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PROBLEM-SOLVING BEHAVIOURS, ORGANISATIONAL FORMS AND THE COMPLEXITY OF TASKS

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1. Introduction

The dominant form of analysis of organisational behaviours and structures, closely drawing from mainstream economics, takes a rather extreme agency approach, seeking to identify the most efficient incentive mechanisms for the coordination of decisions. However, such an incentive-based approach adopts the highly dubious assumption that both the structures for problem-solving and the necessary search heuristics (e.g. 'rules of thumb' for decision making) exist, unproblematically, from the outset. Here and throughout the paper, the term 'problem-solving' includes all the acts undertaken by individuals and groups within economic organisations (firms) to resolve organisational and technological problems and to conceptualise, design, test and build products and processes.

In the case of most firms – new and incumbent ones – facing market and technological uncertainty, what one could call the "problem-free" assumption is profoundly unrealistic and assumes away the difficulty of constructing a theory to explain the co-evolution of problem-solving knowledge and organisational arrangements in firms. In turn, this demands some basic analytical tools to examine how firms deploy and match problem-solving activities with governance arrangements.[1] This is especially important where tasks are inherently complex and non-routine in nature and where many possible problem-solving and organisational solutions are possible.

The first purpose of this paper is to outline an evolutionary framework for analysing how problem-solving knowledge in firms co-evolve with organisational forms in complex task environments. These characteristics apply to most activities performed by new high technology firms and to the many functions in larger established corporations which are non-routine and non-codifiable by nature, including strategy formulation, R&D, marketing, distribution channel management, new product design, process engineering, human resource development and supply chain management.[2]

The second and complementary aim is to operationalise the evolutionary view of how firms as knowledge repositories cope with complex, non-routines tasks by evolving appropriate structures to deal with them. The practical application of the approach considers one important class of economic activity, which represents an extreme case of product and task complexity, namely the production of complex products and systems (or 'CoPS'), including high cost, tailored capital goods, systems constructs and services.[3] Because each new product tends to be different and because production involves feedback loops from later to early stages (and other unpredictable, 'emerging' properties), highly innovative non-functional organisational structures are required to co-ordinate production, particularly in the commonly found case of unclear and uncertain user requirements.

The paper is structured as follows. Section 2 describes the basic principles underlying an evolutionary approach to problem-solving behaviour (PSB) in firms, contrasting these with the

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[1] The terms organisational form, structure and governance arrangements are used interchangeably in this paper.

[2] The paper builds on previous works by Marengo (1999) and Marengo, *et al.* (1999), which provide a formal mathematical treatment of the approach presented here.

[3] Many CoPS confront extreme task complexity because they embody a wide variety of distinctive skills and types of knowledge, and involve large numbers of firms or organisational units in their production. In the past 20 years or so, CoPS have been transformed by software and information technology (IT), leading to new levels of risk and uncertainty in design and production. See Hobday (1998) for definition and discussion of CoPS as an analytical category, and also Miller et al (1995) for an application to the flight simulation industry.

dominant (incentive-centred) formulation of agency in organisations. Section 3 presents the building blocks of an evolutionary theory of PSB and firm organisation, representing PSB as a form of complex design activity. The model – spelled out in more details in Marengo (1999) and Marengo et al. (1999) – develops upon a 'Simonian' representation of PSB grounded on the notions of combination of elementary physical and cognitive acts, and de-composability of firm behaviour and structure in relation to particular product or process outcomes (Simon, 1981; 1991).

Section 4 applies the conceptual framework to CoPS found in sectors such as aerospace, information systems, many utilities, engineering construction, military systems, transportation and telecommunications. Section 5 compares some properties of different organisational set-ups within multi-firm CoPS projects and their implications for innovative PSBs. Section 6 draws upon the organisational behaviour literature to provide a practical set of heuristics for gathering 'benchmark' data for complex non-routine projects: in the language we shall introduce below, such heuristics entail procedures for re-shaping "problem representations" and "problem decompositions". Some examples of the application of these concepts for the purposes of business improvement in CoPS are touched upon.[4]

2. An Evolutionary approach to problem-solving behaviour in firms

Before presenting the basic building blocks of an evolutionary theory of PSB it is useful to briefly recall the governing principles behind the dominant agency approach. As known, agency theory identifies efficient incentive mechanisms for the co-ordination of decisions (see e.g. Tirole, 1986; Grossman and Hart, 1986; Laffont and Tirole, 1986), while implicitly assuming that PSB structures and search heuristics exist from the outset. Within firms, people are postulated to play extremely sophisticated games according to rules designed to prevent them from doing much harm to others (and indirectly to themselves). Neither the complexity of the task itself, nor the product of the firm or the production technology have much, or any, bearing on the subject at hand. The main aim is to generate admissible incentive-compatible procedures based, when taken at face value, on hyper rational agents.[5]

Relatedly, individuals within organisations are assumed to hold the entire plan of what to do, possibly akin to a well-functioning computer model. The issue of firm competence and its relationship with performance does not arise, except for problems of the misrepresentation of 'intrinsic' individual abilities and adverse selection, or incentive misalignment in eliciting effort from individuals. Within the firm, as a first approximation, the social division of tasks is irrelevant to practice and performance. In the extreme, according to the mainstream approach, given the 'right' incentives, any firm can make any product as well as any other firm (e.g.microprocessors as well as Intel or bioengineering products as well as Genetech).[6]

[4] For more details see Hobday and Brady (2000).

