Organizational and technological paradigms:

asynchronized structural breaks, uneven evolution of paradigms and firm growth

between complementarities and substituitabilities

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Abstract

Organization and technology are two crucial factors of firm economic activity. A complementarity relation exists between the two factors such that each of these taken in isolation is unable to entirely explain the consequences of structural breaks in economic activity since the concausal links are lost from sight. In this chapter, we analyze how two concrete technologies (electro-mechanical and electronics) and two organizational modes ('scientific management' and 'Ohnism') have combined, over time giving rise to four different outcomes. Each is characterized by different paths of growth as a result of several mechanisms operating differently and with varying weights. In addition, the distinction between 'technology (and organizational design)-as-artefact' and 'technology (and organizational design)-in-practise' enables asserting that the characteristics of a given artefact are not fixed and universal but emerge from situated processes, from the interpretation and interaction of economic agents with specific artefacts at a given moment.

1. Introduction

Heterogeneity among firms - in terms of efficiency - has been widely documented in literature. Syverson (2004), for example, demonstrates that within 4-digit SIC industries in the U.S manufacturing sector, the ratio of total factor productivity among plants at the 90th percentile of productivity distribution is in the order of 2 to 1 with respect to the 10th percentile. By enlarging the range between the two percentiles, the ratio easily arrives at four. The picture is not very different for other economic systems.[1] It follows that more productive firms are more likely to survive than those with lower productivity: in the American case, the estimates indicate that those that fall below the 20th percentile exit from the market within 5 years.

While the explanations in literature differ, the 'internal' organization of firms, the quality of the technological capital employed and especially their compatibility, are rarely studied. In particular, little attention is paid to analyzing the stratifications that are determined over time with respect to the intrinsic characteristics of not only technological and organizational capital but also social capital (knowledge, cognitive skills, interpersonal skills, non-cognitive skills) that crystallize in the routinization of organizational behaviours.

The stratifications correspond to the different paradigms that follow one another over time. For the sake of space, we here focus only on the technological and organizational paradigms, two essential and complementary factors of economic activity. If a complementarity relation exists between the two factors then relative price is not an applicable tool to assess how the two factors combine; taken in isolation, the two factors are unable to entirely explain the consequences of internal structural breaks on firm economic activity since the concausal links are lost from sight. In addition, the complementary nature of each factor may be *simultaneous* (which implies that the gains from the simultaneous adoption of two factors are greater than the sum of the gains from the adoption of each factor in isolation) or *sequential* (the gains from the adoption of a factor are greater if another factor has already been adopted compared to situations where it has not been previously adopted). Sequential complementarity may refer to a combination of two or more factors, but also to a combination of two or more elements of a single factor forming a bundle. All these aspects have to be taken into consideration in explaining why two apparently identical competing firms react differently to common shocks. Based on this reasoning, the production function framework is not a suitable tool to enable understanding these dynamics in their exogenous and endogenous versions. Nor is the vintage capital

[1] Dosi et al. (2012) record a very similar situation for Italy.

model of new investment suitable for this purpose, since it is *assumed* that the latest investment always incorporates best-practice technology, meaning that firms are never uncertain about the characteristics of new technologies and that technology has a *unique* meaning, with no discrepancy at all between technology as an artefact and its personal and collective use. The same argument is applicable to organizational features.

We consider Kuhn's scientific paradigm an appropriate tool – with its elements of complementarity such as a set of pieces of knowledge, practical and theoretical know-how, methods and procedures to solve selected problems based on certain principles – to analyze the intrinsic properties of two technologies, namely, electro-mechanical and electronics, and two organizational models, specifically, the 'scientific management' and the 'Ohnism' model (all accredited in literature as out-and-out paradigms) to analytically highlight the possible co-evolution or the non-synergistic combination of the two factors. Indeed, a structural break in one of the two factors could give rise to a solution that does not necessarily constitute the best potential and sustainable combination due to several reasons: for example, constitutive principles in contradiction not only within the same factors but also between the same devices adopted in different periods of time and for various motives,[2] or adopted without paying specific attention to their complementary (i.e., information imperfections). Other explanations could be prohibitive costs, financial constraints, and several others that will be considered further on in the analysis. When this is the case, namely, when the change processes a firm faces give rise to spurious combinations (identifiable as 'local' positioning) rather than the full absorption of both complementary paradigms among the factors and complementary ingredients within each factor, resources are wasted and inefficiencies and productivity losses arise. This engenders development paths with either an accumulation or a fragmentation of technological knowledge and organizational competencies resulting in either high or low and stagnant firm growth.

The analysis methodology pursued in this chapter is speculative and empirically oriented, rather than theoretically and mathematically formalized. The chapter is structured as follows: section 2 provides the background to the discussion, defining the paradigm and considering the structural breaks and incremental improvements of a given paradigm; sections 3 and 4 analyze organizational and

[2] For example, Smith (2005) develops a model based on two hypotheses: first, the case where the prices of two innovations are expected to decline at different rates and the firm chooses to adopt the innovation whose price decreases at a slower rate, waiting for the second complementary adoption when its market price will be lower; second, where there is uncertainty about the dynamic path of either the benefits from, or the costs of, adopting the two innovations. Instead, Jovanovic and Stolyarov (1997, 2000) make use of alternative hypotheses (the non-convex adjustment costs or the learning period requirement for one input), reaching the conclusion that the firm is optimal when carrying out an asynchronous, sequential complementarity function.

technological paradigms from the perspective of their constitutive principles and historical sequences.[3] Section 5 considers the complementarity conditions, the spurious and pure combination both within and between factors, and outlines the implications for the empirical evaluation of outcomes. Section 6 considers some ambiguities, aporias and methodological doubts that still exist in empirical literature, while section 7 concludes.

2. Changes and improvements of the paradigm

Firm efficiency does not grow linearly: it very often progresses with relatively regular and modest changes, at times with larger but discontinuous changes. Sometimes this growth is the result of 'reactive' behaviour to stimuli from the external environment and sometimes it is the result of 'pro-active' behaviour. Paraphrasing Dosi (1983) in a certain sense, and borrowing the categories of scientific paradigms from Kuhn (1962), in the case of more or less regular changes we usually speak of movements along the trajectory of a given paradigm that take the form of a moving production possibilities curve and/or the incrementally increasing number of produceable goods. At the origin of discontinuity is almost always the emergence of a new paradigm that gives rise to a significant increase in the variety of products and/or services, or radically new products. The elements that influence these trends differ, but it is clear form literature that in recent decades two factors have attracted the attention of scholars: technology and the ways of organizing economic activity in the firm. In this chapter, we concentrate on these two factors by virtue of their intense incidence in this turbulent period of transition we live in.

A paradigm can be defined as a model and a pattern of solutions to *selected* problems, based on *selected* principles and on *selected* materials (Dosi, 1983: 83). A change of paradigm therefore implies replacing all the constitutive elements and is hence not directly comparable with previous paradigms.

We here analyze how two technological paradigms - electro-mechanical and electronics - and two organizational paradigms - scientific management and Ohnism - succeeded each another (in combination giving rise to four broadly different outcomes) and as such refer to problems of a technological and organizational nature, while both principles and materials refer to (and are derived

[3] Without claiming to be unquestionably accurate, we here assume the interpretation of Taylor's (1911) proposition that "In the past the man has been first [with his individual organisational (e.g., the craftsman's workshop) and technological artefacts (e.g., the individual tools)], in the future [after Taylor] the system will be first" as organizational design (forged for the first time by Taylor himself) as well as the integration of technological devices (successfully carried out by Ford in 1932).

from) natural, organizational and anthropological sciences (since re-organization has to do with human beings).

The transition from one paradigm to another occurs through a process, which makes it difficult to precisely date the occurrence of the event. The movements along a given trajectory - which enter into the *framework* of the underlying principles that are characteristic of the paradigm in question and prescribe the direction - occur as a result of an evolution in *complementary* knowledge, methods, procedures and competencies, in the sense that the development or lack of development of one of these elements can promote or inhibit the development of others. To this must be added the economic forces (e.g., demand-pull, cost-push, market forms), social forces (e.g., the *animal spirits,* learning) and institutional forces that act as real *selective devices* influencing the curvature of the movement in progress, until - according to Freeman and Louçã (2001) - diminishing returns begin to manifest and progress associated with the paradigm consequently slows down. According to Kuhn (1962) instead, the falsification of one or more of the elements or the constitutive theories of the paradigm does not occur first (i.e., results that contradict deeply held expectations) and thereafter the abandonment of the paradigm in favour of a new one, which appears capable of providing more accurate and convincing explanations in the context of a wider sphere of phenomena. The new paradigm that at first sight appears to contrast with the substrate of expectations generally emerges with difficulty due to resistance to accepting anomalous results. Similarly, this also occurs in relation to the acceptance and subsequent questioning of a theory as a result of unsatisfactory explanations and the failure of activities aimed at resolving the problems, which is followed by a phase where the first draft of a new theory is compared to the old theory, and then at a later date, overlapping theories, up to the definitive prevalence of the new over the old.

