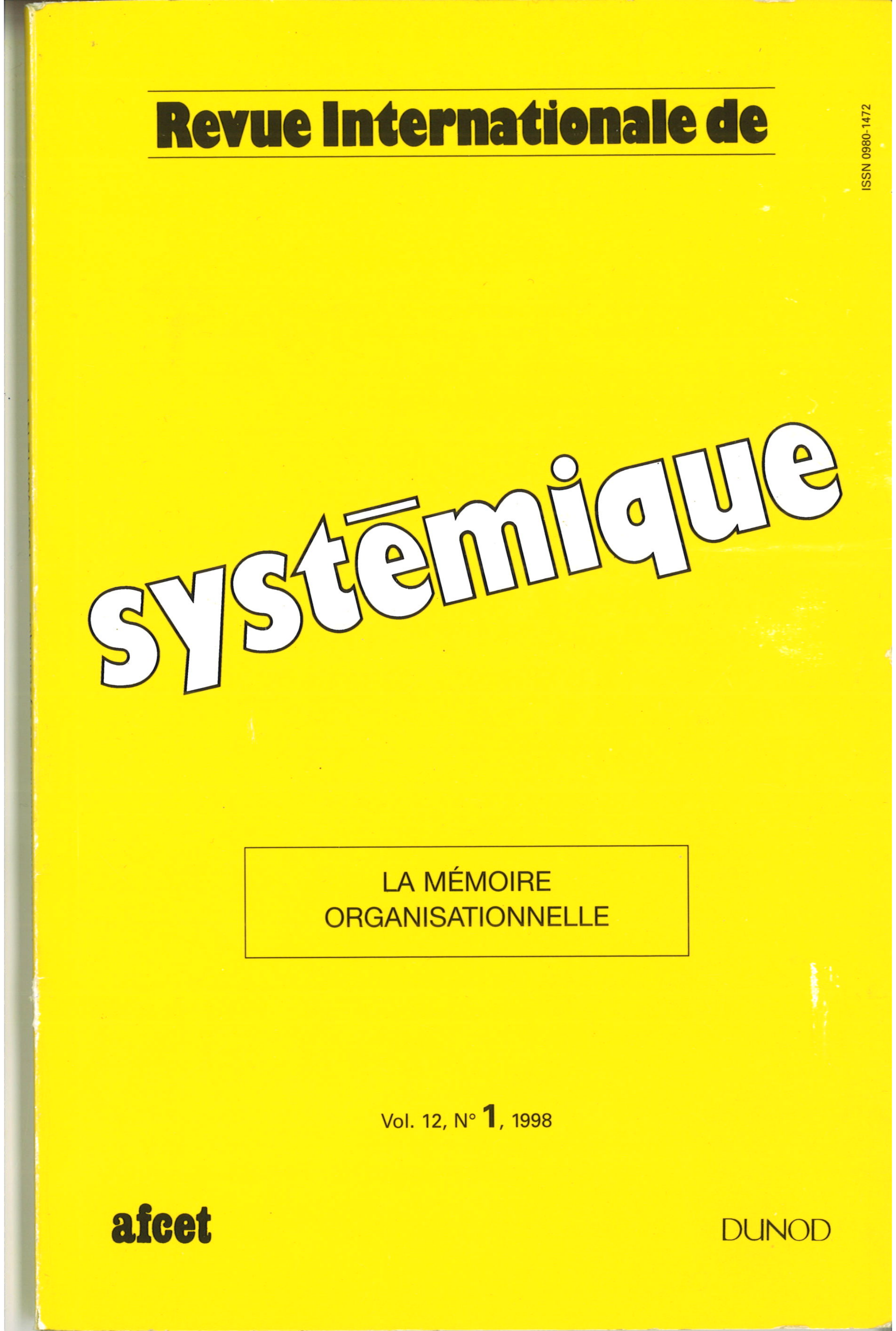

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Technology, codification of knowledge and firm competences

Magherita Balconi

focus their attention on the proper way to use it (e.g. sequence of actions to perform, buttons to press, input to give).

Looking at individual's behavior it is natural to emphasize the individual dimension of expertise; nevertheless, individuals skills are often a result of social interactions. Technicians involved in the maintenance of the air-conditioning system behave according to a reliable and standardized routine which is a social product. Cognitive artifacts work as means that reinforce the routinization, define some accepted practices and constrain team experience on common bases.

References

R. AMIT, P.H.J. SCHOEMAKER, Strategic Assets and Organizational Rent, *Strategic Management Journal, 14*, 33-46, 1993.

J. BARNEY, Firm Resources and Sustained Competitive Advantage, *Journal of Management, 1*, 99-120, 1991.

E. HUTCHINS, *Cognition in the Wild*, The MIT Press, 1995.

B. KOGUT, U. ZANDER, Knowledge of the Firm, Combinative Capabilities, and the Replication of Technology, *Organization Science*, *3*, 383-397, 1992.

B. KOGUT, U. ZANDER, What Firms Do? Coordination, Identity, and Learning, *Organization Science*, *7, 5*, 502, 518, 1996.

J. LAVE, E. WENGER, *Situated Learning,* Cambridge University Press, 1991.

R. R. NELSON, S.G. WINTER, *An Evolutionary Theory of Economic Change*, Belknap Harvard Press, 1982.

D.A. NORMAN, Cognitive artifacts, in J.M. Carroll, ed., *Designing interaction: Psychology at the human-computer interface,* 17-38, Cambridge University Press, 1991.

D.A. NORMAN, *Things that make us smart*, Addison Wesley, 1993.

E.T. PENROSE, *The Theory of the Growth of the Firm*, Wiley, 1959.

J.C. SPENDER, Making Knowledge the Basis of a Dynamic Theory of the Firm, *Strategic Management Journal, 17*, 45-62, 1996.

D. TEECE, Economic Analysis and Strategic Management, *California Management Review, 26, 3*, 87-110, 1984.

D. TEECE, G. PISANO, A. SHUEN, Dynamic Capabilities and Strategic Management, *Strategic Management Journal*, 17, 1996.

L.S. VYGOTSKIJ, *Istorija razvitija vyssick psishiskiceskich funkcij*, Rvstralspo, 1931.

