, organizational economics and business history.

As thoroughly argued by Chandler himself, this organizational dynamics can be interpreted as an evolutionary story of competence accumulation and development of specific organizational routines (Chandler (1992b)).

Did seemingly superior organizational forms spread evenly throughout the world?

Indeed, the Chandlerian enterprise diffused, albeit rather slowing, in other OECD countries (Chandler 1990, Kogut 1992). However, the development of organizational forms, strategies and control methods have differed from nation to nation, because of the difference between national environments (Chandler 1992a: p. 283). Moreover, the diffusion of the archetypical M-form corporation has been limited to around half a dozen already developed countries (and even in countries like Italy, it involved very few companies, if any). Similar differences can be found in the processes of international diffusion of American principles of work organization – e.g. Taylorism and Fordism – (for an analysis of the Japanese case, see Coriat 1990). For the purposes of this work, it is precisely these differences and the diverse learning patterns which they entail that constitute our primary interest.

So, for example, a growing literature identifies some of the roots of the specificities of the German, the Japanese or the Italian systems of production into their early corporate histories which carried over their influence up to the contemporary form of organization and learning (see Chandler 1990, Coriat 1990, Kogut 1993, Dursleifer and Kocka 1993, Dosi, Giannetti and Toninelli 1992).

Even more so, one observes quite different organizational initial conditions, different organizational histories, and together, different patterns of learning across developing countries. Let us consider them at some detail.

During the last three decades, developing countries have shown increased technological dynamics associated with a subsequent development of their industrial structures, thus some significant technological progress did indeed occur in the NIEs and some of them also became exporters of technology.[13]

The evolutionary path of technological learning are related to both the capacity to acquire technologies (capital goods, know how etc) and the capability to absorb these technologies and adopt them to the local conditions. In these respects, one has now a good deal of microeconomic/micro technological evidence highlighting the mechanisms which stimulate and limit endogenous learning in the NIEs.[14]

Without doing any justice to the richness of these contributions, they seem to suggest the existence of some characteristics in the paths of technological learning at the firm level (see also Cimoli 1990 and Cimoli and Dosi 1988). In particular, one might be able to identify some relatively invariant sequences in the learning processes, conditional on the initial organizational characteristics of the firms and the sectors of principal activity.

A first set of regularities regards the varying combinations between acquisition of outside technologies and endogenous learning.[15] As well know, the transfer of technology to developing economies is a common source for the subsequent

[13] See Lall (1982), Teitel (1984) and Teubal (1984).

[14] See, among others, Bell (1982), Dahlman-Westphal (1982), Hobday (1984), Herbert-Copley (1990), Justman-Teubal (1991), Katz (1983), (1984a), (1984b), (1986) and (1987), Teubal (1987), Pack and Westphal (1986).

[15] The technology flows to developing economies show a rapid expansion in the 1960s and 1970s; during the 1980s this process decreased its intensity (UNCTAD 1991). During the whole period the Asian countries show an increasing role as the major recipient of foreign direct investment and capital goods. The flow of capital goods to Latin American countries remain stable during this period.

development of learning capabilities at the firm and sectoral levels. Possibly with too extreme an emphasis, Amsden and Hikino identify the ability to acquire foreign technology as a central characteristic,

> [...] of late industrialization at the core of which is borrowing technology that has already been developed by firms in more advanced countries. Whereas a driving force behind the First and Second Industrial Revolutions was the innovation of radically new products and processes, no major technological breakthrough has been associated with late-industrializing economies. The imperative to learn from others, and then realize lower costs, higher productivity, and better quality in mid-tech industries by means of incremental improvements, has given otherwise diverse 20th century industrializers a common set of properties (Amsden and Hikino 1993: p. 37).[16]

At a general level, learning patterns can be taxonomized according to the relative importance of the corporate activities involved,[17] namely a) the acquisition of an existing technology associated with the paradigm prevailing in the developed world, b) its adaptation and modification in the local environment and c) the creation of new innovation capabilities with respect to products and processes.