The paradigm shift is influenced as much by the evolution of the economic, social and cultural structure and economic factors in the strict sense (income distribution, relative prices, etc.) as by the feedback structure between economic environments, leading towards change and driving the direction of change itself. In turn, however, the incipient paradigm also influences the same economic, social and organizational environment (Perez, 1983). The new paradigm in any case presents a certain degree of independence and autonomy with respect to the evolving structure, and manifests as a cluster of scientific discoveries that pave the way - on the occurrence of a set of additional conditions in relation to the state of the elements that surround an invention: e.g., structural, social, cultural, etc. - to the innovation phenomenon, intended as families of *radically new* products due to their intrinsic quality, which the market pervasively establishes and progressively implements. These new products, although maintaining their fundamental characteristics to some degree, are refined by continuous improvements guided by the criteria of marketability, cost and capital/labour savings, industrial and social conflicts, profitability, and derive from different sources (e.g., formal R&D activities, trial and error, innovation learning-based mechanisms, competition-based mechanisms, quality control, public institutions, etc.), giving rise to the aforementioned movement along the new trajectory. In this progression, continuous recombinations of different forms of knowledge, experience and expertise develop but also new vocabularies, new techniques, new concepts that generate progressive specializations. These contribute to moving along the trajectory but also to a narrower view that becomes the basis of resistance to any change of perspective, vision or paradigm.

On movements along the development trajectory of a given paradigm, economic literature agrees on the relevance of innovative activities pursued through R&D and market structure, although pointing out that the consistency of progress is conditioned by the nature of the paradigm, expressed by the opportunity, appropriability and cumulativeness of innovative results (Nelson and Winter, 1982; Winter, 1984; Pavitt, 1984; Sutton, 1988).

The ideas and concepts expressed above shed light on how these models have been affirmed in recent times in the sphere of technology and organization of work activities, two distinct modes of production that can be considered - albeit with some approximation - as two paradigms. We will begin with organization since the first of the two discontinuities that we examine in this chapter historically manifests itself in this context.

3. Organization and human resources management: from the scientific management paradigm to the Ohnist paradigm

The theoretical framework of reference is that of Taylor (1911) and Ohno (1988), the 'engineers' of the two organizational paradigms (or models) that today contend in the field. Although here we do not discuss in detail the origin of the first paradigm, we analyze the constitutive principles of both their structures together with some attempts at modernizing and adapting them to the context (defined, in analogy with the conceptual categories mentioned above, as movements along the trajectory). In particular, in the second we highlight the fundamental elements at the base of the now consumed discontinuity compared to the first, along with some protocols that are still being defined (interpreted, again, as movements along the trajectory).

3.1 The principles of Taylorist organization

It is well known that early Taylorism manifested in the industrial life of America in the second half of the 1800's. Scientific management developed after a harsh economic crisis, with recovery linked to a resurgence of efficiency to contain English and German competition, in a context characterized by low-skilled labour but a rapidly expanding market of products. The elimination of machine and worker wastefulness, together with production concentrated on a few types of products, prompted the constant and rapid pace of workshops. Even before the study of the minimum time needed for a good worker to carry out a job, a set of guiding principles had to be devised that would steer the entire organization, paradigmatically encoded by Taylor:

1. A clear separation of the execution of work, of problem-solving and of conception work.
2. The maximum breakdown of executive work up to achieving a fragmentation of elementary tasks monitored with 'time-and-motion' studies (TMS) and establishing the minimum amount of time, movements and tools required.
3. The standardization of these tasks - also taking into account the supposedly limited cognitive ability of workers to repetitively perform excessively long production cycles – and conferring the status of 'one-best-way' to the solution found. Elementary tasks were aggregated to form workstations with minimum technology, simple (fool-proof) and automated workstations assigned to workers with minimum qualifications, remunerable according to time (hour), with the possible addition of wage premia related to results (*output-oriented incentives*) to derive the maximum efforts possible, thus achieving the containment of both labour and capital costs (the total cost of production).
4. The vertical division of labour by increasingly specialized tasks and functions to improve procedures and methods, supervision of work execution according to a predetermined plan of instructions (inspectors, team leaders with coordination-command-control tasks, maintenance leaders, etc.), product improvement, marketing, and so forth.
5. The aggregation of the various activities (of execution and coordination-command-control) had to follow the principle (*functional*) of information and technology sharing to exploit economies of scale. From this ensued the configuration of units, offices and departments driven by the criterion of command uniqueness. The most notable representation of this organizational configuration is a series of silos where little communication exists between them.

The corollaries of these principles are:

a) Information circulates in a limited way, intended for individual functional areas, flowing downwards from the top of the hierarchy.

b) Production is driven from upstream to downstream based on *ex-ante* expected market demand.

c) Quality control, if and when implemented, is a specialist function on the final product through statistical procedures.

The management techniques, consistent with the principles of the paradigm, consist of:

i. *Management-by-Objectives* (MBO), according to which the objectives are defined in terms of results (output), ignoring or neglecting the operating processes and modes (input).

ii. *Standard Costing*, which distinguishes between direct and indirect costs, and imputes indirect costs - to determine total costs - with an average percentage mark-up on direct costs to cover, for example, the depreciation of plants and indirect personnel costs, without, however, taking into account the actual extent of absorption of these factors in the production of individual products.

iii. *Budgeting*, which focuses on the accounting aspects of financial, instrumental and human resources allocated to the functional organizational unit to achieve pre-established targets, exclusively based on the factors of production and costs rather than on results, and analysis efforts concentrated on the effects rather than the causes of the deviations; all without pursuing resource use efficiency since the efficiency of a task is resolved *ex-ante* by TMS.

According to Simon (1977), given the complexity and the inevitable mutability and uncertainty of the market, firms could respond in two ways: incorporate flexible response mechanisms or try to stabilize and simplify the environment. The response was the homeostatic control of the environment[4], consistent with the Taylor-Fordist paradigm that enabled decoupling - through redundancy (e.g., stocks of raw materials, semi-finished products in warehouses, spare parts) - the production (denoted by continuous flow) and the market (characterized by changing demand levels). In terms of simplification, the paradigm responded with prices (profitable) affordable to the demand, thanks to cost reductions achieved through economies of scale, which in turn - keeping prices down - would gradually expand market demand but sacrifice its variability.

[4] Homeostatic control (typical of multi-glandular organisms) is the result of the activation of regulation and conformation mechanisms that enable maintaining a stable internal balance (homeostasis) in the face of environmental changes.

Not all the elements that characterize the paradigm, including the corollaries and management techniques, were established and formed at the same time. For example, statistical quality controls were implemented in the Bell Labs in the U.S. in the 1920s (Shewhart, 1931), while thoughts on the connotations of alienation linked to the execution economy, and on how to address these negative aspects, began with Elton Mayo's experiments of worker involvement at the Western Electric Hawthorne plant in the 1920s (Mayo, 1949). The principle of involvement spread with the human relations movement in the 1930s, while the Scandinavian socio-technical system movement focused on the use of autonomous work groups (which we will also address with the Ohnist paradigm) to humanize work and took place in the 1950s with the aim of solving recruitment and retention problems, to increase job satisfaction (which, if maintained over time, should translate into improved job performance) and to reduce turnover and absenteeism (Trist, 1981). The transition from the involvement of the individual worker to that of all workers through their representatives, to motivate them to pro-actively participate at plant level in the early stages of strategic management decision-making and organizational changes, found an innovative solution in the German co-determination system, where the emphasis of labour unions shifted from wage bargaining to job saving.

All these innovations, which could be defined as incremental in scope, constitute an advancement at the margin of the paradigm along a trajectory determined by attempts to remedy the occurrence of inconsistencies, inefficiencies, the inevitable differences between intentions (arising from *principles*) and outcomes, without affecting the underlying principles of the paradigm itself. The results of these advancements are not, however, without controversy, starting from the reviews of psycho-sociologist empirical studies (e.g., Kopelman, 1985) that accredited positive outcomes to work quality, work quantity and reduced absenteeism, to those of economists (e.g., Kochan et al., 1986: 87) who argued that "there is little empirical support to demonstrate that improving individual attitudes and/or motivation produces lasting economic benefits to organizations". The underlying reason for these ambiguous results probably lies in the difficulty of controlling for the fact that for the greater motivation of workers to translate into improved performance for the organization requires workers to build their broad (polyvalence and polycompetence) competencies *within* the organization, exercising these in the production of things that have a sense - due to how they themselves contribute to constructively producing them - so as to fruitfully apply their imagination, intuition and the organizational knowledge acquired in a social participatory organizational structure.

3.2 The principles of the Ohnist organization

The paradigm developed by Ohno (the so-called Toyota system) also took its cue from Taylor's need to improve efficiency by eliminating waste but this time in the presence of a severe shortage of raw materials, a limited internal market and very fragmented demand. The solution was different, however, and was the result of a genuine reversal of thought (Ohno, 1988): production was usually conceived as a flow that runs from 'upstream' to 'downstream'. Reversing the observation point, the production process was conceived as a 'pull operation' from 'downstream' to 'upstream' taking *only* the items needed and *only* when they were needed. Three other pillars were added in this reversal of perspective that created the discontinuity with the previous paradigm: autonomation (combination of autonomy and automation, also defined by Ohno as 'auto-activation'), just-in-time and diversification economies.

