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Capabilities Accumulation and Development: What History Tells the Theory

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Capabilities Accumulation and Development: What History Tells the Theory

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Abstract

In this contribution we offer a broad overview of the technological, institutional and policy dynamics associated with the *great transformation* - borrowing Karl Polanyi (1944) expression - leading from traditional, mostly rural, economies to economies driven by industrial activities (and nowadays also advanced services), able to systematically learn how to implement and eventually how to generate new ways of producing and new products under conditions of dynamic increasing returns.

Such a 'great transformation' entails a major process of *accumulation of knowledge and capabilities*, both at the levels of *individuals* and *organizations*. Certainly, part of such capabilities builds on education and formally acquired skills (what in the economists' jargon often goes under the heading of 'human capital'). However, at least equally important, capabilities have to do with the problem-solving knowledge embodied in organizations - concerning e.g. production technologies, the technical and social division of labor, labor relations as well as 'dynamic capabilities' of search and learning.

In turn, the rates and directions of knowledge accumulation during the catch-up process and the ensuing effects upon the patterns of production and trade are shaped by the economic and institutional framework in which such processes are embedded.

Keywords: catching-up, capability accumulation, innovation, development, Great Transformation

1 Introduction: The Drivers of Great Industrial Transformation

Development, catching-up and possibly forging ahead has to do with the technological, institutional and policy dynamics associated with the *great transformation* - borrowing Karl Polanyi (1944) expression - leading from traditional, mostly rural, economies to economies driven by industrial activities (and nowadays also advanced services), able to systematically learn how to implement and eventually how to generate new ways of producing and new products under conditions of dynamic increasing returns.

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In turn, the rates and directions of knowledge accumulation during the catch-up process and the ensuing effects upon the patterns of production and trade are shaped by the economic and institutional framework in which such processes are embedded.

Simplifying enormously on the nuances of actual history, but much less than the 'representative economists' do, let us distinguish three, *partly independent* but co-evolving sub-systems (Dosi, 1984), namely,

(i) the system of scientific knowledge and technologies;

(ii) the 'economic machine', comprising the mechanisms determinining production, investment, income distribution, structural change, etc;

(iii) the system of social relations and institutions, including those governing labor, financial and goods markets, and of course public agencies and policies.[1]

While we maintain that technological and organizational learning is a sort of *primus inter pares*, a necessary albeit not sufficient ingredient, it is the *matching or mismatching* between the foregoing coupled domains which is at the roots of the early industrial revolution in England and also of later episodes of catching-up, falling behind and forging ahead. Hence, we suggest, what explains earlier and more recent dynamics is *not* one single factor but the patterns of consistency, or not, among them.[2]

So, just to name few pertinent examples, Northern Italy in the 14th century had higher GDP per capita, more sophisticated financial institutions, etc. but it fell striking behind the Low Countries and England; China has plausibly been technologically (and possibly even scientifically) more advanced than Europe for nearly a millennium, but the industrial revolution did not happen there; nowadays oil-rich countries in the Middle East are very rich in terms of capital and wealth but backward in terms of technologies that they can master...

Of course, three domains interact with each other. Our analysis however will be rooted in the following hypotheses:

1. Despite powerful interactions, each of these three domains has rules of its own which shape and constrain every inducement and adjustment mechanism between them.

2. There is a limited number of configurations of these three domains which allows a relatively "well-regulated" and smooth consistency between them. These define, so to speak, the "possible worlds".

3. Unbalanced, or stagnating, or "crisis" configurations do not necessarily also embody the necessity of the transition to other (more balanced or "smoother") ones.

[1] This closely resonates with Freeman (1995), who further distinguishes between science and technology, and between institutions and culture, in its insightful interpretation of the first and subsequent industrial revolution. See also below.

[2] The general conjecture is well in tune with the mainly French *Regulation School* (see Boyer, 1988b; Boyer, 1988a; Boyer and Petit, 1991).

Let us clarify these points in relation to the interaction between the "system of technologies" and the other two.