The importance of the three often follows a temporal sequence. Already the modification of the adopted technology implies learning of new production skills which grows through the adaptation of this capabilities to local specificities. Note, however, that there is no inevitability in the learning-by-doing process which, on the contrary, requires adequate organization conditions, both within each firm and each environment. Interestingly, the initial characteristics of corporate organizations appear to exert a strong influence on subsequent dynamics. For example, evidence on the last four decades (1950–1990) concerning Latin American countries (Argentina, Brazil, Colombia, Mexico and Venezuela) indicate that the evolutionary sequence of organizational and technological learning can be distinguished among four types of firms, taxonomized mainly in terms of the nature of ownership: subsidiaries of MNCs, family firms, large domestic firms and public firms.[18]

The family firm appears to be characterized by a high "propensity to self-sufficiency and self-financing" and the "mechanical ability of an individual", which frequently stems from immigrant entrepreneurs.[19] The technology acquired is related to the technical background of the entrepreneur and the initial phase is characterized by the adoption of a discontinuous mode of production.[20] At the

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[16] Although we share their view on the curent importance of technological assimilation of outside technologies, one should not underestimate the degree to which this occured also in the past experiences of late-coming industrialization and catching-up, for example in the case of the USA or Continental Europe vis-a-vis Britain.

[17] On a similar point Teitel (1987).

[18] Information on the different phases ofthe technological accumulation of firms has been taken from the case studies of the IDB, ECLA and UNDP programmes and from the overviews of the research findings in Katz (1983), (1984a), (1984b), (1986) and (1987), Berlinski, Nosier, Sandoval and Turkieh (1982), Teitel (1984) and (1987), Teubal (1987).

[19] See Katz (1983).

[20] Two alternative modes of production namely, *continuous* and *discontinuous*, appear to be relevant for the analysis of learning patterns. Continuous methods imply 1) specialization of production along precise product lines; 2) production planning for each line of business; 3) relatively high scale economies; 4) relatively low flexibility in product design and rates of throughput. Conversely, discontinuous methods involve 1) low standardization of production; 2) low economies of scale; 3) the organization of production into multi-product "shops"; 4) general purpose, low cost machinery. It is remarkable that in many Latin American examples, (but not in Far Eastern ones) at least until the 1980s, incremental learning appeared to be more successful in discontinuous batch-production as compared to continuous and mass-production activities (such as chemicals, many consumer durables, etc.).

beginning, production is characterized by low economies of scale (also as a consequence of the limitations of the domestic market and the difficulties in exploiting export possibilities).

A sort of ideal learning trajectory for a South American family-stablised firm that is technologically progressive (which is not by any means a general characteristic of the whole population) would run more or less as follows. First, the effort is concentrated on product design activities (most likely due to the incentive provided in the past by import substitution policies), and increasingly, on quality improvements and product differentiation.

Next, attention is focused also on process engineering, the organization of production and the exploitation of some economies of scale, until (in some empirically not too frequent cases) highly mechanized production is achieved. And, along the process, it might happen (again, not too often) that the organization is developed beyond the original family hierarchy and "managerialized".

The story concerning subsidiaries of foreign firms emerges from the set of cases studies cited earlier is quite different. The bulk of competences and technologies derives from the parent company and learning mainly concern the adaptation to the local environment, adjustments in product mixes and re-scaling of production lines. In some cases, this holds throughout the history of the subsidiary, while in others an autonomous capability in product and process design is developed. (Note also that in Latin American foreign subsidiaries tend to be concentrated in mass production activities like vehicles, consumer durables, food processing, etc.).

State-owned firms display yet another archetypical learning story. First, they have been concentrated in sectors that have tended to be considered "strategic" and often happened to be continuous process industries such as bulk materials, steel, basic petrochemicals, in addition – in some countries – to aerospace and military production. Second, the strategies have generally be dictated also by political considerations. Third, learning has often started via agreements with international suppliers of equipment. In the "healthy" scenario – which is not the rule – international technology transfer agreement became more sophisticated, involving adaptation of plants and technologies to local circumstances, while the emphasis was kept on personnel training and learning by using. Finally, autonomous capabilities of plant upgrading and process engineering were sometimes developed.