1) Auto-activation means delegating responsibility for the quality of the product to the worker (line) starting from the elementary tasks themselves, which implies attributing the worker not only the right but also the obligation to take the appropriate time (also stopping the system if necessary) to ensure the maintenance of quality standards at each stage of production. The conceptual framework of this indication prompted Koike (1994) to highlight that the *principle behind* the design of the individual workplace is radically different: more precisely, it involves abandoning the principle of 'separation' of the Taylor mould (whereby the workstation for unusual operations is next to the workstation intended for usual operations), in favour of the principle of 'integration' (according to which every workstation must be able to carry out 'usual and unusual operations'). The consequences of this principle of integration are:

> a) Job competencies are broader and more ample since to the execution of operations defined in advance[5] are added maintenance and machine retooling tasks but most of all diagnostic and problem-solving tasks,[6] which in turn help redefine the 'pre-defined tasks' and the 'requested competencies'. This last component ensures the firm a certain *dynamic efficiency,* as well as an *adaptive efficiency,* to the extent that the solutions go far beyond fixing errors with respect to expected standards, with variants, options, upgrades and customizations that the market appreciates. We argue that this circularity should nullify (or mitigate) the 'organizational

[5] This implies that TMS - in other words, the economics of time - is common to both Taylorism and Ohnism, even if resolved in a different way, as in the latter case, time is no longer categorically established *ex- ante*.

[6] A significant degree of autonomy and responsibility is nestled in this set of competencies, but without being free of higher control: indeed, *Andon* type technological devices (which through light displays show the progress of regular and irregular production) allow upper-level managers immediate access to all kinds of information they may require (so-called 'management by eyes').

defensive routines' of Argyris and Schön (1978), precisely the organizational behaviours that tend to *justify* practical actions, thus preventing having to deal with malfunctions and perplexing, threatening or unexpected situations, which effectively reduce the likelihood of productive learning.

Linked to higher labour costs are different types of cost-savings due to the greater professionalism of workers including the lesser need for, and use of, specialist workers, quality control (traditionally applied at the end of the work process to the finished product) and other types of cost-savings that we consider hereinafter.

b) Repeated problem-solving tasks (linked to unusual operations) tacitly expand (Koike, 1994) the intellectual skills of workers, with the result that (first) informal learning is associated with (second) additional cost-savings resulting from reduced recourse to formal training.

c) The suggestions system constitutes the workers' legitimacy to exercise self-reflexivity in the cognitive effort to bring continuous improvements *(Kaizen)*. This exercise adds stimulus to expanding their abilities and can be further strengthened through economic incentives *(input-oriented)* that acknowledge learning and skill development.[7] These mechanisms help stimulate the firm's dynamic efficiency.

d) Team and production islands[8] constitute another *principle* of the Ohnist paradigm. Teamwork is defined as a 'productive unit of work' that through the cooperation of participating members - called upon to individually and collectively undertake but also identify flaws and fix them, and to build and share information and knowledge within the team (according to the four phases of Nonaka and Takeuchi, 1993) - must transfer to the team and to the downstream island a (semi) product that varies according to contingencies but is always considered 'work' (or a piece of work) in Arendt's sense (1958), due to the continuous improvement that the individuals and the team as a whole make[9]. This is clearly in conflict with the Taylor principle of repeatedly

[7] Coriat (2000:238) sees this transfer of ideas to the firm as a form of dispossessing workers of their improvement ideas and know-how; this process starts with the codification of personal knowledge to turn it into organizational knowledge, which management then appropriates. However, if this 'transfer' of ideas is contracted and economically recognized, then dispossession hardly applies.

[8] The team concept also applies to inline production where a group of workers are responsible - in the Ohnist sense - for part of the line.

[9] According to Arendt (1958), 'labour' never indicates a finished product, but the result of work activity and the ability to carry out or perform, while 'product' is invariably derived from the word that indicates 'work', namely, to resolve or accomplish.

‘executing’ a predefined set of elementary tasks incorporated in the workstation, which results in the provision of 'labour' in the form of mechanical energy. We argue that in terms of meaning, the former condition places the worker in a position to train in a broader cognitive map, to practice self-reflexivity and restrain opportunism (since his first supervisors are his colleague downstream and his team) to activate subjectivity and develop professionalism (see job rotation in the next point) that contribute to shaping his identity, to build - starting from work activities and operating - a ‘*vita activa*’ with sense and meaning, while the latter condition places the worker in a state of estrangement and alienation with respect to the orientation of his efforts. The principle of inline manufacturing and assembly procedures also changes in favour of a ’U’ shaped organization, interlocking the islands to facilitate 'passing the baton' (the transfer of semi-manufactured goods from one island to a downstream island) and to define the 'productive units of work' to be assigned to teams.

e) Through job rotation (workers moving from upstream to downstream) within and between teams and production islands, the intellectual but also relational skills of workers are continuously stimulated to expand, thereby generating a (second) informal learning mechanism, from which a second cost-saving ensues in terms of formal training. Job rotation constitutes the mechanism of constructing multispecialization and multifunctionalism, through which the worker is able to reduce the defects that have eluded the upstream workstations and contributing indirectly to reducing costs.

2) Just-in-time means programming production from ‘downstream’, starting with orders already placed by customers, namely, products that have *already* been sold. This is achieved by inverting the Taylor-Ford meaning of 'programmed' according to which as much as possible should be produced in a minimum given time, but now attributing it the value of information coming from the market, converted into instructions and then made operational in production programs through the technique of signals *(kanban)* transported backwards from downstream to upstream. These signals indicate the quantity of products, semi-finished products and raw materials that must systematically flow to the downstream stations. Production is thus pulled by 'demand' in terms of quantity, time and types of products required, and leads to the elimination of stocks of materials, semi-finished products and unsold final products.

3) The concept of a market where every customer seeks a customized product requires 'production-on-demand' with zero buffer stocks. This entails the possibility of producing multiple versions and multiple objects on a given set of machinery and equipment, which requires speeding up changes in installations

and moulds and their frequent repositioning. This goes against the *principle* of mass production (and associated economies of scale) and against 'dedicated' technology (*see below).* The solution sought in flexible modular technology goes hand in hand with the multispecialization and multifunctionalism of workers.

The corollaries of these principles are:

i. Information now travels horizontally, from the customer to line workers with polyvalent competencies to interpret the commercial information reaching them and then transform it into operating programmes by quickly retooling machines for products already purchased by customers. In the Taylor-Fordist system instead, commercial information initially travels upwards (i.e., up in the hierarchal direction), to be coded and transformed into operational orders that flow downwards to the production lines.

ii. Production is pulled upstream from downstream based on orders the firm has received.

iii. Immediate deduction of the combination of the just-in-time and kanban principles, which is the reconfiguration of the aggregation of assets that shifts from a 'function' (silos) to a 'process' logic, entailing a shift of the entire sequence of activities aimed at customer satisfaction that pass through the old functional areas. The overall organizational area of the process is put in the hands of a manager (process-owner) who reports directly to the top management; on the one hand, engaging as a real supplier with the customer and market, and on the other, as a real customer with internal (consisting of those few process support activities that the company chooses to preserve) and external suppliers.

iv. Quality control is undertaken in the course of the production process at each stage of advancement of the process itself.

The management techniques consistent with the principles of the new paradigm are:

I. *Activity-Based Management* (ABM), which foresees paying attention to how activities consume resources (in terms of time, materials, etc.) and how they contribute to achieving customer satisfaction, eliminating downtime, speeding up the production process throughput *(lead-time)* and the response to market demand (developing and introducing new products: so-called *time-to-market*), removing those activities that do not generate added value while continuously improving the operating procedures throughout the process. *Lead-times*, and especially *time-to-market* (through *Concurrent Engineering* (CE) in product development [10]) enable the firm to exploit, in the first part of the life of a new product or its innovations and improvements, the higher (lower) income elasticity of demand (price), obtaining revenue[11] that outweighs the cost of additional flexibility, represented by the adjustment costs and sunk costs linked to the potential irreversibility of the choices made *ex-ante.*

II. *Activity-Based Costing* (ABC), a procedure estimating the costs of products and services based on the amount of resources actually absorbed (space used, raw materials, machine hours and man-hours), avoiding loading prices with inappropriate costs such as those resulting from the underutilization of plants and machinery. This enables identifying the available resources that are not absorbed in processes, which will subsequently be reconsidered (in the ABM above) for their removal.

III. *Activity-Based Budgeting* (ABB), which focuses on activities such as value added, and is expressed as units of budget in relation to the cost of activities. Traditional budgeting focuses on monetary inputs rather than on outputs, does not identify product and customer characteristics, does not support continuous improvement and does not identify waste, which are at the core of ABB.

The slow maturation of these principles, corollaries and mechanisms, which were not simultaneously recognized but nevertheless constitute complementary parts, can be seen as an advancement (irregular or accelerating and decelerating) along a trajectory of the new paradigm, which takes the form of a spiral (under the pressure of a constant trade-off between cost and relative returns) as a result of age, selection and intensity of the organizational variables adopted by firms.