2 Some properties of technical change

We firmly believe that the standard ideas of "production possibility sets" or "production functions", with their corollary of technology as a malleable and reactive black box, to use Rosenberg's terminology (Rosenberg, 1982), has been one of the most poisonous tools economic theory has offered the students of the development process, in that it has deprived the analysis of any lens related to knowledge and to problem-solving procedures - which on the contrary are the core of what technology is and of how it evolves. Indeed the view of technology we propose as comprises (a) a specific body of practice - in the form of processes for achieving particular ends - together of course with an ensemble of required artifacts on the "input side"; (b) quite often some distinct notion of a design of a desired "output" artifacts; and (c) a specific body of understanding, some relatively private, but much of it shared among professionals in a field. These elements, together, can be usefully considered as constituent parts of a technological paradigm (Dosi, 1982, 1988), somewhat in analogy with Kuhn's (1962) scientific paradigm.[3] A paradigm embodies an outlook, a definition of the relevant problems to be addressed and the patterns of enquiry in order to address them. It entails a view of the purported needs of the users and the attributes of the products or services they value. It encompasses the scientific and technical principles relevant to meeting those tasks, and the specific technologies employed. A paradigm entails specific patterns of solution to selected techno-economic problems - that is, specific families of recipes and routines - based on highly selected principles derived from natural sciences, jointly with specific rules aimed at acquiring related new knowledge. Together,

[3] Here as well as in Dosi (1982), we use the notion of paradigm in a microtechnological sense: for example, the semiconductor paradigm, the internal combustion engine paradigm, etc. This is distinct from the more "macro" notion of "techno-economic paradigm" used by Perez (1985, 2010) and Freeman and Perez (1988) which is a constellation of paradigms in our narrow sense: for example, the electricity techno-economic paradigm, ICTs, etc. The latter broader notion overlaps with the idea of "general purpose technologies" from Bresnahan and Trajtenberg (1995). Moreover, the notion of paradigm used here bears a good deal of overlapping with that of "regimes" put forward in Nelson and Winter (1977).

the paradigm includes a (generally imperfect) understanding about just how and (to some extent) why prevailing practice works. An important part of paradigmatic knowledge takes the form of design concepts which characterize in general the configuration of the particular artifacts or processes that are operative at any time. Shared general design concepts are an important reason why there often is strong similarity among the range of particular products manufactured at any time - as the large passenger aircrafts produced by different aircraft companies, the different television sets available at the electronics stores, etc. Indeed, the establishment of a given technological paradigm is quite often linked with the emergence of some dominant design (see Abernathy and Utterback, 1978; Henderson and Clark, 1990; Rosenbloom and Cusumano, 1987; Suárez and Utterback, 1995; Utterback and Suarez, 1993; and the critical review of the whole literature in Murmann and Frenken, 2006). A dominant design is defined in the space of artifacts and is characterized both by a set of core design concepts embodied in components that correspond to the major functions performed by the product and by a product architecture that defines the ways in which these components are integrated (Murmann and Frenken, 2006; drawing upon Henderson and Clark, 1990). However, sometimes the establishment of a dominant paradigm is not associated with a dominant design. A revealing case to the point are pharmaceutical technologies which do involve specific knowledge basis, specific search heuristics, etc. - that is, the strong mark of paradigms - without however any hint at any dominant design. Molecules, even when aimed at the same pathology, might have quite different structures: in that space, one is unlikely to find similarities akin those linking even a Volkswagen Beetle 1937 and a Ferrari 2000. Still, the notion of "paradigm" holds in terms of underlying features of knowledge bases and search processes. Whether the establishment of a dominant paradigm entails also the established of a dominant design or not bears a lot of importance also in terms of dynamics of industry structure along the life cycle of the industries to which a particular paradigm is associated.