As regards large domestic firms, it is hard to trace any modal patterns. Scanning through the case studies, they sometime appear to follow patterns not too different from the family firms, in other cases they seem to perform like East Asian business groups (see below), and yet in others learning appears to be much more directed toward he exploitation of political rents and financial opportunities rather than technological accumulation.

It is interesting to compare these sketchy Latin American "corporate trajectories" with other experiences, such as the Korean one.[21] To make a long and variegated story very short, in Korea it seems that the major actors in technological learning have been large business groups – *the chaebols* – which have been able at a very early stage of development to internalize the skills for the selection among technologies acquired from abroad, their efficient use and adaptation, and, not much later, have been able to grow impressive engineering capabilities.

[21] As discussed at greater depth in Amsden (1989), Amseden and Hikino (1993 and 1994), Enos and Park (1988), Bell and Pavitt (1993), Lall (1992), Kim, Westphal and Dahlman (1985).

Conversely, the Taiwanese organizational learning has rested much more in large networks of small and medium firms very open to the international markets and often developing production capabilities which complement those of first world companies (Dahlman and Sananikone 1990, Ernest and O'Connor 1989).

This impressionistic list of stylized organizational patterns of learning could be of course very lengthy. For our purposes, it should be understood only as an illustration of the multiplicity of evolutionary paths that organizational learning can take. The fundamental point here is that the rates and directions of learning are not at all independent from the ways corporate organizations emerge, change, develop particular problem-solving, capabilities, diversify, etc. It is the core co-evolutionary view emphasized by Nelson (1994).

The analysis in term of paradigms, trajectories, technological asymmetries, etc. outlined in the first part of this paper is the most abstract level of description of production pattern and technical change, whereby the "primitives" of the analysis itself are entities like "bits of knowledge" and the outcomes of their implementation in the spaces of production process and output characteristics. However, knowledge is to a large extent embodied, reproduced and augmented within specific organizations. Thus, a lot of the action is reflected in the behaviours, evolution and learning of these organizations – in primis, business firms. At this level, evolutionary analyses match and cross-fertilize with investigations on organizational dynamics, industrial demography and business history.

Inter-sectoral networks and production capacity

Of course the multiple business histories of learning and organizational change (or lack of them) in each country, as mentioned earlier, is nested into flows of commodities and knowledge across different sectors and different institutional actors. At this level, can one identify some broad regularities in the processes of system-construction.

It is useful to maintain the distinction emphasized by Bell and Pavitt (1993) (which indeed bears some Listian flavour!) between the development of a "production capacity" and of "technological capabilities". Production capacity concerns the stocks of resources, the nature of capital-embodied technologies, labour skills, product and input specification and the organizational routines in use. Technological capabilities rest on the knowledge and resources requested for the generation and management of technical change.

These seem to be some patterns, albeit rather loose, in the development of a national production capacity. For example, practically every country starts with manufacturing of clothing and textile, possibly natural resource processing, and moves on – if it does – to more complex and knowledge intensive activities. However, the tricky question is whether there are some activities which hold a special status in the construction of a national system of production and innovation, also due to the property that having a production capacity in them makes it easier, other things being equal, to develop technological capabilities. The conjecture is quite old (and goes back at least to List, Ferrier and Hamilton) and is present in contemporary notions such those of fili re or Dahmen's "development blocks", but it might gain strength on the grounds of the evolutionary microeconomics outlined above.[22]

[22] Classic contributions of the importance of intersectoral linkages are Dahmen (1971) and Hirschman (1992).

Whenever one abandons a view of development exclusively shaped by endowments, the degrees of perfection of market signals, and the like, but focuses on the conditions for technological/organizational learning, then it also becomes easier to appreciate the diversity of the sources in learning opportunities and their different economic potentials.