4. Technologies: from the electromechanical to the electronic-computing paradigm

Technological innovation implies solving technological or economic problems and entails discovering - in most cases through tacit knowledge - the reason why a given product or machine tool does not work, or

[10] CE is a set of techniques that puts traditionally conceived sequential operations in parallel along the 'design-production-marketing-industrialization' path. CE contributes to surmounting the traditional idea that product innovation (in the form of variants, options and customizations) is confined to the R&D function, in favour of the idea that innovation is the output of a process that involves multiple business functions. This does not imply a devaluation of the classic functions of acquisition of technological knowledge in the broadest sense and stimuli for creativity and innovation, which constitute the source of that part of innovation that is ascribable to 'impulse' , but at the same time recognizes that innovation *also* consists in problem-solving that can originate downstream along the production process (in the diagnostic and problem-solving activities of operators of a production island) or from the customer or market and implying greater interaction between production and design.

[11] They so-called revenue resulting from product differentiation as theorized by Chamberlain, and in Ohno's version, quality/customer satisfaction.

why it is relatively expensive, or how to satisfy a potential or actual need, and to create a new solution (Dosi, 1988: 1125). This type of activity takes place within a set of scientific principles and heuristic rules, which define and delimit a pattern of solutions to selected techno-economic problems.[12]

Theoretical references to technology in relation to organization are numerous and more distributed over time, in the sense that the industrial artefact or technological tool takes shape as a result of repeated attempts to achieve increasing levels of precision and functionality with respect to specific requirements and specific functions, and experimenting with different materials. Military requirements for guns have certainly been a good driver of the advancement of metalworking technologies in recent history: the case of North's milling machine in 1818 in the U.S. is well-known, made universal by Howe in 1852 and soon becoming a world standard (Ayres, 1990). The same can be said for the advent of the steam-engine, and the coke-based puddling-rolling process to convert pig iron into bar (wrought) iron for engineering purposes (ibid), allowing overtaking the power of human muscles. The rapid adoption of electric power-generating plants brought about a reduction in the cost (and, subsequently, the price) of electric power, favoured by large (and efficient) steam turbines located at a central power plant, which crowded out the relatively small and inefficient localized (on-site) plants.

4.1 The electromechanical paradigm

The combination of the theoretical and hands-on aspects of electrical, mechanical and fluid power gave rise to devices that carry out operations with moving parts known as electromechanical parts. An example is the relay device,[13] widely used in complicated subsystems. In general, the growing demand for machinery capable of forming and cutting iron (e.g., rolling mills, lathes, grinding and stamping machines) – equipped with electromechanical devices - led to large scale production, which led to the greater decomposition of tools (and at a later stage, of products: e.g., reaper, sewing machine, bicycle, typewriter, car, etc.) into a larger numbers of components, in turn requiring the greater specialization of high-precision machine tools to produce these components (and guarantee the *interchangeability* of each component).

[12] Egidi (2013) provides a good example, although in the form of an analogy: language can be considered equivalent to a paradigm, while semantics and syntax play the role of heuristic rules with respect to what is said and how it is said. However, the quality of outcomes depends on cumulatively augmented abilities and skills. This is also true for technology.

[13] A relay is an electrical device such that current flowing through it in one circuit can switch on and off a current in a second circuit.

The *principle* that dominated was still that of machine tools *dedicated* to specific operations, exclusively controlled by humans (semi-skilled workers), namely, machine tools with the capacity to repetitively perform a sequence of prescribed actions, usable in industrial production to pursue economies of scale. Soon the electromechanical technology as a means of overcoming the limits of human muscles came to substitute these human muscles and *manual abilities*. If manufactured products could previously be easily assembled by one man in a few minutes, and when necessary the components could be *manually fitted* by the same man, production complexity soon began to increase as a result of (i) the increase in product characteristics, (ii) the greater decomposition of a given product into many small and simple components (Taylor's principle), and (iii) the greater specialization of high-precision machine tools that guaranteed the standardization (i.e., interchangeability) of parts and components, which drastically reduced manual fitting and consequently various professional competencies.

All this prompted the use of complex but *standardized subassemblies*, through the agency of inventions such as ball bearing assembly, spoked wheels, gear changers and roller-chains, and progressively led to significant economies of scale (Giedion, 1969).

In the second half of the 1800's, the car took the place of the gun industry as a technological driver (*American Machinist*, 1977; Rosenberg, 1976) as a result of two factors: first, the decentralization of mechanical power from large immobile central steam engines to small mobile internal-combustion engines (invented by the Germans) or even more dispersed electric motor drives; second, the sheer complexity, which required the assembly of a huge number of parts and components (most produced elsewhere) by specialized suppliers and subcontractors. Ford contributed greatly with his moving assembly line ("bringing the work to the man"), which on one hand imposed a mechanical order on the production process, and on the other forced assembly workers to pace their work to the motion of the line. His contribution continued with first the mechanical link between specialized machines (though not originally designed to be compatible) by means of a (dedicated) transfer machine, and second with the organization of all major machining operations into a single, synchronous line, obtaining a considerable reduction of labour and an increased utilization of capital. The *sine qua non* condition was standardization, which implied *dramatically cutting flexibility* to pursue economies of scale by means of mass production.

4.2 The microprocessor-based technologies paradigm: from the origin of CIM to ERP and ICT

The increased complexity of production, also due to the increase of product characteristics, was soon transformed into increased demand for a variety of models and products. Mass production at first attempted to contain and counter such demand by decoupling - as mentioned earlier - the production and the market. The persistent retail consumer demand for variety generated tension among manufacturers in search of some feasible solution. Among the many innovations pursued by firms (cutting tools and tool materials, casting and forging technology, powder metallurgy, etc.), the most relevant was certainly the *flexible nature of the technology*. Punched paper or magnetic tape controls for machine tools were the key to opening the door to a new technological paradigm: applied in the first instance to feed data to milling machines (American Machinist, 1977) and accomplished by what was, in fact, rudimentary and highly dedicated digital technology, namely, the numerical control machine (NC). With strong impetus from the development of semiconductor-switching elements, this became the computerized numerical control machine (CNC) capable of carrying out a sequence of operations on a single part and using different tools. The simultaneous control of a number of independent stand-alone NC machines by a single computer initially generated *machining centres* (called CAM: computer aid manufacturing), consisting of (at least) a CNC machine tool, a workpiece store, work- and tool-handling devices, and an automatic control and supervision subsystem. Thereafter it generated *flexible manufacturing systems* (FMS) containing several automated (CNC) machine tools of either a universal or specific type, flexible manufacturing islands, and when necessary, additional manual or automated work stations, as a consequence of the parallel development of software, which cut programming time for CNC and FMS systems. An obvious extension was automatic tool changing to make a group of multipurpose machines producing a wide variety of different products more efficient and improve the cost/performance ratio; this was achieved by incorporating into a single machine tool all the machining operations needed for a given part.

The parallel (albeit autonomous) development of robots (in the handling process versions, especially welding and assembly) and CAD (Computer Aid Design), were channelled and absorbed by the increasingly complex and sophisticated FMS, thanks to progressively overcoming problems arising from non-common standards and lack of interfaces in the sphere of material flows and information flows. The reason for these developments in the first instance was a reduction in the use of unskilled and semi-skilled labour, and secondly, the shortening of lead times from design to production and in perfecting the product design.

The improvement of sensors and actuators made robots and other production equipment more versatile, quicker and exact than human beings. The advancement of the paradigm, with progress, improvements and incremental innovations, took place on one hand under the pressure of the level of changes in demand for consumer goods, by the capital equipment itself as well as by the relative prices (i.e., so-called market-mechanism inducements) and on the other hand, from the combination of opportunity, appropriability and complementary technologies incorporated in individual capital equipment.

The substitution of electronic sensors for human eyes and ears, and computers (to some extent, through expert systems) for human brains, at least in certain categories of routine on-line manufacturing operations, and in a wide range of equipment (amongst other things, increasingly small-scale), initiated - from a technological point of view - the transition from the old electro-mechanical paradigm towards a new paradigm founded on microprocessor-based technologies.

The off-line functions directly linked to on-line functions led to the evolution of production into a real *computer integrating manufacturing* (CIM) system, interconnecting hardware and software starting from ideas up to customers by means of design, production, production control, quality control, product delivery and so forth, providing a glimpse of the concept of being able to achieve an ‘unmanned factory’ able to cope with time-based competition and product variety, two cornerstones of the modern economy. The benefits were fuelled by three expectations: labour and capital saving, increasing capacity and product quality improvement.

The technological determinism (or techno-centric approach) underlying CIM prompted the gradual emergence of several intractable problems over the 1990s, on one hand shattering the illusion that an error-free system could be constructed, capable of managing the unforeseen in its subsequent concatenated and uncontrolled failure, and on the other fostering the emergence of the fragility of the aforementioned production-market decoupling, in the face of the unavoidable and persistent instability of the competitive environment and the uncertainty in production process management.