More generally, they are the cognitive frames shared by technological professionals in a field that orient what they think they can do to advance a technology (Constant, 1980). Technological paradigms also encompass normative aspects, like criteria for assessing performance, and thus provide ways of judging what is better than what, and goals for the improvement of practice. Each paradigm involves a specific "technology of technical change," that is specific heuristics of search. So, for example in some sectors, such as organic chemicals these heuristics relate to the ability of coupling basic scientific knowledge with the development of molecules that present the required characteristics, while in pharmaceutical field the additional requirement is the ability to match the molecular knowledge with receptors and pathologies. In microelectronics search concerns methods for further miniaturization of electrical circuits, the development of the appropriate hardware capable of "writing" semiconductor chips at such a required level of miniaturization and advances in the programming logic to be built into the chip. The examples are very many: a few are discussed in Dosi (1988). Here notice in particular that distinct (paradigm-specific) search and learning procedures, first, imply as such diverse modes of creating and accessing novel technological opportunities, and, second, entail also different organizational forms suited to such research procedures. Together, the foregoing features of technological paradigms both provide a focus for efforts to advance a technology and channel them along distinct technological trajectories, with advances (made by many different agents) proceeding over significant periods of time in certain relatively invariant directions, in the space of techno-economic characteristics of artifacts and production processes. As paradigms embody the identification of the needs and technical requirements of the users, trajectories may be understood in terms of the progressive refinement and improvement in the supply responses to such potential demand requirements. A growing number of examples of technological trajectories include aircrafts, helicopters, various kinds of agricultural equipment, automobiles, semiconductors, and a few other technologies (Dosi, 1984; Gordon and Munson, 1981; Grupp, 1992; Sahal, 1981, 1985; Saviotti, 1996; Saviotti and Trickett, 1992). So, for example, technological advances in aircraft technologies have followed two quite distinct trajectories (one civilian and one military) characterized by log-linear improvements in the tradeoffs between horsepower, gross takeoff weight, cruise speed, wing load, and cruise range (Frenken and Leydesdorff, 2000;

Frenken et al., 1999; Giuri et al., 2007; Sahal, 1985; and more specifically on aircraft engines Bonaccorsi and Giuri, 2000). Analogously, in microelectronics, technical advances are accurately represented by an exponential trajectory of improvement in the relationship between density of electronic chips, speed of computation, and cost per bit of information (see Dosi, 1984, but the trajectory has persisted since then). We could say that the paradigmatic, cumulative, nature of technological knowledge provides innovation avenues (Sahal, 1985) which channel technological evolution, while major discontinuities tend to be associated with changes in paradigms. Indeed, here and throughout we shall call "normal" technical progress those advances occurring along a given trajectory - irrespectively of how "big" they are and how fast they occur - while we reserve the name of "radical innovations" to those innovations linked with paradigm changes. A change in the paradigm generally implies a change in the trajectories. Together with different knowledge bases and different prototypes of artifacts, the techno-economic dimensions of innovation also vary. Some characteristics may become easier to achieve, new desirable characteristics may emerge, some others may lose importance. Relatedly, the engineers vision of future technological advances changes, together with a changing emphasis on the various tradeoffs that characterize the new artifacts. So, for example, the technological trajectory in active electrical components based on thermionic valves had as fundamental dimensions heat-loss vacuum parameters, miniaturization and reliability over time. With the appearance of solid-state components (the fundamental building block of the microelectronic revolution) heat loss became relatively less relevant, while miniaturization increased enormously in importance. Similar examples of change in the dimensions of the design space can be found in most transitions from one paradigm to another. Of course, one does not always observes clear-cut paradigmatic "revolutions". It is sometimes the case that "normal" advances on established knowledge bases is intertwined with new sources of knowledge. This appears to be the case nowadays in electronics-based industrial automation converging with Artificial Intelligence, and might apply also to drugs and biotech: cf. Hopkins et al. (2007).

3 Technological dominance, micro heterogeneity and non-substitution

The notion of paradigms contains elements of both a theory of production and a theory of innovation and bears straightforward implications for the interpretation of the processes of catching-up. Concerning the theory of production, we suggest

1. In general, there is at any point in time one or very few best practice techniques which dominate the others irrespectively of relative prices.

2. Different agents are characterized by persistently diverse (better and worse) techniques.

3. 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.

4. 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).

Let us further illustrate the previous points with a graphical example (Figure 1).

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.[4]

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, ..., c_n; where 1, ..., n are the various techniques/firms labelled in order of decreasing efficiency at time

[4]Note that fixed inputs, vintage effects and economies of scale would just strengthen the argument.