In fact, there is a good circumstantial evidence from contemporary as well as previous late-industrializing countries (such as, in their days, the USA, Germany, the Scandinavian countries, Japan, etc.). Suggesting that there are technologies whose domains of application are so wide and their role has been so crucial that the pattern of technical change of each country depends to a large degree on the national capabilities in mastering production/imitation/innovation in a set of crucial knowledge areas (e.g. in the past, mechanical engineering, electricity and electrical devices, and nowadays, also information technologies). Moreover, the linkages among production activities embody structured hierarchies whereby the most dynamic technological paradigms play a fundamental role as sources of technological skills, problem-solving opportunities and productivity improvements.[23] Thus, these core technologies shape the overall absolute advantages/ disadvantages of each country. In other words, the pattern of technical change of each country in these technologies does not average out with the technological capabilities in other activities but are complementary to them. These core technologies often also imply basic infrastructures and networks common to a wide range of activities (such as, for example, the electricity grid, the road system, telecommunications and more recently the information network). Many pieces of empirical evidence strongly convey the idea that a proper technological dynamism in developing countries is impossible without major structural changes and a sequential construction of a widening manufacturing sector involving also indigenous skills in a set of "core" technologies.

We do not at all suggest that there is any invariant sequence of industrial sectors which account for the upgrading of national technological capabilities.[24] However, one might still be able to identify some rough sequences in the predominant modes of technological learning. In this respect, the taxonomy of the sectoral patterns of acquisition of innovative knowledge suggested by Pavitt (1984) is a good – albeit somewhat theoretically fuzzy – point of departure. As known, Pavitt distinguishes four groups of industrial sectors, namely (i) *supplier dominated* – where innovations mainly enter as exogenously generated changes in capital and intermediate good, and where learning is primarely associated with adoption and production skills; (ii) *specialized suppliers* – providing equipment and instruments to the industrial system, and relying in their innovative activities on both formal (more or less scientific) knowledge and more tacit one based also on the user-producer relationships; (iii) *scale-intensive sectors* – whose innovative abilities draw, jointly, on the development adoption of innovative equipment, on the design of complex products, on the exploitation of some scale economies, and on the ability of mastering complex organizations; (iv) *science-based sectors* – whose innovative opportunities link more directly with advances in basic research.

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[23] See Rosenberg (1976), and, for contemporary late comers, Chudnovsky, Nagao and Jacobsson (1984) and Fransman (1986).

[24] Indeed, any detailed comparison of the sectoral composition of output of e.g. USA, Germany, Japan, France, Italy between 1850 and 1950, or Korea, Brazil, Taiwan, and Singapore between 1950 and 1990 – we conjecture – would show enough dispersion.

The important issue here is whether one may use that taxonomy in order to detect some patterns over the development process. The emergence of manufacturing sector is generally characterized by an initial stage where supplier-dominated sectors dominate accompanied by the emergence of specialized suppliers. The process of technical change in these sectors is characterized by a sequential development of various forms of tacit and incremental learning related to the transfer and acquisition of foreign technology. These learning activities are mainly related to the use of equipment, development of engineering skills in machine-transformation, adaptation of existing machines and final products to specific environmental conditions.

The emergence of "scale-intensive" industries entails further forms of learning related to the development and use of capital equipment. Moreover, unlike the supplier-dominated sectors, technological efforts are also focused on (i) the development of technological synergies between production and use of innovations, often internalized via horizontal and vertical integration; (ii) the exploitation of static and dynamic economies of scale; (iii) the establishment of formal institutions undertaking search (typically, corporate R&D laboratories), and complementary to informal learning and diffusion of technological knowledge.

Sectoral learning patterns are clearly nested into broader ("macro") conditions such as those definining the educational system. For example, in "supplier-dominated" and "specialized supplier" sectors, a significant role is played by the levels of literacy and skills of the workforce, and the skills and technical competence of engineers and designers in the mechanical and (increasingly) electronics fields. In scale-intensive sectors, the existence of managers capable of efficiently running complex organizations is also likely be important. In science based sectors, the quality of higher education and research capabilities is obviously relevant.

Moreover, sectoral learning patterns and overall national capabilities are dynamically coupled via input-output flows, knowledge-spillovers, complementarities and context-specific externalities.[25] Together, they contribute to shape the organizational and technological context within which each economic activity takes place. In a sense, they set the opportunities and constraints facing each individual process of production and innovation – including the availability of complementary skills, information on intermediate inputs and capital goods, and demand stimuli to improve particular products.