S.G. WINTER, Knowledge and competence a strategic assets, in D. Teece, ed., *The Competitive Challenge, Strategies for Industrial Innovation and Renewal,* Ballinger, 1987.

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TECHNOLOGY, CODIFICATION OF KNOWLEDGE AND FIRM COMPETENCES

Margherita BALCONI [1]

Résumé

A partir de l'expérience de la codification dans la métallurgie, cet article examine la nature du savoir-faire technologique en vue d'une conceptualisation. Après avoir examiné les différentes acceptions du terme « tacite » dans la littérature économique, il présente une taxinomie des approches utilisées pour produire de nouvelles connaissances. Elle permet de comprendre la différence entre science et technologie. Les déterminants de la vitesse du mouvement de codification des connaissances technologiques et organisationnelle sont discutés et l'intérêt des compétences tacites, complémentaires des compétences s'appuyant sur des connaissances codifiées, est mis en évidence.

Abstract

Drawing upon the historical experience of the codification of steel technologies, this paper discusses the nature of technological know-how in general terms. After examining the meanings of tacitness in the economic literature, it presents a taxonomy of the approaches used in generating new knowledge, useful to understand the diverse nature of science and technology. The determinants of the pace of codification of technological and organisational knowledge are discussed and the roles both of formalized training and of tacit competences complementary to a codified knowledge base are highlighted.

INTRODUCTION

The conceptualizations and propositions advanced in this paper have been largely inspired by the recent transformations of the technological base of the steel industry, which occured under the impact of the progress achieved in electronics, the increasing provision of instruments of measurement and the broad application of computerized automation. On the one hand a few revolutionary new technologies have appeared (like thin slab or strip casting, conti-

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nuous annealing, new galvanizing methods), which could not even be conceived without the advances in instrumentation, electronics and automation, and on the other hand the operation mode of traditional ones has been transformed through the application of computerized automation. On the whole, there has been an almost complete –or at least very far reaching– elimination of the role directly played by human action and skilled evaluation in the routine production process, and its substitution by instrument measurement and automatic equipment operation managed by software. Modern technology implies doing things infinetely more powerfully than human abilities, strength, rapidity and memory would enable. The transfer of production skills from man to software has been allowed by codification of production knowledge on a staggering scale.

During the Twentieth century, after the introduction of the technologies characterizing the Second Industrial Revolution, steel production and steel semi-finished products fabrication continued to rely heavily on human tacit skills. It was not until the Seventies that technical abilities started to be "shifted away" from workers (Tomiura, 1996) and embodied in the software developed to operate computerized equipment. For example, the skills in estimating the carbon content of molten steel by watching the sparks emitted from the liquid metal, or the temperature of molten steel from the colour of flames, being no longer required, have disappeared. Production workers have become pulpitists, namely controllers who must incessantly check on a range of computer displays (mounted on pulpits located in special sound-proof, pressurized rooms) that process parameters are kept at the right values.

A fundamental trajectory of innovation has been the elimination of interruptions in the production cycle and its transformation into a continuous in-line process. This has led to higher complexity and sophistication of the new compact plants, along with the increasing automation and reliance on software to integrate the various steps, traditionally disjointed.

The problem raised in this paper is whether the kind of historical evolution very briefly sketched above –whose degree of generality among the various sectors should be assessed through a broad investigation– can be interpreted through the conceptual tools developed by economic theory. In my opinion, the conceptualization of technology requires a critical reappraisal; the role of tacitness and of humans skills has to be restated and the relationship between science and technology needs a better understanding.

This paper is organized in the following way. In section 2 the various notions of tacitness emerging from the economic literature are distinguished and redefined, in order to avoid misunderstandings in the following discussion. Section 3 presents a conceptualization of technology that can account for difficult transferability, without relying on the purported tacitness of technology itself. Section 4 illustrates some particular features of technological knowledge and of its generation that distinguish it from scientific knowledge; the importance of in-house technological capability is also emphasized. Section 5 sheds light on the need for firms to invest in training the workforce, since codified know-how is no longer learned by example from the master, and at a higher level to form experienced problem-solvers (both specialists and knowledge integrators). Section 6 discusses the economic forces determining the extent of codification of technological knowledge, while in section 7 some features of the codification of organizational knowledge are briefly introduced. Some conclusions are drawn in section 8.

MEANINGS OF TACITNESS

The notion of tacitness (synthesised by Polanyi in the phrase "We know more than we can tell") has been imported into the economic literature by Nelson and Winter (1982) and has become a *locus classicus* in the evolutionary thought [1], which has considered tacitness a fundamental property of technology. Recently, a debate has taken place about the extent of codification and the importance of tacit knowledge in contemporary economies (Foray and Lundvall 1996, among others).

The idea developed in this paper is that the concept of tacitness emerging from the new literature may be the starting point for understanding why technology transfer is difficult (though in many industries less than in the past), whilst accepting that technological know-how is well defined and fully codified.

I shall then proceed to distinguish the various meanings of tacitness, and the shift which has occured in firms' knowledge bases from one characterized by tacitness in a strong sense to one characterized by codification supported by tacit competences (in my terminology, tacitness complementary to codification). It thus becomes possible to grasp the transformation of the knowledge requirements of firms and the new forms of organizational memory.

First, the distinction has to be drawn between three main conceptualizations of tacitness:

A) Tacitness in a strong sense.

It refers to technical skills whose acquisition requires the imitation of a master by the apprentice and a long-lasting practical application and experience (Rosenberg 1976, p.155). They cannot be transferred simply by symbolic communication, as the rules followed in the skilled performance are not precisely known and articulable. These skills include: i) the content of those parts of technological knowledge which, as yet uncodified, are person-embodied. Why given actions yield certain results is unknown, or how certain phenomena are evaluated is not explainable; it is about doing things (Cohendet *et al.,* 1993) and/or measuring phenomena without the proper scientific instruments. The content of these tacit skills might not be codifiable at a given point in time, but become codifiable later at certain costs, due to advances in general knowledge and to the availability of instruments of measurement and computation; ii) those manual tasks that require dexterity, like typewriting or sewing. A number of these manual tasks has been eliminated *tout court*: sometimes they have been substituted by automatic execution performed by machinery, while at other times automation has brought the introduction of entirely new ways of doing things.