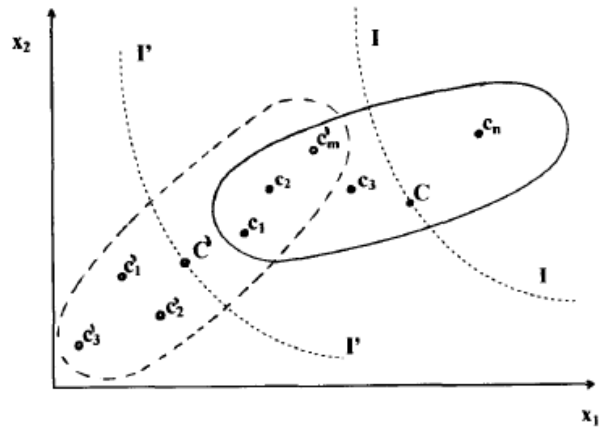

Figure 1: Microheterogeneity and technological trajectories. Source: Cimoli and Dosi (1995)

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 c_1? To simplify a more articulated argument (see Freeman, 1982; Nelson and Winter, 1982; Dosi, 1988; Dosi et al., 1990; Dosi et al., 2008), 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 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 is a reflection of this widespread phenomenon).

Suppose now that at some subsequent time t' we observe the distribution of micro coefficients c'_3, ..., 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, all the available evidence robustly supports these conjectures: there appear to be wide and persistent asymmetries in efficiency among firms within the same industry (surveys and discussions include Nelson, 1981; Bartelsman and Doms, 2000; Dosi, 2007; Dosi and Grazzi, 2006; Syverson, 2011).

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. A growing evidence suggests 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 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. More on this evidence in Dosi and Nelson (2010).

4 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' , ... , 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' , ... 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 patterns 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 micro dynamics 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 international 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 (Fig. 1 illustrates a similar case: compare for example, techniques c_3' and c_n).

Some important implications emerge from this approach.

First, the theory predicts 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 efficiencies: see Dosi et al. (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. In a fundamental sense the process of catching-up concerns the shortening of the gap between the distributions of the coefficients in the "advanced" and "catching up" country. As a vivid illustration consider Figure 2 depicting the dynamics in the distributions of labour productivity in France and China.

Second, 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 et al., 1990). Indeed the progressive entry into such exclusive club is the other side of