This links straightforwardly with the analyses focusing on structural change and development (here within a vast literature, contributions that come immediately to mind range from Hirschman to Rosenstein Rodan, Gerschenkron, Prebisch – notwithstanding his sometimes extremist interpretations -, Lowe, Kuznets, Chenery, Sirquin among others). Certanly, the dynamics of development also rest upon major structural transformations which entail a changing importance of different branches of economic activity as generators of both technological/organizational innovations and demand impulses. So, for example, in this interpretative framework, it does not sound so outragions to conjecture that the "quality" (in terms of

[25] An obvious question concerns the unit of analysis to which these externalities and system effect apply. Why shouldn't international trade compensate for spatially circumscribed specificities? What is unique of a nation distinguishing it from a geographical region, or a firm, or a group of individuals? Far from any intent to reduce the importance of other levels of description (e.g. regional dynamics), we maintain that nations are also specified by particular modes of institutional governance which extent make them diverse auto-reproducing entities.

technological opportunities and demand elasticities) of any one structure of production and export is bound to influence the relative ability of a country to absorve its labour supply, meet its foreign balance constraints, grow in its per capita income... At this level of analysis, one empirically finds, for example, that Latin American countries have increasingly biased their structure of production, in the 1980s, in favour of resource-based sectors, while East Asian NICs have move toward scale-intensive and science-base sectors. Obviously, in some ideal General Equilibrium world, all this is just an irrelevant epiphenomenon. Conversely, under the microfoundation sketched above, there might be reasons to worry (even if naive technologically deterministic conclusions should be obviously discussed). Indeed, some fundamental trade-off between "static allocative efficiency" and "dynamic efficiency" of any one pattern of production might plausibly emerge (more on all this in Dosi, Pavitt and Soete 1990 and Dosi, Tyson and Zysman 1989).

Moreover, the specificities of each system of production interact with those of each national system of innovation – as throughly analyzed in Nelson (1993) – and tend to yield recognizeable national patterns or trajectories shaped by the institutions supporting technical advances and reproduced through time also by processes of lock-in into particular knowledge bases, corporate organizations and sectoral specialization.

4. From micro technological paradigms to national systems of production and innovation: some tentative conclusions and many research avenues

The third major element, mentioned earlier linking microeconomic learning with national patterns of development was the embeddedness of the thread of incentives, constraints, forms of corporate organization into the broader institutional framework of the political economy of each country. It is beyond the scope of this paper to discuss that issue at any satisfactory detail. For our purposes, let us just mention that the micro- and meso-economic theoretical building blocks sketched above and drawn from an evolutionary perspective are in principle consistent with broader institutionalist analyses of national systems of production, innovation and governance of socio-economic relations. Indeed, one can see multiple links which one is only beginning to explore. For example, an evolutionary perspective is quite at ease with the idea that markets are themselves "social constructs" which – depending on their rules and organizing principles – shape microbehaviours and adjustment mechanisms. The emphasis on patterned and local learning, and bounded rationaly assumptions, go well together with the view of political economists and sociologists of development according to which a major ingredient of development is the process of change in social norms, expectations and forms of collective organization. The patterns of *socio-economic Regulation* (Boyer 1988a and 1988b) can be in principle microfounded into underlying evolutionary processes of self-organization, learning and selection. In fact, there seem to be a large domain where more "bottom-up" evolutionary theories and more "top-down" institutional analyses can develop a fruitful dialogue.

Notions like those of technological trajectories, path-dependencies, organizational competences, self-organization, learning and selection dynamics – and many others stemming from evolutionary investigations – are becoming part of the tool-kit of many social disciplines. As regards more specifically development issue, they start becoming building blocks which might provide firmer grounds to the broad intuitions of an earlier generation of development theorists – from Myrdal to Hirschman, from Rosenstein-Rodan to Gerschenkron... In this respect our *tour de force* from technological paradigms to national systems should just be considered as a tentative roadmap over still largely unexplored terrains.

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