In relation to the first issue, despite significant advances in this field, technical systems broke down frequently and the costs of such interruptions were high. These systems aimed to ensure the automatic exchange of information without the intervention of a human operator, they were created and developed in a unified and integrated way, compatible with a hierarchical and stable environment (or presumed as such, based on the production-market decoupling), and characterized by aversion towards industrial relations. These systems were certainly adjustable and improvable, but only with the intervention of professional engineers and technicians - who became the de facto repository of production know-how to the detriment of production workers - to assess situations, to interpret the system crashes, to analyze the choices and to make decisions without technological or artificial intelligence apparatuses being able to replace them. The fundamental limitation of CIM was dealing with information in terms of a set of *bits* (binary digits), neglecting the semantic dimension, in line with the mathematical theory of communication that postulated, "semantic aspects of communication are irrelevant to the engineering problem" (Shannon, 1948: 379).

In relation to the second issue (the fragility of production-market decoupling), instability and uncertainty required higher levels of delegation and consistent decision-making autonomy to satisfy the changes sought by the market as quickly as possible. However, the very emergence of technological breakdowns at times implied changes if not redesigns of the processes that required a different structure of interdependencies, changes that were diagnosed and implemented by operators near the workstations, but who at the same time had to battle with the economy of time.

In any case, investments in capital-intensive and sophisticated technologies were always expected to overcome deep-seated structural problems.

Two events marked a deviation in the evolutionary path of the techno-centred approach. The Japanese approach to CIM, more human-centred, and the taking-off of MRP (Material Resource Planning), which became the modern ERP (Enterprise Resource Planning).

Regarding the Japanese humanizing approach, the *principle* is that in the face of instability and uncertainty the most flexible element in the technological system is the people who make it work, that is, the motivation of engineers, technicians and workers on the shop floor who are familiar with the system. From this principle follows a more frugal approach to technology compared to the massive investments of Western companies, preferring - as rule - gradual improvements in the production process and in quality rather than sophisticated installations (Ayres and Ebel, 1990).

As far as the second event (MRP) is concerned, this started as a conventional short-term forecast tool of demand and a computation of all the implications (materials, decisions on whether to make or buy, purchase orders to outside suppliers, etc.), thereafter evolving into a new generation of management software (MRP_II) that included orders and production cycles, and allowed verifying that the production hours needed for work and for the human machine did not exceed availability, to then arrive at the modern ERP, namely, a set of integrated tools for the management of all the information in a productive organization of goods or services, from research to production, from finance to marketing, and from suppliers to customers. Despite the recognition that these new management systems have not yet acquired a unanimous definition - with different variations in the last decade from both the conceptual and technological infrastructure perspectives, designed to provide the functional capability required to turn the ERP concept into a reality (see the survey carried out by Nazemi et al., 2012) - empirical literature agrees, based of an analysis of the main software packages in the world market (SAP, Oracle, Baan, Peoplesoft, Edwards, etc), on accrediting the *principle* underlying the development of these systems using as a point of reference firm organizational design based on processes (conceived by Ohno) rather than on functions (Taylor) to capture organization-wide information, with minimum redundancy. This means that a firm seeking sustainable competitive advantages by adopting ERP must re-engineer the entire organization, from the organizational lay-out to responsibilities and from coordination mechanisms to the role of human resources, otherwise implying the total failure of the entire investment (Christensen, 1997; Umble et al., 2003; Aloini et al., 2007; Shaul and Tauber, 2013,).

The excitement around the new technology, in the form of ERP, but especially ICT (Information and Communication Technologies) in respect of which the term 'general purpose technologies' (GPTs) was coined (Bresnahan and Trajtenberg, 1995) to denote their enormous adaptability and ubiquity, peaked at the turn of the twentieth and twenty-first century and then began to decline with the 'dot-com' bubble. The decline of the exuberance for the supposed economic value of activities related to these technological solutions did not however stop the spread of ICT, especially in the service sector, although its rate was lower than expected and more varied in space and heterogeneous in time. The reasons were to be found in underestimating the social, political and institutional factors (for example, social injustice, educational policies and different degrees of trade barriers and obstacles to the flow of capital) that created *resistance* to the smooth adoption of ICT, similarly to what occurred in prior regime changes (Perez, 2002; Freeman, 2007). Among the obstacles to change, a significant role was played by the standardization of the interfaces of various components of ICT and by more appropriate cultural aspects.

With regard to the first point (standardization), single ICT innovations such as an artefact or device or even a software improvement seldom ‘stand alone’ (as other pieces of technological or organizational innovations) and consequently have to be integrated with existing and other newly emerging technologies; it follows that compatibility standardization plays a central role in how technological opportunities are exploited, namely, the rate and direction of this exploitation. Market competition *per se* does not lead to a convergence of standards, even taking into account that the key determinants of costs (and the underlying economies of scale, of scope and of industrial coordination[14]) guide the firm's decisions and those of the demand (governed to a great extent by 'interdependency', since the demand of one user depends upon the choices made by other users).[15] Schumpeterian competition *per se* in fact pushes in the direction of diversifying innovations, unless market processes are guided by either industrial policy, or (inter)governmental organizations that induce compatibility standards by virtue of greater expected social welfare, or again governed by coalitions of firms that 'sponsor' standards in view of greater firm opportunities and market growth. In these contexts, long-term improvements in the quality of standards occur at the cost of short-term losses to users of what will become obsolete standards, as and when superior and incompatible standards emerge.

In terms of the cultural aspects, even though the continuous overloaded flows of (bits of) *infotainment* (sounds, images, data) are far from being a universally (centralized) asserted culture, and closer to a globally produced customized product, locally selected by individuals (Castells, 1996:341), these continuous overloaded flows give the impression of democratic *participation* in creative activities and inter-personal relationships. On the other side of the coin, the risk cannot be ignored that modern ICT gives rise to a real 'appropriation of technological subjectivity' if the cognitive, communications and relational competencies of individuals are not adequately developed at the level of the new and sophisticated communication mechanisms, so as to make sense, construct and communicate understanding in a world of great dissonances and ambiguities, which ICT on one hand contributes to creating and on the other can help resolve.

However, no one can fail to see that – precisely starting from the fact that we are entering into the second machine age, where thinking machines nourished by artificial intelligence are capable of dealing with pattern recognition,[16] complex communication[17] and other domains traditionally considered human fields,[18] and where most people on the planet are connected via a common digital network (Brynjolfsson and McAfee, 2014) – the firm decision-maker may again be tempted by the technical-

[14] Economies of industrial coordination refers to combinations of variants in the multi-components forming a system (e.g., a platform or a modular platform) produced by many different firms.

[15] A different issue is if users are able to make rational choices in favour of pieces of a system that are compatible with an existing system, without considering the significant differences in capabilities between users on one hand and large corporations equipped with an information system department on the other: the latter is very likely to be more capable of choosing and constructing an integrated system than an individual user.

[16] The comparison is with respect to prior computerized algorithms only capable of following rules.

[17] The reference is to IBM Watson's supercomputer performance. It is worth recalling that Watson's victories in the TV game Jeopardy! were the result of specifically targeted programming (in other words constituting a type of dedicated technology), and that its use in other fields required substantial reprogramming by its human creators.

[18] The reference is to modern robotics, considered by experts as on the cusp of exploding because of its capacity to execute complex task in dangerous, degraded, human-engineered environments.

centric path. Efficiency is at the centre of concern, which in the background sustains the concept of information as equivalent to a signal (a *bit* or their combination) and ends up attributing excessive importance to the information process itself [19] rather than to the human-centric path that rests on the idea that information not only has a syntactic but also a semantic dimension. The focus is on the meaning conveyed by the message and on the fact that the semantic dimension is activated by an interpreter – endowed with a cognitive system (i.e., resources to interpret signals, holding beliefs and acquiring knowledge) - and by a process of interpretation. The meaning can evolve and has a decisive role in the construction and production of knowledge (Dretske, 1981) and, in the end, knowledge – because of the interaction that occurs between language and human action in terms of the subject's 'intentionality' and 'involvement' – orients the action (Searle, 1969) with a focus on effectiveness rather than efficiency.

Support for the techno-centred path, and the vertical configuration of the organization, could be provided by the ambiguous role that ICT plays if these technologies were to be 'bent' in the direction of communication (CT) rather than information (IT), which could be the result of a cost and performance effect, but also of the *weltanschauung* of top management with respect to defining their prerogatives. Using data on manufacturing firms in the U.S. and Europe, Bloom and Garicano (2013) show that information technologies (in this case, ERP and CAD/CAM) are associated with greater autonomy and a wider span of control, while technologies that improve communication (such as data intranets) decrease autonomy for workers and plant managers. The technological evolution in this field, enabled by the wishes and choices of firms and the varying adoption of ICT technologies and content, may propel firms towards one organizational structure rather than another. What the theory of complementarities highlights (below) is that the emphasis on CT is more compatible with the Taylor-Fordist organizational design system, while IC is more compatible with the Ohnist system.

We began this section by stating that military requirements for guns were undeniably a good driver of technological advancements, thereafter passing the baton to the automotive industry. However, we would not want to create the impression that all the good technological things available today are the result of animal spirits and venture capitals that stimulate the private sector of the economy. The need to win wars (during the Second World War and the Cold War era) has always provided a strong impetus for technological innovation, pushing the entrepreneurial State (mainly the U.S., but not only) through its agencies, its orders (for manufactured goods but also problem solving), its regulatory functions in mobilizing innovation in many sectors, from semiconductors to computers from the internet to GPS,

[19] This role was also foreseen and theorized for workers by Wiener (1948), the father of cybernetics.

from jet planes to civilian nuclear energy, from lasers to bio-and nanotechnologies, in order "to bridge the gap between blue-sky academic work, with long time horizons, and the more incremental technological development occurring with the military" (Mazzucato, 2013: 75) to strengthen technological capabilities for national security.