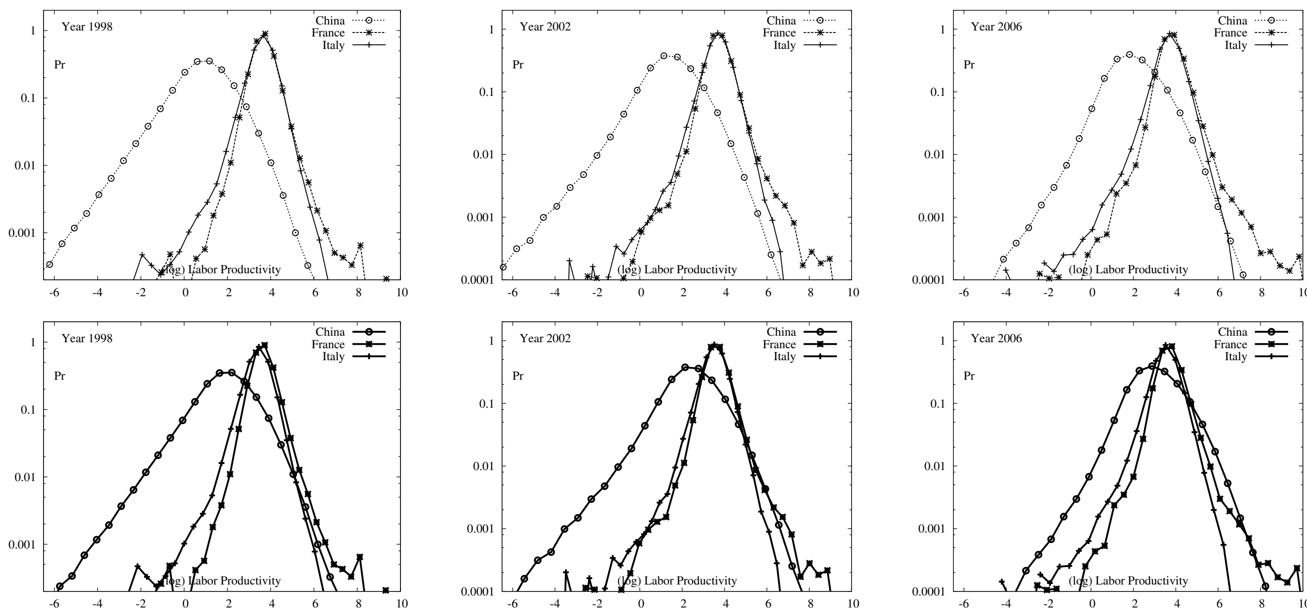

Figure 2: Empirical density of labour productivities, whole manufacturing of China, France and Italy, years 1998, 2002 and 2006. Note: The first row - constant 2000 prices and exchange rates (IMF source); the second row - PPP adjusted price (World Bank source). Source: Yu et al. (2015).

catching up.[5]

More generally , 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, *in primis*, of domestic firms of each economy.

In this context, 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

[5]For thorough discussions of catching up processes see Lee and Malerba (2017) and Lee (2018).

per capita incomes. We shall briefly come back to this issue below, when looking at some lessons from China. 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: 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, firms are embedded in rich networks of relations with each other and with other institutional actors - ranging from government agencies to universities, to banks...

5 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 his 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).

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 1992b: 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; Durleifer and Kocka 1993; Dosi et al. 1993).

Even more so, one observes quite different organizational initial conditions, different organizational histories, and together, different patterns of learning across emerging countries. However some pattern appear. (Here we refer essentially to some examples excluding the Chinese Miracle to which this whole book is dedicated: we shall just make some comments at the end.)

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.[6] As well know, the transfer of technology to developing economies is a common source for the subsequent development of learning capabilities at the firm and sectoral levels. Possibly with too extreme an emphasis, Amsden and Hikino (1993) 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).[7]

At a general level, learning patterns can be taxonomized according to the relative importance of the corporate activities involved,[8] 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

[6] 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.

[7] Although we share their view on the current 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.

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

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.[9]

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.[10] 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.[11] At the 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

[9] Information on the different phases of the 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), (1984b), (1984a) and (1987), Berlinski et al. (1982), Teitel (1984) and (1987), Teubal (1987).

[10] See Katz (1983).

[11] 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.).

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.[12] 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.

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 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.

Indeed, as we discuss in Yu et al. (2015) different forms of corporate governance have powerfully influenced also the evolution of Chinese manufacturing and the dynamics of productivity thereof.

[12] As discussed at greater depth in Amsden (1989), Amsden and Hikino (1993, 1994), Enos and Park (1988), Bell and Pavitt (1993), Lall (1992).

6 The institutional development of technological capabilities, organizations and incentive structures: co-evolutionary dynamics

A fundamental element in countries that successfully caught-up with the leaders during the 19th and 20th centuries was active government support of the catch-up process, involving various forms of protection and direct and indirect subsidy. The guiding policy argument has been the need of domestic industry in the industries of the day judged critical in the development process for some protection from advanced firms in the leading nations. Alexander Hamilton's argument (1791) for infant industry protection in the new United States was virtually identical to that put forth decades later by Friederich List (1841) regarding Germanys needs. Gershenkron's (1962) famous essay documents the policies and new institutions used in Continental Europe to enable catch-up with Britain. The same story also fits well with the case of Japan, and of Korea and Taiwan somewhat later. In many countries these policies engendered not successful catch-up but a protected inefficient home industry. However, they also were the hallmark during the 20th century of all the countries that have achieved their goals of catching-up. We need to learn more about the circumstances under which infant industry protection leads to a strong indigenous industry, and the conditions under which it is self defeating, and indeed several contributions to this project shed new light on the issue.

These policies obviously angered companies in the leading countries, and their governments, particularly if the supported industry not only supplied its home market but began to invade the world market. While the case made after World War II for free trade was mostly concerned with eliminating protection and subsidy among the rich countries, and at that time there was sympathy for the argument that some infant industry protection was often useful in developing countries, the more recent international treaties that have been made increasingly have been used against import protection and subsidy in countries seeking to catch-up from far behind.

Our belief is that Hamilton and List were and continue to be right that successful catch-up in industries where international trade is considerable requires some kind of infant industry protection or other modes of support.