B) Tacitness complementary to a codified knowledge base.

It implies the interiorization of well defined and articulated (or at least easily definable and articulable) rules and knowledge, and the ability to apply them unconsciously or intuitively. I define intuition as the skill in rapidly recognizing in simple cues patterns that have been recorded and become familiar through study and past experience (March and Simon, 1993) and in envisaging new procedures and directions of development that lead to the creative (and codified) solution of problems as yet unsolved. Such intellectual skills are acquired through both theoretical study and experience. Though the ability to retrieve stored knowledge and to apply it in new directions (e.g. in proving a new theorem or in designing a new kind of car etc.) is not reducible, in itself, to well-defined algorithms or well-defined rules of search (Dosi, 1995), however such capability draws upon codified knowledge and generates new codified knowledge in the form of scientific discovery and technological innovation. It is a tacit, intellectual competence which is complementary to a codified knowledge content.

C) Purported tacitness.

It refers to the situation whereby a given piece of knowledge is not disclosed, though codifiable, where "codified" means "reduced and converted into messages that can be easily communicated among agents". Thus, codification is the step which logically precedes disclosure, and one might well be able to codify or to diclose the knowledge possessed, but prefers not to. In this sense, also scientific knowledge might be tacit, whereas according to meaning A, the attribute "scientific" is inconsistent with tacitness, by definition [2]. At the extreme, the term tacit is used to mean "secret". "The extent to which knowledge generated in various fields gets codified for packaging as information, rather than retained in tacit form, will reflect the reward structures within which researchers are working, as well as the costs of codification" (Dasgupta and David, 1994, p. 494) [3].

Finally, at the level of the organization, the term tacitness is used to characterize recurring action patterns or routines which are not deliberative choices. (Cohen *et al.*, 1995). However, the fact that routines are uncounsciously and automatically applied by the agents does not mean that the routines themselves are tacit. For example, the codification of routines and procedures accomplished by firms in order to obtain quality assurance by the standard ISO 9000, does not mean that these routines are ususally applied by deliberative choices.

THE CONCEPTUALIZATION OF TECHNOLOGY

Having shed some light on the meanings of tacitness, I can now easily discuss the two contrasting views developed by economic theory as to what technology is. On the one hand the neocassical tradition (Arrow, 1962) has depicted technology as a set of well-defined blueprints and considered it easily transferable and generally applicable information, whereas, on the other hand, the evolutionary school has stressed the attributes of cumulativeness, specificity and tacitness, and the importance of firm in-house technological capabilities "in order to recognize, evaluate, negotiate, and finally adapt the technology potentially available from others" (Dosi, 1988). The tacit aspect is, following this view, related both to the purportedly "poorly defined" know-how and to the problem-solving activities involved in the use of technology.

In this section it will be argued that neither conceptualization of technology is fully acceptable, even though the main conclusion of the evolutionary approach, pointing to the importance of in-house capabilities, is correct. Interestingly, this same conclusion will be drawn abstaining from considering tacitness an inherent characteristic of know-how.

The starting point is that the empirical observation of the changes yielded by computerization (and briefly illustrated in the introduction) invalidates the statement of tacitness as an inherent characteristic of technology as far as know-how is concerned. Overwhelmingly, know-how has ceased to be person-embodied, is codifiable and has been mostly codified, and is transmissible as information. However, why this emerging stylized fact (that will increasingly shape the future) does not eliminate difficult transferability can be accounted for considering: i) the specific nature of technological information and, relatedly, the conditions underlying its understanding and mastery; ii) the problems entailed in negotiating its transfer, given the asymmetric position of the transferor and the transferee; iii) the difficulties created by its use in a context different from that of its generation; iv) the conditions for its adaptation and development. In this view, tacitness re-emerges as a characteristic of the human capabilities needed to use and to generate codified technology (hence complementary to the contemporary mostly codified technological knowledge base). The reliance on tacit competences is a sufficient condition to account for the empirical evidence of difficult transferability of technology.

TECHNOLOGICAL INFORMATION AND KNOWLEDGE

That information has to be distinguished from knowledge has been repeatedly stated by evolutionary economists. Here the difference between the two concepts is illustrated with specific reference to the technological domain [4].

I define technological information as a "knowledge item", or "a piece of knowledge" reduced into a communicable form, and removed from its wider context, but implying it. A knowledge item is meaningful only within its wider knowledge context, which entails some specific language (code), some world view stating a few fundamental principles and assumptions, some theory expressing the basic insights, and some specific methods that enable one to perform operations. In this definition general knowledge is person-disembodied, codified, corresponding to what is publicly known about a certain domain at a given point in time. Since the communication of information clearly does not entail the transmission of the general knowledge involved, the possession of this general knowledge on the part of the information recipient is a precondition for understanding the information itself (i.e. what certain blueprints mean), and learning to use the new technology. That in order to achieve any knowledge improvement (which is a step-wise process) through the learning process activated by new information, the latter must be compatible to the learner's prior knowledge (or background knowledge), is well known in artificial intelligence (see Michalski, 1993). Background knowledge is precisely what the learner (i.e. the firm adopting the new technology) already knows (i.e. the set of the various parts of general bodies of knowledge that are possessed). In the technological domain, a firm's prior knowledge is mainly person-embodied [5]. Only in the sense of being stored in the brain of some knowledgeable people, and automatically retrieved in order to activate the understanding of the new information and learning, can background knowledge be considered tacit, its content being instead mostly codified and learned through formal training and experience.

Concisely putting what argued above, the following proposition is asserted: the understanding and absorption of new technological information requires compatibility between the general knowledge contextual to it and the background (tacit) knowledge possessed by the recipient. From this angle, codified and tacit knowledge are complements and not substitutes (Foray and Cowan, 1997).

However, in a more general perspective, one has to recognize that a meaningful part of the contemporary codified knowledge base is a substitute for the older tacit technological knowledge base, even though a presumably even larger part of the new knowledge generated by scientific discovery is a direct expansion of the codified knowledge base.