5. Complementarity, substitution and performance 'chemistry'

From a historical perspective, empirical evidence shows that the great majority of firms use a mixed collection of elements of old and new technologies, and old and new organizational characteristics, adopted to different degrees and belonging to different steps of sequential paths along which the elements have been adopted. It is however very likely that the huge reduction of prices in ICT-based equipment in the last two decades has contributed in the first instance to the relatively greater investments in new technologies than in organization, rendering the lacking organizational innovations a barrier to additional investments in ICT technologies (Bugamelli and Pagano, 2004) or holding back technological investments while awaiting the development or the adoption of complementarity innovations (Rosenberg, 1976).

The empirically observable performance of a working paradigm is not only ascribable to theoretical efficiency or to the intensity of incremental adoption of innovations along the trajectory, but also to social practices in the ongoing use and change of technologies or workplace organizational designs (Bijker et al., 1987); more precisely, how people – as they interact with a technology or organizational prescription, or both – enact the structure that shapes their emergent and situated use of these tools. Orlikoswki (2000: 408), focusing on technology, suggests a practical lens to view its use as a process of enactment that enables deeper understanding of the constitutive role of social practices.

She points to a useful distinction between *technology as artefact* (the bundle of material and symbolic properties packaged in some socially recognizable form, e.g., hardware, software, techniques) and the *use of technology* (what people actually do with the technological artefact in their recurring, situated practices). From this emerges that technological knowledge is, at a given time, what the practice has made it, in that the users appropriate the technology "ignoring certain properties or inventing new ones that may go beyond or even contradict designers' expectations and inscriptions" (*ibidem*: 407). This occurs because they approach a new technology based on their previous experience with other technologies and their participation in workplace communities.[20] More precisely, the process of using the technology involves users interacting with 'facilities' (such as the properties of the technological artefact), 'norms' (such as protocols for using the technology) and 'interpretive schemes' (such as the skills, knowledge and assumptions of the technology that the user has). Following Marengo (1996), one can add that to manage and become familiar with a new tool, a worker has to collect all relevant information on its technical, functional and management aspects; this activity is costly not only from an economic perspective as it takes time away from productive activity in a strict sense, but also from a cognitive perspective since the information must be processed and interpreted. This activity can be restricted by considerations of expediency, convenience and economic and cognitive limitations, thereby generating a *knowledge gap* between what individuals know and the technological information available to them, as well as a *problem-solving gap* between the complexity of this information and the ability to manage it effectively and efficiently and reach a solution.[21]

These kinds of arguments, used to support the plausibility of the hypothesis of bounded rationality against the neoclassical assumption of unbounded rationality, enable understanding the reason why two groups enact diverse technologies-in-practice using the same tool. It is precisely because different users choose to enact the same technological artefact in different ways, in so doing potentially limiting the ability of the technology to deliver the organisational benefits that were expected from the system. It follows that the presumption that technology and humans are essentially different and separate realities is a useful expedient only to analytically isolate the intrinsic characteristics of the subject under analysis. However, for an empirical assessment, the presumption of separateness may be misleading in that it prevents understanding the temporally emergent sociomaterial realities that shape contemporary organisations (Orlikoswki, 2010). This risk is appreciable when moving from a speculative to an empirical dimension, from a theoretical achievement to its implementation, and particularly to the diffusion and adoption of a given innovation.

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[20] Dretske (1981) argues that people process information based on knowledge/beliefs and thus visions, which are the result of information they have received and processed in the past according to their personal cognitive algorithm. The author also includes information on the effects of experience and learning, and defines information (*ibid:* 44) as «that commodity capable of yielding knowledge», identifying knowledge (*ibid*: 86) «with information-produced (or-sustained) beliefs».

[21] Two classic examples of the problem-solving skills gap are the 'Rubik's cube' and the game of chess: given the initial configuration, the moves allowed to arrive at a solution are known. Nevertheless, being able to identify and apply the optimal sequence of all the moves is a complex task that normally exceeds the average computational capacity of the human mind (Dosi and Marengo, 1994). The rule is to proceed with a limited set of information and a given interpretation of the same, and then adjust the decisions in light of new information that is acquired and interpreted, or new interpretations of the original information.

In our view, Orlikowski's argument with reference to technology also holds for theoretical organizational design and human resources practices.

A sphere where the significance of these considerations can be measured is that of complementarity between different technological devices, or between different organizational practices, belonging to the same paradigm. The same relevance also, and above all, emerges in complementarity between technology and organization. With reference to the historically manifested situation, two technological and organizational paradigms were combined and intertwined, giving rise to the following four different outcomes (Figure 1).

Quadrant A is the combination of the organizational capital (OK) in the Taylor-Fordist mould and the technological capital (TK) of the electromechanical paradigm that historically dominated the way in which industrial firms operated until the mid-1990s, with high-volume mass production of standardized products, and cumulative gains in productivity by means of economies of scale.[22]

Quadrants B and C represent the combinations pursued by firms in the second half of the 1990s, favouring the change of only one of the constituent factors: the replacement of the technological paradigm with the electro-electronics paradigm (in the case of Western companies), and the organizational paradigm of lean organization with the Taylor-Fordist (in the case of Japanese companies). In the first case, the driving factor was the replacement of employment with technological capital in the unmanned factory perspective; in the second case, it was the variability of products and their quality in the customer centrality perspective.

The past three decades have witnessed the significant efforts of many Japanese companies to incorporate into their business processes - even if frugally - ERP/ICT technologies, thus moving from quadrant C to quadrant D; several Western companies (particularly in the U.S.) moved differently, increasingly re-engineering the organization along processes and simultaneously adopting work practices consistent with the lean principles (thus moving from C to D).

Quarter D is the new winning combination (so-called Word-Class Manufacturing), capable of ensuring top performance by combining flexible technology and flexible internal organization, able to satisfy (efficiently and effectively) global markets, characterized by high volatility and substantial uncertainty. The nature of the new technologies allows involving the service sector for the first time in

[22] In this context, several variants should be considered and analyzed such as the German diversified quality production model and the Italian flexible specialization model: for these analyses see Appelbaum and Batt (1994).

history, traditionally regarded as 'residual' with respect to innovation dynamics and thus changing the WCM acronym into World-Class Management. [23]

<INSERT FIGURE 12.1 HERE>

A formalization of the possible combinations of technology and organization through the mathematical concepts of convexity and concavity for the study of optimality conditions requires assuming hypotheses that are hardly plausible, such as the infinite divisibility of choices and the possibility that a choice may be exercised on a single variable (from which emerges that the effect on performance of a marginal increase of the selected variables decreases to become negative). Not only the non-divisibility (e.g., of plants, but also of certain organizational practices) but also the economies of scale and learning are incompatible with the concavity of the objective function.

An analysis of the transitions between states may prove to be a useful tool, but the situations described in the previous sections are of a 'non-ergodic' nature, for example, path dependency (and therefore turning to non-ergodic Markov chains) while also having characteristics that are incompatible with the Markovian ‘memoryless’ property, since they relate to events that occur in the form of stochastic sequential processes (David, 2001); consider, for example, the information imperfections, the knowledge gap and problem-solving gap, the regulatory institutional regime and structural inertia put forward in our analysis. Consequently, we should empirically specify non-Markovian processes, specifically discrete-time stochastic processes, to give account of dynamic economic processes where history does not always matter in the same way. However, the quantity and quality of information needed to be able to undertake such an econometric test render it prohibitive for now.

For illustrative purposes, we limit ourselves here to using a graphic representation of the problem similar to that used by Roberts (2004, Chapter 2) based on the concept of 'locally best' positioning in a mountainous area that is formed by several ridges interspersed with plateaus (see Figure 2).

<INSERT FIGURE 12.2 HERE>

[23] The crucial importance of this technological 'complement' with respect to organization emerges from the fact that companies attempted to implement ERP technologies without first re-engineering the organization in the process perspective, met with modest, if not disappointing, results. Devadoss and Pan (2007) estimate that 60% of ERP implementations fail, certainly not due to the characteristics of the technologies adopted but rather - according to Peppard and Ward (2005) – due to issues related to process re-engineering. In the initial phase of change, disturbances and delays in production activities are considerable difficulties to overcome and productivity often temporarily drops; the time to implement an entire ERP system or the programmed costs tend in 90% of cases to be exceeded, and returns occur in the medium to long term (3 to 5 years): see Brynjolfsson et al. (2002), Bloom et al. (2012) and Huang et al. (2009).