Moreover, during the 19th and early 20th century, many developing countries operated with intellectual property rights regimes which did not restrict seriously the ability of their companies to in effect copy technologies used in the advanced countries. There are many examples where licensing agreements were involved, but we believe that for the most part these were vehicles through which technology transfer was effected for a fee or other considerations, rather than instances of aggressive protection of intellectual property by the company in the advanced country.

Like infant industry protection and subsidy, conflicts tended to emerge largely when the catching up company began to encroach onto world markets, or even to export to the home market of the company with the patent rights. Increasing instances of this clearly were a major factor in inducing the treaty on Trade Related Intellectual Property Rights. But this treaty makes vulnerable to prosecution not just companies in developing countries that are exporting, but also companies that stay in their home markets.

Given that, what are the different domains of policy intervention and how do they map into different policy measures and related institutions?

Table 1 summarizes an exploratory taxonomy.

In the last resort, policies and other activities of "institutional engineering" affect together (i) the technological capabilities of individual and corporate organizations, and the rate at which they actually learn; (ii) the economic signals that they face (including of course profitability signals and perceived opportunity costs); (iii) the ways they interact with each other and with non-market institutions (e.g. public agencies, development banks, training and research entities, etc.).

It happens that all major developed countries present indeed relatively high degrees of intervention - whether consciously conceived as industrial policies or not - that affect all the above variables. And this

Domain of policy intervention	Policy measures	Related institutions
(i) Opportunities of scientific and technological innovation	Science policies, graduate education, "frontier" technological projects	Research universities, public research centers, medical institutes, space and military agencies, etc.
(ii) Socially distributed learning and technological capabilities	Broader education and training policies	From primary education to polytechnics, to US-type "land-grant colleges", etc.
(iii) Targeted Industrial Support Measures, affecting e.g. types of firms, etc. - *in primis* the structure, ownership, modes of governance of business firms (e.g. domestic vs. foreign, family vs. publicly owned companies, etc.)	From the formation of state-owned firms to their privatization, from "national champions" policies to policies affecting MNCs investments; all the way to the legislation affecting corporate governance	State-owned holdings, public merchant banks, public "venture capitalist", public utilities
(iv) The capabilities of economic agents (in the first instance business firms) in terms of the technological knowledge they embody, the effectiveness and speed with which they search for new technological and organizational advances, etc.	cf. especially points (ii), (iii) and also R&D policies; policies affecting the adoption of new equipment, etc	
(v) The economic signals and incentives profit-motivated agents face (including actual and expected prices and profit rates, appropriability conditions for innovations, entry barriers, etc.)	Price regulations; tariffs and quotas in international trade; Intellectual Property Rights regimes, etc.	Related regulatory agencies, agencies governing research and production subsidies, trade controlling entities, agencies granting and controlling IPRs
(vi) Selection mechanisms (overlapping with the above)	Policies and legislation affecting Anti-trust and competition; entry and bankruptcy; allocation of finance; markets for corporate ownership; etc.	Anti-trust authorities, institutions governing bankruptcy procedures, etc.
(vii) Patterns of distribution of information and of interaction amongst different types of agents (e.g. customers, suppliers, banks, shareholders, managers, workers, etc.)	Governance of labor markets, product markets, bank-industry relationships, etc. all the way to collectively shared arrangements for within-firms information-sharing mobility and control, forms of cooperation and competition amongst rival firms, etc. (cf. for example the historical differences between Japanese vs. Anglo-Saxon firms)	

Table 1: Some classification of the variables and processes which institutions and policies act upon (in general and with particular reference to technological learning)

applies, even more so, to the period when today' s developed countries were catching-up with the international leader. What primarily differentiate the various countries are the instruments, the institutional arrangements and the philosophy of intervention.

In another work, one of us considers the case of Japanese policies, especially in relation to electronic technologies, after WW II, as a paradigmatic example of catching-up policies (Dosi, 1984).

Interestingly, Japan appears to have acted comprehensively upon all the variables categorized in our taxonomy above. A heavy discretionary intervention upon the structure of signals (also involving formal and informal protection against imports and foreign investments) recreated the "vacuum environment" that is generally enjoyed only by the technological leader(s). However, this was matched by a pattern of fierce oligopolistic rivalry between Japanese companies and a heavy export orientation which fostered technological dynamism and prevented any exploitation of protection simply in terms of collusive monopolistic pricing.