TECHNOLOGY AS INCOMPLETE INFORMATION

In the transfer of information concerning a new technology and its related know-how, one crucial point to consider is the "amount" of information transmitted. Since, as will be argued, what is transmitted is incomplete information, attention has to be drawn to the extent of such incompleteness.

This aspect is to be addressed in a Williamsonian framework, stressing the importance of opportunism in transactions between self-seeking agents aiming at maximizing the profits obtainable in the exchange.

The transferor, after his technology has been chosen among a few similar ones, acquires a position of power over the transferee. This position can be easily exploited if, after signing the transfer contract and during the adoption stage, the buyer discovers that further information is required in order to realize the expected performance. The new transfer(s) of information might then be monopolistically priced by the supplier. Obviously, the technology supplier might be a monopolist from the outset, but whereas before signing any transfer contract the buyer is free to choose whether or not to make the deal, *ex-post* he might be compelled to accept a further very unfavorable offer, if he considers it necessary to implement the adopted technology.

This *ex-post* advantage is an incentive to the supplier to convey scanty and incomplete information in the principal negotiation, in order to create the need for a supplementary highly priced new transfer. Even if such an opportunistic hold-back is not resorted to, usually only the basic know-how is transmitted, since no free lunch is offered by the seller and also the buyer is intended to spend as little as possible and to perform himself the required developments later.

Thus, the buyer capability to understand and to express correctly at the outset his/her needs of information (what to ask for) is extremely important, in order to avoid a risky dependance situation.

TECHNOLOGY AS LOCAL AND SPECIFIC INFORMATION

A costly illusion often held by technology buyers is that what has been bought is applicable as such in the new local context, with no significant modifications. But a technology is a device to transform inputs into outputs following some prescriptions, and a situation cannot be envisaged whereby two firms, usually located in different areas or countries, use exactly the same material inputs to produce exactly the same range of outputs of the same quality, since each one has to meet at least slightly differing user needs. In addition, the cultural and educational level of the workforce usually varies among firms, and it is normally higher at technology suppliers than at technology buyers.

The problem arises since any technology embodies in its generation some unaware assumptions about the conditions of its use, and the effectiveness of the prescriptions sold as know-how depends on whether such underlying assumptions hold. Which among them holds is unknown by the parties, who are also unaware of their existence and importance. Moreover, the supplier has little interest in highlighting this problem, since if things do not work for the transferee, more information might be requested and some problem solving elicited, on which further profit can be extracted (see above).

The more sophisticated the plant, the more important is the cultural and educational level of the workforce charged with its operation. An inadequate level might be an unexpected and unsurmountable obstacle to the realization of the same level of efficiency or product quality of the transferor.

SOME FUNDAMENTAL FEATURES OF TECHNOLOGICAL KNOWLEDGE AND ITS GENERATION

The discussion above suggests that to absorb information from external sources a firm has to generate new knowledge in-house (Cohen and Levinthal, 1990). In fact it is necessary to carry out some adaptation of the "imported" technology to local conditions (or even some debugging and design improvement) and to develop know-how (creating new operating procedures), in order to satisfy user needs, and in a longer time span, to improve the quality of products and broaden their range. The building of an in-house capability of "new knowledge generation" and, more generally, of problem-solving is thus a primary task of firms, at least in the industrialized countries, where competitiveness cannot be grounded on low input costs, but the cultural level and education of the labor force permit specialization in the high quality end of the market.

Before addressing this question, I shall briefly discuss some general features of knowledge generation in the technological field that bear significant implications on the type of problem-solving capabilities required by firms and throw some light on the difference between science and technology.

With the exception of directly science-based technologies (like biotechnologies), a great number of technologies achieve their production goal even though many of the physical transformations they perform are not scientifically grounded, the phenomena taking place not being fully understood. Hence, in the searching activity pursued to create a new technology, the use of computers to simulate processes is limited, and much trial and error experimentation has to be conducted, even though simulations play a crucial role in the initial stage, enabling the screening of the various designs and the choice of which one to develop on a full scale (Pisano, 1996). However, the transfer of the results obtained in the laboratory to full scale objects (or plants), working in real conditions, remains highly uncertain, time-consuming and costly.

In the course of the full scale development of a new technology, even if problems are faced in a formalized way, by building models, quite frequently the reasons why a given solution works, rather than others which are theoretically admissible, remain unknown. Thus the solution working in practice is adopted, the definite proof (i.e. the underlying physical law) of its correctness not having been found. The puzzle brought to light might then represent an interesting subject of scientific investigation and stimulate the involvement of the scientific community [6].

In the following table a synthetic taxonomy is presented which distinguishes different types of approach used in generating new technological knowledge on the basis of two criteria: a) whether or not they rest on an articulated and even formalized solution to the production problems met, and b) whether, in addition, the reasons why a given solution works are understood. In this latter case generalizations are allowed, and it also becomes possible to understand how a different plant could function.

Types of approach used in generating new technological knowledge

Types of problem solution	Tacit	Empirical	Scientific[7]
Formalized, articulated	no	yes	yes
With understanding of the causes	no	no	yes

At present, I suggest that (like in the steel industry) most of the knowledge embodied in new technologies is of the empirical kind[8].

Another fundamental feature of technological knowledge (contrary to scientific knowledge), is its intrinsic multidisciplinarity. Any full scale plant realization requires, besides a specific domain's knowledge content (be it metallurgy, chemistry or other), notions of automation, electronics, electricity, mechanics and engineering. Hence an integrative capability, which is person-embodied, is badly needed to carry out innovation.

The ability to conduct an articulated problem-solving activity, oriented to understanding the causes of the events, and supported by the integration of specialistic knowledges, is needed not only by the innovator, but also by the "adopter/adaptor" of an innovative technology. Clearly, the innovator will be endowed whith broader resources specialized in the task of searching (commanding also an ample competence in engineering, which may be lacking at the adopter), but the presence of similar capabilities, even if on a smaller scale, is necessary to the adopter as well.

Both with the innovator and with the adopter engaged in the adaptation and development task, integrators usually play a prominent role as top technologists, and, since their judgement is required to make the crucial technological choices, the top managerial position in the plant (or in the firm itself) is commonly held by one of the most talented and experienced among them. Such integrative skills are tacit, and they should be supplemented by the relational skill needed to coordinate the various specialists (in automation, electronics, electricity, mechanics), who cooperate and interact in the problem-solving activity.