The representation refers to the plurality of positions of companies as a reflection of their efficiency. Assuming, for simplicity, that TFP is the performance measure of interest, and that this is in some way a function of the different combinations of technology and organization, and that all these factors are heterogeneous due to their intrinsic characteristics, the topographic image is a series of optimal 'local' positions that are higher or lower than others, each of which reflects a certain 'consistency' of the various ingredients used. Simply put, in our case, optimality represents the most efficient combinations of 'local' positions with respect to technology and organization: each different combination gives rise to lower performance, and it is likely that combinations around the optimal local position - being less efficient - are transient in nature, and subject to small movements towards the most efficient local position. Local positions are the result of several variables, such as chances and choices, constraints, prohibitive adjustment costs in the combination and intensity of investments in the two factors, different degrees of coherence between the characteristics of the factors themselves (old and new technologies, old and new organizational practices), different degrees of connection between the complementary variables (tightly or loosely coupled). Therefore, it is as if the firm were in a state of lock-in, in a trapping region from which it can only exit with a radical and coordinated change of both factors, or with the intervention of external forces.

If we introduce a third element, time (and therefore the occurrence of improvements but also the rupture in the paradigms of the intrinsic characteristics of each of the factors that combine), we may observe a change in the entire topography. This occurs due to the different dynamics in the variables that determine the positions and where classic variables involved in major changes interact such as inertia, resistance, time and the difficulty of moving from a 'local' learning domain to another far away, and so forth. The firms themselves may thus eventually find different positions in the distribution, resulting in a completely different topographic profile.

Empirical evidence supporting the above-mentioned categories is abundant, even if the analyses and econometric estimates were undertaken without unravelling or specifying the qualitative scope of the stochastic sequential processes underlying the explained outcomes. To mention but a few:

- On complementarities among different technological devices, in other words, the company-wide integration of all computer systems, we refer to Sethi and Sethi (1990) and Kovács and Haidegger (1992) for CIM, and to Dery et al. (2006a), Aloini et al. (2007) and Shaul and Tauber (2013) for ERP;

- On complementarity within resource management practices as well as organizational design, see for example, Ichniowski, Shaw and Prennushi (1997), Black and Lynch (2004) and Boning et al. (2007) for the US; Patterson, West, Lawthom and Nickell (1997) and Guest et al. (2003) for the UK; Bauer (2003) and Zwick (2004) for Germany; Greenan and Guellec (1998), Janod and Saint-Martin (2004) on French data, Caroli and Van Reenen (2001) on both French and UK data; Cristini et al. (2003), Piva et al. (2005), Mazzanti et al. (2006), Colombo et al. (2007) and Leoni (2012) for Italy; Bloom and Van Reenen (2010) for several industrialized and non-industrialized countries, and Rizov and Croucher (2008) for European firms.
- On the simultaneous and sequential complementarity between technology and work organization see Greenan (1996a, 1996b), Hitt and Brynjolfsson (1997), Black and Lynch (2001), Bresnahan et al. (2002), Brynjolfsson et al. (2002, 2003), Colombo and Delmastro (2002), Bartel et al. (2007), Cristini et al. (2008), Bloom et al. (2012) and Battisti et al. (2014);
- On a sequential paths analysis along which work practices belonging to the organizational paradigm are adopted see Freeman et al. (2000) and Lynch (2007). It is very likely that similar paths of adoption for technological devices exist: unfortunately, to the best of our knowledge, no research paper has yet been published on this issue;
- On the Orlikowski effect, see Cainarca et al. (2005) and Dery et al. (2006b).

Leoni (2013) undertook a survey of part of the above-listed literature through a critical narrative review, arriving at a provisional positive conclusion indicating that each paradigm and above all each combination of technological and organizational paradigms - once affirmed as superior with respect to the predecessors - developed along not necessarily linear trajectories due to the effect of the different mechanisms operating within firms and the varying weights thereof, giving rise to divergent spiral paths of firm growth. A relevant tool to interpret these outcomes is the complementary theory on groups of activities formalized by Milgrom and Roberts (1990) into a non-differentiable, non-convex profit-maximization model of a monopolistic (or a monopolistically competitive) firm. The defining characteristic of a given group of complements is that if the levels of any subset of activities are increased, then the marginal return to increases in any or all of the remaining activities increases. For example, a number of flexibility aspects are represented in the model by way of including such variables as the number of product improvements per product per period, design cost per product improvement, setup costs on newly changed products, number of setups per period, and delivery time. Milgrom and Roberts use purely algebraic (lattice-theoretic) methods to argue that performance over time generates many of the observed patterns (or bundles of characteristics) that mark modern manufacturing.

However, we argue that a new organizational or technological performance practice or a new performance bundle of practices is the result not only of different ingredients but also of the different weights of each ingredient. Hence, the employer has two levers to pursue in the search for efficiency and performance: the ingredients and their intensity of application in potentially innumerable combinations. For example, if one considers the impact on performance of a bundle composed of three work practices, measured with respective coefficients (three main effects and four interactive effects), in the presence of continuous variables, the marginal return depends on the value of each work practice, namely, the intensity of the adoption, which is firm specific. It follows that one obtains different results when reducing or increasing the mean value of one or more practices, or else when enlarging (to four practices) or restricting (to two practices) the bundle.

This idea opens up a completely new perspective in the world of organizational and technological conceptualizations with respect to those relating to simple complementarity, but also with respect to substitution governed by relative prices, reaching a powerful techno-organizational configuration as a result of an 'internal chemistry of the firm' (Grandori and Furnari, 2008), and factors of a dynamic nature such as ‘social capabilities’ (Abramowitz, 1989), which primarily include learning and knowledge creation in the human-centred version of technology and organization. These are primary internal sources of innovation that are not easily transferable and require – to become powerful – appropriate workplace design, specific new work practices and organizational well-being (usually, good and trusting industrial relations), which research has recently empirical identified and documented as improving firm performance, worker competencies and innovations.

6. Some open empirical questions

A great problem with respect to firm performance and growth is the lack of understanding of the complementarity first within the technological and organizational paradigms and secondly among the two paradigms that must be in place at the firm level. It is not easy to answer the question on whether one combination is tangibly more efficient and more profitable than others, tested by robust and incontrovertible estimates, since researchers have to battle with a set of ambiguities, aporias and methodological doubts that still exist in empirical literature and which are worth reviewing briefly.

i) *Subjective versus objective measures*

The evaluation of organizational design, activated work practices and technology-in-use, as well as some performance measures (in the case of plants), originate from interviews with business managers or workplace supervisors and as such reflect subjective judgments that may conflict with objective evaluations.

There are essentially two reasons to use subjective measures: on the one hand, the economic character of the information collected through questionnaires, strictly combined with information on organizational design, work practices and technology-in-use; on the other, the impossibility of otherwise observing practices or performance relating to the single-site of a multi-sited firm: in many firms, work practices, organizational design and technology differ considerably across workplaces or sites, thus suggesting that the analysis of the elements under study should always be as homogenous as possible.

Both cases require facing the problem of a potential measurement error in the variables relating to performance. On this issue, it would however be useful to take into account the scepticism of mainstream economic theory mistrusting the subjectivist approach because of the absence of a set metrics, be it a quantitative scale or even any universal point of origin. Of particular importance in surveys is modulating questions with respect to not only the presence or the absence of a given element, but also the real observed behaviour of individuals, since performance does not concern firm policy towards investments in given elements, but what has actually been implemented and how and what workers do (Green, 2006: 10).

ii) Single rater versus multiple raters: is measurement error a significant issue?

The question of the potential measurement error in subjective evaluations is coupled with that of the reliability of a single respondent to be able to assess – as the investigation unit increases – the actual practices in place in the various departments and offices. The alternative would be the use of several evaluators (raters), one for each organizational sub-unit. However, in microeconometrics, reliability is also undermined by other sources, such as the incorrect coding of correct responses and the use of a correctly measured variable as a proxy for another theoretically valid but unobserved variable. All these doubts disappear with aggregate data because it is usually assumed that aggregation results in counterbalancing the measurement errors of the opposite sign, while measurement errors persist in individual-level data. If this were true, then the independent variables that enter the relation between work organization, technology and performance are characterized by random errors, preventing the identification of the parameters of interest.

Under these conditions, the parameters of a given relation estimated with the OLS method are distorted (Cameron and Trivedi, 2005: chapter 26) and thus requires making use of the IV method (Instrumental Variables), with the difficult problem of finding the appropriate instruments, namely, passing all the validity tests of the instruments themselves and the orthogonality of the explanatory variables. In the case of failure – given that the coefficients are consequently not identifiable – the researcher should limit the target testing hypothesis first to whether the effect size of the coefficients of interest are different from zero, and secondly identify the consistent bounds by reverse regressions, searching for lower and upper bounds on the values of the true slope coefficients in order to provide the magnitude of the effect.