[5] Curiously, in the field of software engineering a vaguely similar approach (actually called "rational") dominates and is defended as a practical way of producing complex software systems (Parnas and Clements, 1986). See Hobday and Brady (1998) for a critique.

[6] Although, as presented here, this "rational" incentive-based view is a caricature, it does help convey the nature of the major difference between the latter view of economic behaviour in organisations and the problem-solving evolutionary perspective suggested in the following.

By contrast, at its most general level, the evolutionary approach sees economic organisations as problem-solving arrangements, viewing the different observed institutional set ups in the real world as reflecting the complexity of the tasks and objectives faced by the firm (March and Simon, 1958; Nelson and Winter, 1982; Dosi and Marengo, 1994). In the world of non trivial, complex and uncertain tasks, governance arrangements and search heuristics play a central part in determining which eventual solutions are considered as possibilities, tested and ultimately selected. Relatedly, a key evolutionary proposition is that in making decisions, firms and individuals and groups within them, confront extremely large, computationally intractable search 'spaces' to chose from. Therefore the particular organisational arrangements and approaches, skill and experience in proceeding shape and define the distinctive competence of individual firms.[7]

As can be formally demonstrated, the design of suitable organisational arrangements tends to be even more computationally complex than finding an optimal solution to the problem itself (Marengo et al, 1999). To the extent that this is a correct representation of real world decision making, this implies that it is not sensible to assume that problem-solvers operate within *ex-ante* established organisational structures, governance arrangements and PSB routines. Indeed, organisational form has to be established as part of, and alongside, the problem-solving activity. Within this co-evolution of PSBs and organisational arrangements, individuals, groups and entire firms are far from having perfect knowledge or foresight, but 'bounded rationality', broadly defined, is the rule (Simon, 1981; Dosi and Egidi, 1991; Dosi, Marengo and Fagiolo, 1996).[8]

To resolve highly complex dynamic problems, boundedly rational individuals and groups within firms (as with the firm itself) are highly likely to adopt problem decomposition procedures, (for a thorough illustration, cf. among others, the example of aeronautical engineering in Vincenti, 1990). Here and throughout this work, largely in tune with Herbert Simon's perspective on problem-solving, by "decomposition" we mean the identification of ensembles of tasks or "sub-problems" whose solution is meant to yield also to the solution of the overall problem. So, for example, if the general problem is the development and construction of an airplane with certain technical characteristics, "decompositions" might involve the identification of "sub-problems" concerning e.g. engine thrust, wing loads, aerodynamic shapes of the body, etc.
Over time, decomposition heuristics and routines are likely to evolve differently in different firms as they learn to reduce the dimensions of search space through experience. As a result, not all decomposition strategies are necessarily successful (or equally successful), and no selection mechanism or process of choice (e.g. incentives) necessarily exists to ensure an optimum solution to product, process or organisational problems.

Consequently it is reasonable to assume that the problem-solving abilities of firms are nested within an 'ubiquitous sub-optimality'. Rather, intra-firm learning patterns and inter-organisational selection

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[7] With roots in the earlier contributions of Penrose (1958), Chandler (1962) and Richardson (1972), a growing literature is exploring the nature of organisations in terms of "competencies" and "capabilities": see, among others, Teece, Pisano and Schuen (1994), Teece et al. (1994), Barney (1991) and the contributions in Dosi, Nelson and Winter (2000).

[8] Problem-solvers in firms most likely include engineers, designers or project managers, but also, in different ways, most other employees. This applies in particular to CoPS projects, wherein each worker or 'practitioner' (e.g. a software writer or draftsperson) is an 'intelligent agent' responsible for managing his or her task and interfacing with other individuals and groups working on different aspects of the same product or problem (Hobday and Brady, 1998).

processes need first to be considered as evolutionary processes, even neglecting, in a first approximation, the diverse incentive-driven behaviours which different organisational forms elicit.[9]

These propositions are naturally consistent with an emerging evolutionary approach to 'what business firms are and do' (e.g. Nelson and Winter, 1982; Winter, 1982 and 1988; Dosi, 1988, Teece et al, 1994, Dosi and Marengo 1994 and Marengo, 1996) and are largely overlapping and complementary with the view expressed by Simon (1991), March and Simon (1958) and Radner (1992) among others.

In this approach, the product in question clearly matters (e.g. steel, computers or polypropylene) as does the great diversity in processes and organisational arrangements deployed to make a particular product. No single individual knows the entire production plan and, within both the management of business-as-usual and in the search for new product designs and efficient processes, organisations display an ensemble of routine procedures, through which organisations often manage to co-ordinate their tasks well enough to deliver a coherent set of processes and products. In contrast to the 'optimal machine' analogy, the firm can be viewed as an intelligent but fallible "organism" trying to adapt imperfectly and path-dependently to a changing environment shaped also by other organisms (including competitors, suppliers and buyers).