With regard to the adopter, the problem-solving capability is distributed in the firm at various levels. One finds a sort of hierarchy of problem solvers, with at the top the integrators, then the specialists who may be located in various functional departments (R&D, maintenance, quality, technical office), and at the bottom production operators.

Unexpected breakdowns and accidents require the assistance of skilled maintenance people, specialized in the various fields, able to understand such unrecurring events and to find out the way to address them. In the most difficult cases they need to be coordinated by some integrator. Recording the history of breakdowns and accidents is important, since it provides the basic information for attempting to prevent them and to improve equipment reliability, by carrying out minor modifications. Team work coordinated by integrators is then called for again.

Finally, the role of pulpitists is not limited to checking that production flows inside the "black pipe" following the codified prescriptions applied by software. Indeed, at in-line processes some decentralization of responsibilities is inevitable, since many decisions must be taken immediately on site. Pulpitists must then possess the ability to judge the consequences of their actions. This amounts to saying that they must understand the meaning of the parameters under control. For example: What happens if the temperature goes beyond normal levels? They must be able to evaluate the seriousness of such an event and of many others, in order to decide knowledgeably how to act. On their ability depends the smoothness of the production process and to a certain extent even of the quality of the product.

BUILDING TECHNOLOGICAL AND PRODUCTION CAPABILITIES (HUMAN CAPITAL CREATION)

Bell and Pavitt (1993) draw a useful distinction between the stocks of resources incorporated in production capacity and in technological capabilities. The former are the resources used to produce industrial goods routinely, at given levels of efficiency (equipment, labour skills, operating and managerial know-how, product and input specifications), while technological capabilities consist of the resources needed to generate and manage technical change, including skills, knowledge, experience and external linkages.

In their opinion, given the widening gap emerging between technology-using and increasingly complex and specialized technology-changing skills, the latter cannot be acquired any more by experience in the former, and explicit investment in accumulating technological capabilities has become necessary. "The learning process by which those resources are accumulated are also complex and specialized. In particular, although formal education and training in institutions outside industry provide essential bases of skill, this has to be augmented by learning within firms" (p. 201).

However, the evidence of firms making use of complex modern technologies suggests that Bell and Pavitt's distinction is a little too sharp. The need to continuously improve efficiency, to learn new operating procedures, to address unrecurring events implies that problem-solving capability and a basic understanding of the transformations taking place must be possessed even by production workers. As a consequence, firms have to undertake deliberate investment not only to build change-generating skills, but also the skills necessary to operate the plants, by training operators with specific intra-firm programs (including a considerable number of theoretical lessons)[9].

The same evidence also contradicts Polanyi's (Polanyi, 1958, p.53; Lundvall, 1996, p.124) view that know-how is learned "only by example from master to apprentice" (which instead was true in the Fifties, when Polanyi wrote), but in the most traditional sectors or in the case of the exercise of some particular function which is still too costly to codify. The way of learning production skills "by watching the master and emulating his efforts in the presence of his example", depended on the underlying premise that "the rules of the art" were based upon tacit knowledge (*strictu sensu*). In fact they were "unconsciously picked up" by the apprentice "including those which are not explicitly known to the master himself".

The change in the way of transmitting production skills is strictly connected to the change in the nature of production knowledge, namely its codification and increasing level of complexity, whereby "the rules of the art" (and the word "art" should be dropped) have been transformed into codified and routinized operating procedures. Secondly, with complex technologies operator skills need to include also a certain level of knowing-why (Lundvall and Johnson, 1994), since to take the decisions for which they are responsible rationally, operators must be able to evaluate their consequences, which can be very far-reaching and costly[10].

In this context, training has the function of transmitting the knowledge and capabilities needed to operate a plant, not only by illustrating the operation procedures to be employed, but also by explaining the theoretical notions underlying them. In other words, the aim of training is to transmit know-how by teaching know-why (the explanations of the causes of the physical transformations carried out) and know-what (codified operation practices).

For example, in the training courses organized by the Italian Arvedi group, a quality tube producer and radical innovator in the field of thin slab casting, questions are addressed such as: "When you tighten a certain metal ring around the tube, why does it get rounder?" The effects of various stresses given to a strip are explained, as well as those of various combinations of stresses. In the past, a newly hired worker had to learn by looking at the movements of an expert operator and at the results produced on the shape of the tube, but nothing was explained and not even the expert knew why his actions produced certain effects.

Trained operators are able in turn to train single newly hired workers. A trained pulpitist is then flanked by the newcomer, to whom he transmits what he knows, under the supervision of the foreman, who bears the responsibility of controlling that such a training (which includes theoretical teachings) be correctly effected. On the whole, it takes about one year to learn such a skill fully.

Going back to the distinction between production capacity and technological capability, it is indisputable that the training of the operators comprised in the former is a completely different task to the building of the latter, which is a more demanding activity. In order to accumulate technological capabilities firms have to invest *ad hoc* in a particularly intensive training, especially devoted to the people to be specialized in the fundamental role of problem-solvers and change-generators.

The fact that skilled (applied) researchers have to be formed by firms, that cannot rely only on the formal education provided by universities, depends on the complex nature of technology. Due to the number of different very specific aspects and variables interacting, on the one hand it is necessary to give newly hired researchers very specific training and on the other experience plays a prominent role in the process of skill acquisition. It takes years to understand how to define problems, how to assess the reliability of the data, where to find the needed information sources, how to formulate a correct hypothesis, how to select from the tests made in the lab indications of lines of development to be further pursued at a larger scale.

Also maintenance people acquire their skill partly through formal learning, and partly through practical experience. The flanking of an expert may be an important way of learning for a novice, but without the support of an articulate explanation of what is happening such a flanking would be of little use. Practical activity and theoretical lessons complement one another, and the former is considered an important background to stimulate a quicker theoretical learning. On the whole, experience has a fundamental role in increasing skills, in creating a problem-solving ability which becomes partly automatic and unaware.