It is tempting to measure this Japanese experience - notwithstanding, recent, mostly macroeconomic difficulties - with others, on average less successful, such as the European ones, which heavily relied upon one single instrument, financial transfers (especially R&D subsidies and transfers on capital account), leaving to the endogenous working of the international market both the determination of the patterns of signals and the response capabilities of individual firms. Certainly, there are country-specific features of the Japanese example which are hardly transferable. However, that case, in its striking outcome, points at a general possibility of reshaping the patterns of "comparative advantages" as they emerge from the endogenous evolution of the international markets.

The comparison between the experience of Far Eastern countries and Latin American ones is equally revealing (cf. Amsden, 1989, 2001; Wade, 1990; Kim and Nelson, 2000; Dosi et al., 1994; among others).

In a nutshell, Korea - as well as other far-eastern economies - has been able to "twist around" absolute and relative prices and channel the resources stemming from "static" comparative advantages toward the development of activities characterized by higher learning opportunities and demand elasticities (Amsden, 1989). And they did that in ways which penalized rent-seeking behaviors by private firms. In fact, the major actors in technological learning have been large business groups - *the chaebols* - which were able at a very early stage of development to internalize skills for the selection of technologies acquired from abroad, their efficient use and their adaptation and, not much later, were able to grow impressive engineering capabilities (cf. Kim, 1993).

This process has been further supported by a set of institutions and networks for improving human resources (Amsden, 1989). All this sharply contrasts with the Latin American experience, where the arrangement between the State and the private sector has often been more indulgent over inefficiencies and rent-accumulation, and less attentive to the accumulation of socially diffused technological capabilities and skills.

Ultimately, success or failure appears to depend on the combinations of different institutional arrangements and policies, in so far as they affect learning processes by individuals and organizations, on the one hand, and selection processes (including of course market competition), on the other.

Certainly, the historical experience shows a great variety of country and sector-specific combinations between the types of policies illustrated above. Some subtle regularities nonetheless emerge.

First, a regularity, holding from 19th century Europe and US all the way to contemporary times, is the centrality of public agencies, such as universities, and public policies in the generation and establishment of new technological paradigms.

Second, and relatedly, incentives are generally not enough. A crucial role of policies is to affect the capabilities of the actors, especially in the foregoing case of new technological paradigms, but also in all cases of catching-up whereby no reasonable incentive structure might be sufficient to motivate private actors to surmount big technological lags.

Third, market discipline is helpful in so far as it weeds out the low performers and rewards the high performers within particular populations of firms. However, nothing guarantees that too high selective shocks will not wipe out the entire populations themselves, thus also eliminating any future learning possibility.

Fourth, policies - especially those aimed at catching-up - generally face the need to balance measures aimed at capability building (and also at protecting the "infant learner") with mechanisms curbing inertia and rent-seeking. For example, the latter are indeed one of the major elements missing in the old Latin American experience of import substitution while the former are what is lacking under many more recent "liberalization" policies.

Fifth, historically, a successful catching-up effort in terms of per capita income and wages has always been accompanied by catching-up in the new and most dynamic technological paradigms, irrespective of the initial patterns of comparative advantages, specialization and market-generated signals. Our conjecture is that, *ceteris paribus*, the structural need for policies affecting also the patterns of economic signals (including relative prices and relative profitabilities) as they emerge from the international market will be greater, the higher the distance of any one country from the technological frontier. This is what Amsden (1989) has provocatively called policies of deliberately "getting the prices wrong". Conversely, endogenous market mechanisms tend to behave in a "virtuous" manner for those countries that happen to be on the frontier, especially in the newest/most promising technologies. This is broadly confirmed by historical experience: unconditional free trade often happened to be advocated and fully exploited only by the technologically and politically leading countries.