However, researchers usually simply bypass the argument by assuming (implicitly or explicitly) that as the investigated unit size increases, the process of filling out the questionnaire involves more than one respondent. Survey designers should be encouraged to improve their efforts in this direction, explicitly requesting that each section of the questionnaire be filled out – under the supervision of a senior manager – by key informants and thus pursuing, *ex-ante*, the greater precision and objectivity of the data gathered.

iii) The question of minimum firm size

Assuming a link between bundles of techno-organizational ingredients and improved economic performance, one can speculate whether this also applies to small firms, usually left out of the sample survey based on the argument that organization in small firms takes on very informal connotations and as such is difficult to identify and quantify. Should this be the case, one could argue that firm size is therefore a 'contingent' factor (a typical argument of 'contingency theories'). Conversely, one could counter argue that the effectiveness of a series of bundles could depend on the fact that 'other' managerial practices must be active, which in small organizations may not be implementable. If so, then the discourse should not be so much about contingent factors, but about the impossibility of extending the bundles 'practiced'.

iv) Different characterizations of the constructs underlying survey questionnaires

One aspect to be carefully considered in using survey databases is the different constructs that underlie questionnaires designed to identify organizational unit policies on organizational design, technology and human resources with respect to questionnaires aimed at identifying what actually happens (in practice) in a given organizational unit. This may be interpreted as a semantic question but it is not. The first characterization tends to depict the project of change, which may only be partially implemented; this could be relevant for studies on adoptions of new practices, where it would be very useful to identify the degree of implementation of the project and any resistance to change. The second characterization has the advantage of being appropriate for the techno-organizational and performance relation, since it tends to measure the real behaviours, organizational traits and technology-in-practice that most directly affect outcomes. Moreover, this is likely to incorporate less distortion in relation to the respondent's perception since the questions tend towards measuring the phenomena actually practiced.

v) Bundling single practices to represent a multi-dimensional concept

It is not uncommon in numerous surveys to see single respondents being asked to provide a single numerical rating that describes a given practice or a given technological device used. It is unlikely that broad and profound concepts cannot be reliably measured with a single question (or single item), asking whether or not a given practice is implemented, or a given technological tool is used, while a sequence of specific questions is more suitable to portray several dimensions of a given practice. Naturally, the end user of a survey is constrained by the survey designer's choices upstream of the process.

As an example, some questionnaires ask respondents whether or not there is a 'joint consultative committee' concerned with consultation in their organizational unit. Other questionnaires go further, asking, for example, how often meetings are held (indicating a rising number, for a given period), what proportion of meetings were attended by senior management (again, indicating a rising percentage, sometimes in size-bands) and what issues had been discussed (again, listing a varying number of issues). Unfortunately, however, the metrics used change from questionnaire to questionnaire, with the risk of providing a different empirical picture even if apparently under the same or similar construct. There are mainly two ways of combining individual practices to represent a multi-dimensional phenomenon. The first is an additive index that summarizes several items generally expressed in terms of dichotomy dummies: the outcome forms a scalar variable that depicts a given single practice for each single organizational unit; alternatively, a factor analysis can also be used. The latter (very popular) may consist of exploratory or confirmatory factor analyses, forming orthogonal and one-dimensional factors. This method is mainly used to transform single practices into bundle of practices. A bundle refers to a systematic interrelationship (that is, mutually reinforcing the effects of multiple elements) among the variables under investigation, and to the extent to which it is confirmed by factor analysis, is equivalent to 'internal' complementarity among the various ingredients (or variables) that form the bundle.

vi) Adoption of changes: altogether simultaneously or a sequence of adoptions?

Have new technological and/or organizational ingredients that form a bundle, identified at the time of a survey, been adopted by the firm simultaneously, or does each simply constitute a step along a sequential process of adoption? In the latter case, is the sequential process the same for all the adopting firms or is there a specific sequential process for each form? These are still open and relevant questions. On the one hand, the existence of different initial conditions, or different constraints or even the different worldviews of managers, could induce each firm to start the process of change by adopting different ingredients with different intensity with respect to other firms, so that the bundles identified at a point in time (precisely, at the time of the survey) reflect the heterogeneity of adoptions among firms in terms of both number and intensity of ingredients adopted. On the other hand, one might imagine that the path along which adoption starts and is completed is unique, but each firm, for a number of reasons starts the adoption process at different historical times. The cross-sectional picture that emerges would be observationally equivalent to the previous picture but would in fact reflect a different adoption process. Unfortunately, the temporal dimension of studies on workplace changes typically suffer from poor data since no information on the time of adoption of each ingredient is usually available.

All this complicates the framework of analysis: let us imagine that firm productivity growth requires not only investments in CIM/ERP/ICT but also investments in complementary organizational changes and that these changes not only follow sequential-type adoption, but have also time-lagged returns. It follows that the comparison between two firms, at a given point in time, may reveal that – for the same investment in new technological artefacts – a firm shows an acceleration of its TFP and another a deceleration due to the simple fact that the former could have made investments in complementary organizational capital in some previous period, or because the latter has violated the sequential adoption of new practices, or its organizational learning mechanisms are less efficient and effective.

vii) The temporal and staggered lags of effects

We expect that investments in new general-purpose technology (CIM/ERP/ICT) are a relatively low cost and an easy change to make whereas other changes, specifically those relating to organizational changes and new work practices, are both costlier and slower to activate.[24] A further argument holds that some time needs to elapse for new workplace systems to show their entire effect on productivity: workers need to acquire the necessary competencies, become familiar with the new work methods, get used to the new role, responsibilities and decision-making before performing in the new organizational environment.[25] Thus, it is possible that complementarity between contemporaneous ICT and organizational changes does not emerge or may even be negative in some cases, signalling, for example, that the process of adjustment has not yet be completed or that the adjustment costs outweigh the gains. Moreover, adjustment costs may depend on the extent of reorganization: a situation where the workplace is undergoing extensive restructuring (many dimensions are being changed) differs considerably from a situation where only a few changes are introduced, although the sign of the difference is not clear. For example, one expects that where many changes are being undertaken, potential complementarity gains are higher, although workers in this case may need more time to learn and adapt to the new environment or may even resist the change and thereby reduce the benefits of restructuring.

7. Final considerations

In the introduction of this chapter, we highlighted that heterogeneity in terms of efficiency, as measured by total factor productivity, is a statistically significant and widespread phenomenon. The traditional econometric studies we recalled previously, while offering a significant contribution, are unable to provide an exhaustive explanation of the phenomenon. The main reasons are the focus on routines and capabilities on one side, and the institutions and governance structures on the other. Very little attention has instead been paid to the intrinsic characteristics of technology and organization, and the conditions necessary to efficiently couple them, such as, for example:

a) the fact that these factors materialize through a set of constitutive principles that are paradigmatic in nature;
b) that the organizational and technological paradigms, which were historically substantiated in the second half of the 1800’s and early 1900’s (respectively, the technological electro-

[24] With reference to American manufacturing firms, Brynjolfsson et al. (2002) estimate that the ratio between hardware and software costs and total investment costs (including those relating to consultancy, manager time, reorganization and training of the labour force) is equal to 1 in 9.
[25] See for example the analysis in Robey et al (2002).

mechanical paradigm and the Taylor-Fordist organizational paradigm), were reciprocally refined over time giving rise to a complementarity relation;

c) that these paradigms met with - in part because of internal pressures, in part for the market reasons previously analyzed - a profound structural crises following the emergence of a new set of constitutive principles, which from time to time gave rise to a new paradigm;

d) that the structural breaks occurred in an asynchronized way, inducing non-strictly homogeneous combinations in technological-organizational factors, rendering the returns from innovative investments in the context of the respective factors less appealing than simplistic promises; in other words, as though firms found themselves - as a result of selective, self-enforcing and reinforcing processes - in a lock-in situation, in a trapping region;

e) that less appealing returns are very often due to the fact that the innovations and the related investments are conceived as artefacts placed within firms, rather than being understood as not only embedded, but also to a large extent as co-constructed within firms, as a consequence of personal and collective ways of using new technological tools and as a consequence of internal capabilities built through stochastic sequential processes.

The hope is that in the future, research will take into account the ambiguities, aporias and methodological doubts that still exist in the above-cited empirical literature, and will be able to specify stochastic sequential processes through which the techno-organizational stratification that reflects in performance is consolidated.

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FIG. 12.1 - The combination of organizational and technological paradigms

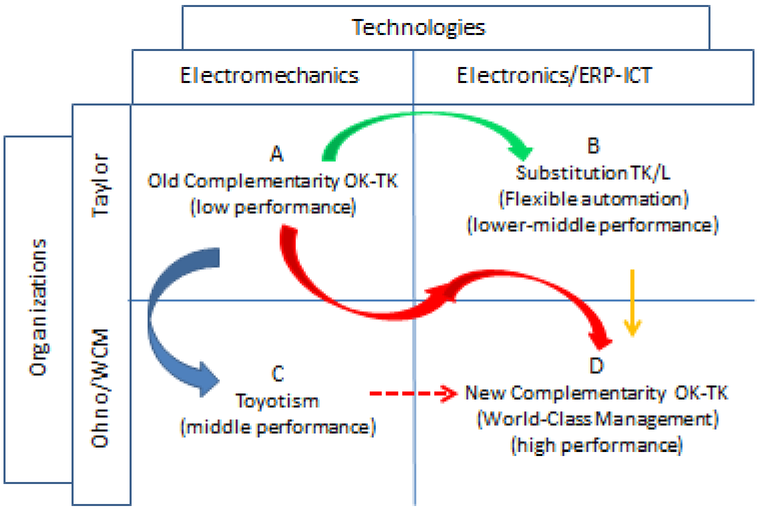

FIG. 12.2 – Non-concavity and multiplicity of positioning of ‘local’ congruence