ON THE ENDOGENEITY OF CODIFICATION OF TECHNOLOGICAL KNOWLEDGE

The historical evolution sketched in the introduction can now be framed in a theoretical perspective, by identifing the general determinants of the pace of codification of technological knowledge in the economies or, more precisely, in industries and firms.

The starting point is recognizing the significance of two propositions already advanced by Nelson and Winter (1982), relating to the articulation of

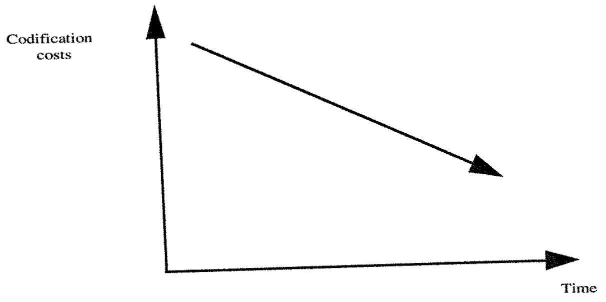

Figure 1. The time dimension of codifiability

knowledge: namely, that costs and incentives matter. Nelson and Winter assert that: "Whether a particular piece of knowledge is *in principle* articulable or necessarily tacit is not the relevant question in most behavioural situations. Rather the question is whether the costs associated with the obstacles to articulation are sufficiently high so that the knowledge *in fact* remains tacit" (p. 82). And also: "The same knowledge, apparently, is more tacit for some people than for others. Incentives, too, clearly matter: when circumstances place a great premium on effective articulation, remarkable things can sometimes be accomplished" (p. 78).

These propositions point to the fact that tacitness is not an inherent property of technology, but can be managed to a certain extent on the basis of an economic calculation of the costs and benefits of articulation [11]. The limits to codifiability at a given point in time are set by the technological opportunities to codify, which depend on technological developments, particularly the advances in the fields of electronics, computer science, and the availability of scientific instruments of measurement, which are exogenous with respect to the agents who have to decide whether to spend efforts in codifying the specific technologies to be used. These advances yield a reduction of the costs of articulation and widen the range of the articulability of knowledge (figure 1), shifting the frontier of codifiability in the various fields over time.

This implies a growing tendency to codify and in many fields, as the steel sector shows, new technologies that substitute labour, based on codified knowledge, have been developed[12], and perform what were tacit operations in a much more reliable and effective way. On the whole I suggest that a general

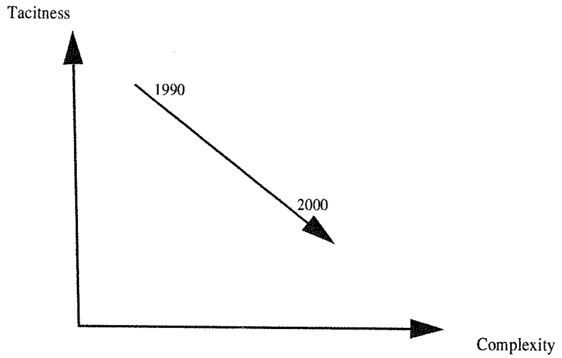

Figure 2. The evolving character of technologies over time

tendency is underway whereby technologies are increasingly articulated and complex (figure 2). However, industries will continue to differ as to the "degree of codification", to a large extent depending on the perceived costs and benefits of articulation.

When firms evaluate whether it pays to codify a particular piece of knowledge (to "unstick" an information, as von Hippel (1994) puts it), their decision will depend not only on the costs and advantages of codification, but also on the constraints stemming from their technological competences. Thus, they will differ as to the degree of codification of the technological knowledge they rely upon [13]. In conclusion, D. Hicks' (1995, p. 418) observation that "companies manage the public/private nature of their knowledge and manipulate these categories" applies also to the divide between tacitness and codification, under the constraint of in-house technological competence [14].

CODIFICATION IN THE ORGANIZATIONAL DOMAIN

A last point that I shall very briefly mention concerns organizational knowledge: in fact the use of information systems permits the codification of both organizational routines, know-what and know-who traditionally stored in the memory of firms' employees (with regard to the connections in certain markets, coordination of plants, teams etc.). In this case as well, codification depends on economic incentives.

Usually, small firms rely on personal relationships to a great extent, but when they start to grow the possibility to extract know-what and know-who from the employees' heads and to make it available to the whole organization, through the introduction of information systems and firm databases, begins to be perceived as a great benefit. Thus, organizational knowledge being articulated and stored in the databases, can "live its own life" (Mangolte, 1996), uncoupled from the fate of the firm's employees.

This means a shift of power from the individuals to the whole organization, since the new support of organizational memory becomes a fully controlled organizational asset. As the possession of key information can no longer empower some employees far beyond their own merits, the transfer of organizational memory to databases makes for an easier hierarchical control over employees' efforts and capabilities, reducing the distortions due to asymmetric information.

In addition, the full accessibility of the memory of the organization renders easier the insertion of a new member. However, since the content of the messages memorized in the databases does not become really general simply as a consequence of the symbolic form in which they are stored, a new entrant still needs the assistance of an expert employeee in order to interpret their idiosyncratic and contextual meaning. This amounts to saying that human tacit competences complementary to the codified knowledge base mantain a fundamental role in the organizational domain too.

CONCLUSIONS

This paper has shown that considering technology and know-how well-defined and codified does not mean understating the importance of firms' in-house technical competence in order to effectively negotiate the transfer of technology, to efficiently run a plant over a long period of time, to improve its reliability and performance and to adapt its use to market demands, given the fundamental openness of technology and know-how to improvements experience-related (though codifiable).

All this means that the capability to dip into the pool of technological information is far from free, contrary to the neoclassical view. However, difficult transferability of technology does not depend on its purported opaqueness, but on the need of (partly tacit) competency in order to adopt it.

It has been argued that codification is partly endogenous and that the new innovative equipment implies a considerable evolution. Above all, since the underlying knowledge base is more directly linked to scientific knowledge than it was in the past, the workers' required characteristics and the way of operating technology have changed. The new plants need to be strictly controlled by highly specialized operators, able to understand not only how to act, but also why to act in a certain way and what the consequences of different actions are. Production capability, in the new context, is mostly based on formalized training rather than on the example of the master. This points to the importance of the school system in providing a basic cultural-technical background but also of the supplementary in-house training by firms to provide a more specific knowledge. Particularly significant is the investment that firms must make in order to build problem solving and change-generating capabilities, since a consequence of higher technological complexity is the need to spend much effort in problem solving.