7 Some remarks on the Chinese transformation, by way of a conclusion

The spectacular success of China in its *Great Transformation* is also, we suggest, a striking vindication of a co-evolutionary view linking technological learning, organizational transformation and institutional change ubiquitously characterized by widespread dynamic increasing returns (see Myrdal 1957; Kaldor

1972; Cimoli et al. 2009 among many unortodox others). In fact, the patterns of accumulation of knowledge and capabilities, at the levels of individuals, organizations and countries are at the core of increasing returns. The 'unbound Prometheus' systematically accumulating and improving technological and organizational knowledge has been a crucial *deus ex machina* of the early industrialization of almost three centuries ago, and as well as of subsequent episodes of development (Landes 1969; Freeman 1995; Freeman and Soete 1997). The rapid economic catch-up and industrialization in China is no exception. Its institutional set-ups in fact has entailed more of learning and "creative restructuring" of domestic firms rather than sheer "creative destruction" and even less so a multinational corporation-led drive (Yu et al., 2015).

Points often forgotten are, *first*, that the rapid catching-up since 1978 has been characterized by mobilization of the technological and organizational *capabilities* accumulated in the pre-liberalized stage.

Second, but relatedly, Chinese industrialization has certainly involved catching-up of all sectors by means of big and coordinated investment and capital accumulation, in the spirit of what suggested by the founding fathers of development economics (Nurkse 1953; Gerschenkron 1962; Rosenstein-Rodan 1943, 1961; Hirschman 1958; Prebisch 1949).

Third, note that, more importantly, the catching-up has been associated with learning effects well beyond the sheer accumulation of capital, involving the improvement of technological and organizational capabilities and the more efficient use of both capital and labour (Cimoli et al. 2009; Lee 2013).

Last but not least, the "Chinese Miracle", as basically all other modernizing miracles following the First Industrial Revolution, begins with the painstaking formation of a working class, with all the changes in the whole anthropology of perception of time, discipline, skilfulness, obedience (possibly with some solidarity and rebellion ...).[13]

In our view there is little doubt on the historical lessons, of which China is by far the most striking

[13] As Gerschenkron (1962) puts it "[...] industrial labor, in the sense of stable, reliable and disciplined group that has cut the umbilical connecting it with the land and it has become suitable for utilization in factories, is not abundant but extremely scarce in a backward country. Creation of an industrial labor force that really deserves its name is a most difficult and protracted process [....]" (p. 9)

one, pointing out the crucial importance of various ensembles of industrial policies and institution-building efforts in nurturing capabilities accumulation and industrial development. However, we face three interrelated questions. The *first* concerns whether what applied to the past will apply to the future: if magic that was not done by the Washington Consensus policy medicines is going to come around nonetheless as a natural by-product of 'globalization'. Our major message here is that *divergence and heterogeneity* have been and continue to be the dominant tendencies in the world economy. In fact it could well be that under conditions of dynamic increasing returns, more international openness of capital and trade flows might well 'naturally' induce divergence across regions and countries (more in Dosi et al. 2017). Hence, in our view also the continuing importance of measures of discretionary policy intervention able to trigger and fuel what we have called the 'great industrial transformation'. Clearly, the international conditions have changed compared to when, say, the United States were moving their first steps toward catching-up, and even compared to when Korea or Taiwan were entering the international scene. The WTO and the TRIPS agreements have been putting novel constraints on what policies can and cannot do with respect to both their domestic industry and to trade flows (Caveat the noise shocks from some contemporary Presidents ...). First-world companies are as aggressive as ever before in the defence of their proprietary technologies. But it is the very emergence of China as a major industrial player which has profoundly changed the patterns of opportunities and constraints facing other actual or would-be industrializers. However, the processes of knowledge accumulation and industrial development will continue to require relative massive doses of public policies and institution-building molding a national political economy friendly to technological and organizational learning.

This leads to our *second* major question. Putting provocatively, how long will it take before China "throws away the ladder" - as Chang (2002) puts it - and moves to the club of the winners, praising Ricardo the free-trader, and dismissing List the theorist of capability accumulation? This has been a robust secular patterns. All countries achieving world industrial leadership tend to re-write history, reconstructing their free-trade virginity: it happened to England, next to the USA, we would be surprise if it will not happen to a winning China ...

No matter, *third*, as soon as China joins the "club of innovators", the couple dynamics we were talking at the beginning of this chapter are bound to profoundly change. Catching-up is quite different from maintaining and exploiting technological leadership. In that, institutions and relations among them are bound to change, too. For example, among science, technology and industry; or the mechanisms governing income distribution... But this is the subject of an entirely different essay.

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