The approach developed here also allows for different levels of performance among firms in the same industry, depending on the technological competence they have accumulated. Relatedly, limited transferability of technologies can be seen more as an effect than as the cause of firm differences.

Still more generally, this perspective points to the fact that the irreplaceable role of man in a production system does not lie any more in the practical skills embodying technological knowledge, but in his problem solving ability, in his integrative capabilities and in the flexibility of his mental models (Holland 1986), upon which the generation of change relies.

Notes

1. See Winter (1987), Dosi (1988) and the more recent contributions by Senker (1995), Lundvall (1996), Foray and Cowan (1997) among a number of others.

2. I refer here to the content of scientific knowledge, not to the heuristics used in searching. The fact that the content of technological knowledge, unlike scientific knowledge, is neither inherently tacit nor articulated (see later), in my opinion (contrary to what Dasgupta and David, 1994, assert on this point) implies a different epistemological status from the latter which, having the aim of rigorously and systematically understanding the laws of nature, is inherently articulated.

3. In section 2 I have shown that the possible insufficiency of the information contained in blueprints to enable a successful implementation does not imply that what has not been transmitted is tacit à la Rosenberg, but instead that it is tacit à la Dasgupta/David, since it reflects an unwillingness of complete disclosure.

4. Information and knowledge, other than technology, may concern the enviroment where firms are located, which includes primarily the activities of competitors and consumer needs. This kind of knowledge seems much less objective than the technological one and I think it should be discussed separately (which is beyond the scope of this essay).

5. On the whole, what a firm knows is embodied both in the persons operating in it and in its routines. However, since in order to use a new technology the old routines may need to be radically changed, the firm prior knowledge which matters is that contained in the head of its employees.

6. Mowery and Rosenberg (1989) have stressed the importance and "the extent of the interplay between science and technology" (p. 22) which have been blurred "by the prevailing tendency to view the causal relationships as if they ran exclusively from science to technology and in which it is common to think of technology as if it were reducible to the application of prior scientific knowledge". The Authors also argue (p. 33) that "the sequence of technological knowledge preceding scientific knowledge has by no means been eliminated in the twentieth century. Much of the work of the scientist today involves systematizing and restructuring in an internally consistent way the knowledge and practical solutions and methods previously developed by the technologist. Technology has shaped science in important ways, because it acquired some bodies of knowledge first and, as a result, provided data that in turn became the '*explicanda*' of scientists, who attempted to account for and to codify these observations at a deeper level".

7. In this taxonomy the word "scientific" is used somewhat loosely, to indicate an approach of the problem-solving activity turned to generalizing the solutions found by understanding their causes, whereas the term usually refers to a rigorously systematized body of knowledge theoretically framed.

8. Frequently cited as proof of the tacit character of technological knowledge is the fact that contracts for technology transfer usually include the provision of some kind of training on the part of the technology supplier and at least some of this training consists of practical demonstrations executed on site. Rather, one should consider that the training even of completely formalized subjects is always based on some mixture of tacit, empirical and scientific teaching methods. It is usually very effective, besides explaining the rules at work, to show their application visually, the sequence and timeliness of the operations to be carried out, to correct directly the would-be operators, to clear up some points not explained in enough detail in the "how to do it book" and so on. Also on university courses, laboratory lessons are provided.

9. On this topic see Balconi (1996), where the interesting case-history of the Italian group Arvedi, pioneering the adoption of a complex thin slab casting technology to produce special steel strips, is presented and discussed in-depth. In the opinion of an expert in industrial relations working for the Arvedi group "For the acquisition of the needed specific skill internal training is increasingly important, in order to transfer to the operator the specific competence required by plants with peculiar features. Specific know-how is getting more important than technical knowledges offered by the school system, which has to be considered an essential cultural-technical background"(Balzarini, 1996, p. 6).

10. The fact that even in order to proficiently execute a standardized, well-articulated productive practice workers need some experience, some assimilation of the sequence of acts they must perform etc., or that even in manoeuvring a joystick some tacit knowledge is involved, does not seem to merit much attention from an economic view point. That some tacit knowledge is involved also in using a joystick effectively is a second order consequence of the codification of production activity, whose economic significance is low since the skill involved is easily acquired and has a general, unspecific character.

11. The endogeneity of codification of knowledge is also asserted by Foray and Cowan (1997) in a more general perspective.

12. Obviously, codification does not necessarily imply capital substitution for labour. Codification of the knowledge underlying a given production phase might even imply no change in the way of its execution if it proved advantageous to a given firm (or inevitable, as for example in an underdeveloped country, where one cannot find any workforce with a basic training) to continue to rely on tacit skills. Otherwise, codified knowledge might still imply the use of human effort, but the conscious understanding of the "rules" by the operator permits a more flexible and easy learning, to a lesser extent based on the imitation of the instructor. An even greater change is realized when measurement instruments are introduced, and finally when the articulated knowledge is embodied in pieces of capital equipment that substitute labour in executing the operation, and the worker becomes a trained and knowledgeable controller.

13. Even in plants at the frontier of codification, some uncodified production phases and operations continue to exist. Thus, there are still some "tacit jobs", which require many years of experience and training by flanking. They usually imply, as I was told in an interview, "the interpretation of something that is happening but lies outside the scope of processed data".

14. The argument presented above, asserting the "technological opportunities-bound" endogeneity of the articulation of technological knowledge, clearly differs from Dasgupta and David's assertion of the endogeneity of tacitness, first of all since it is based on a different concept of tacitness/codification. Indeed, those authors focus their attention on the incentives to disclose -hence on the reward system facing the individual agents- an inherently codifiable knowledge, since they draw no distinction between the epistemological status of technological and scientific knowledge (see footnote 2 above).

References

K. ARROW, *Economic Welfare and the Allocation of Resources for Invention,* in National Bureau of Economic Research, *The Rate and Direction of Inventive activity,* Princeton University Press, Princeton, 1962.

M. BALCONI, *Technological capabilities, learning and codification of knowledge. A paradigmatic case of radical innovation in the steel industry,* Working Paper, International Conference *"Technological Learning, Innovation and Industrial Policy"*, City of Mexico, September, 1996.

C. BALZARINI, *The small firm: multiskilling, team working, flexibility,* paper presented at the International Conference on *"The Steel Industry in the New Millennium: Technological Change, Market Strategies and Institutions"*, Terni, 4-5 July 1996.

M. BELL M. and K. PAVITT, *Technological Accumulation and Industrial Growth: Contrasts Between Developed and Developing Countries,* Industrial and Corporate Change, 2, 157-210, 1993.

M.D. COHEN *et al., Routines and Other Recurring Action Patterns of Organizations: Contemporary Research Issues,* Santa Fe Institute Working Paper, 1995.

V.M. COHEN and D.A. LEVINTHAL, *Absorptive Capacity: A New Perspective on Learning and Innovation,* Administrative Science Quarterly, 35, 128-152, 1990.

P. COHENDET *et al., Technological learning, economic networks and innovation appropriability,* in D. Foray and C. Freeman, *Technology and the Wealth of Nations,* Pinter Publishers, London, 1993.

P. DASGUPTA and P.A. DAVID, *Toward a new economics of science,* Research Policy, 23, 487-521, 1994.

G. DOSI, *Sources, Procedures and Microeconomic Effects of Innovation,* Journal of Economic Literature, *26*, 1120-1171, 1988.

G. DOSI, The *Contribution of Economic Theory to the Understanding of a Knowledge-Based Economy,* Working Paper, IIASA, 1995.

D. FORAY and R. COWAN, *New information and communication technologies and the economics of knowledge*, mimeo, 1997.

D. FORAY and B.A. LUNDVALL, *The knowledge-based economy: from the economics of knowledge to the learning economy* in Foray and Lundvall (eds.), *Employment and growth in the knowledge-based economy,* OECD, 1996.

D. HICKS, *Published Papers, Tacit Competencies and Corporate Management of the Public/Private Character of Knowledge,* Industrial and Corporate Change, 4, 401-424, 1995.

J. HOLLAND *et al., Induction. Processes of Inference, Learning and Discovery,* MIT Press, Cambridge MA, 1986.

B. LUNDVALL, *L'economia dell'apprendimento. Una sfida alla teoria e alla politica economica,* Economia e politica industriale, N.89, 119-145, 1996.

B. LUNDVALL and B. JOHNSON, *The Learning Economy, Journal of Industry Studies, 2*, 23-42, 1994.

P.A. MANGOLTE, *Mémoire organisationnelle ou mémoires dans et hors de l'organisation ?*, draft, CREI, Université Paris Nord, 1996.

J.G. MARCH and H.A. SIMON, *Organizations revisited,* Industrial and Corporate Change, 3, pp.299-316, 1993.

R.S. MICHALSKI, *Toward a unified theory of learning,* in B.G.Buchanan and D. Wilkins (eds.), *Knowledge acquisition and learning,* Morgan Kaufmann Publishers, San Mateo (California), 1993.

D.C. MOWERY and N. ROSENBERG, *Technology and the Pursuit of Economic Growth,* Cambridge University Press, Cambridge, 1989.

R.R. NELSON and S. WINTER, *An evolutionary theory of economic change,* Belknap Press of Harvard University Press, Cambridge M.A, 1982.

G.P. PISANO, *Learning-before-doing in the development of new process technology,* Research Policy, *25*, 1097-1119, 1996.

M. POLANYI, *Personal Knowledge. Towards a Post-Critical Philosophy,* Routledge & Kegan Paul, London, 1958.

N. ROSENBERG, *Perspectives on Technology,* Cambridge University Press, Cambridge, 1976.

J. SENKER, *Tacit Knowledge and Models of Innovation,* Industrial and Corporate Change, 4, 425-447, 1995.

A. TOMIURA, *Technology Transfer and Hollowing out,* mimeo, 1996.

E. VON HIPPEL, *Sticky Information and the Locus of Problem Solving: Implications for Innovation,* Management Science, *40*, 429-439, 1994.

S. WINTER, *Knowledge and Competence as Strategic Assets*, in D.Teece (ed.), *The competitive Challenge. Strategies for Industrial Innovation and Renewall,* Ballinger, Cambridge MA, 1987.

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CODIFICATION ET AJUSTEMENT : DEUX MOYENS POUR L'ÉLABORATION D'UNE MÉMOIRE DE L'ORGANISATION

LE CAS D'UNE ACTIVITÉ DE SERVICE

Sophie DUBUISSON [1]

Résumé

L'article se propose d'étudier deux modalités de production et de stockage de la connaissance au sein d'une organisation économique. L'étude de la réorganisation d'une offre de service par un prestataire de restauration collective permet de mettre à jour diverses opérations cognitives qui sous-tendent la coordination des activités économiques. Certaines opérations relèvent de ce que l'on peut appeler de la codification, la connaissance produite à cette occasion se trouve stockée dans différents dispositifs qui normalisent et stabilisent l'activité économique. Ce stockage est particulièrement opérationnel pour gérer le multi-sites. Par ailleurs, la coordination économique à l'œuvre se traduit également par diverses actions d'ajustements supportées par les acteurs et les objets qui redéfinissent les manières de faire et capitalisent la connaissance produite à cette occasion. C'est l'articulation de ces deux modalités de mémorisation qui est en jeu dans la capacité d'un acteur économique à s'adapter aux éventuelles variations de la demande.

Abstract

The paper analyzes two ways of production and storage of knowledge within an economic organization. In an organizational innovation context, we identified several cognitive processes grounding the coordination of an economic activity from the service industry (catering). We call some of them codification operations since the knowledge they allow to create is stored in standardized and stabilized devices. This system is efficient for multiple plants organizations. Furthermore, other operations are more oriented towards learning by doing processes : the knowlegde is stored through experiences of adpatation and adjustement of actors and objects. The condition of efficiency of an economic organization is based on its capacity to articulate these two memorization processes in order to adapt and react to the variability of demand.

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