In the evolutionary view, the basic units of analysis for PSBs are, on the one hand, elementary physical acts (such as moving a drawing from one office to another) and elementary cognitive acts (such as a simple calculation) on the other. Problem-solving can then be defined as a combination of elementary acts within a procedure, leading eventually to a feasible outcome (e.g. an aircraft engine or a chemical compound). Or, seen the other way round, given the possibly infinite set of procedures leading to a given outcome or product, it is possible to decompose these procedures into diverse series of elementary cognitive and physical acts of varying lengths which may be executed according to various possible execution architectures (e.g. sequential, parallel or hierarchical).

PBSs straightforwardly link with the notion of organisational competencies and capabilities. First, a firm displays the operational competencies associated with its actual problem-solving procedures (in line with the routines discussed by Nelson and Winter, 1982 and Cohen *et al.*, 1996). Second, the formal and informal organisational structure of the firm determines the way in which cognitive and physical acts are distributed and the decomposition rules which govern what is and what is not admissible within a particular firm (providing a route into the analysis of incentive structures and processes). Third, the organisation shapes the search heuristics for, as yet, unresolved problems, thereby governing creative processes within the firm.

This theoretical approach to PSB within the firm also corresponds closely to empirical accounts of firm behaviour from the economics of innovation (Freeman, 1982; Dosi, 1988; Pavitt, 1999). Moreover, it has the benefit of being applicable both to the analysis of intra-firm structures and to the analysis of the boundaries between firms and the market. Indeed, such boundaries can be seen as particular patterns of decomposition of an overall problem-solving task. In other words, the boundary of the firm is shaped, in part, by the problem to be solved, often corresponding to the product to be created (e.g. a car or a piece of steel). Particular decomposition strategies will range from the totally centralised and autarkic types (with no decomposition at all) to the equivalent of a

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[9] A comprehensive account of economic behaviour of firms should, of course, account for incentives as well as the co-evolution of PSBs and governance arrangements, as argued by Coriat and Dosi (1998) and Dosi and Marengo (1994). However, a second point of departure is given by the understanding of the diverse PSBs of firms, and then proceeding to assess the ways in which incentive structures co-evolve with PSBs.

pure market, where one person acts on each task with market-like transactions linking each elementary act.

From an empirical perspective, it then becomes important to ask whether and under which circumstances ‘markets’ (i.e. complete decentralised distributions of knowledge) have problem-solving advantages over more centralised, ‘hierarchical’ forms of decomposition. The next section presents some simple conceptual building blocks for analysing this type of question.

3. Products, tasks and organisations as problems of design

It is helpful to think of complex problem-solving activities as problems of design: the design of elaborate artefacts and the design of the processes and organisational structures required to produce them. In turn, these processes require the design of complex sequences of moves, rules, behaviours and search heuristics involving one or many different actors to solve problems, create new "representations" of problems themselves and ultimately to achieve the techno-economic goals at hand. Common to all these design activities is that they involve search in large combinatorial spaces of ‘components’ (as defined above in terms of elementary physical and cognitive acts) which have to be closely co-ordinated. To complicate matters still further, the functional relations among these elements are only partly understood and can only be locally explored through a process of trial-and-error learning, often involving also the application of expert, partly tacit knowledge.

For example, the design of a complex artefact such as an aircraft or a flight simulator requires the co-ordination of many different design elements, including engine type and power, wing size and shape and other materials. The interaction between each of the sub-systems and components is only partly understood and each comprises many smaller components and sub-systems (Miller et. al, 1995; Prencipe, 1997). The interactions between the elements of the system can only be partly expressed by general models and have to be tested through simulation, prototype building, and trial-and-error moves where learning and tacit knowledge play an important part. Producing an effective solution, such as a new aircraft, involves a long sequence of moves, each of which is chosen out of an enormous set of possibilities. In turn, the relations among the moves in the sequence can only be partly known as a full understanding would (impossibly) require the knowledge of the entire set of possibilities. The likelihood of combinatorial explosion within the search space presents a computationally intractable task for boundedly rational agents. As Metcalfe and de Liso (1995) argue, the beliefs and routines of the firm act as a focusing device, indicating where to search in order to produce functioning artefacts: “Paradoxical though it may seem, to make progress it is necessary to limit progress” (p. 21). In that, also the "culture" of the firm acts as an interpretative system grounded in the community of practice of the firm, which allows progress and learning under conditions of extreme uncertainty and vast opportunities for design choice.

Business firms as well as collaborative ventures among them can therefore be seen as complex, multi-dimensional bundles of routines, decision rules, procedures and incentive schemes, whose interplay is often largely unknown both to the managers of the organisation and also to managers, designers and engineers responsible for single projects. Of course, over time many repeated technical and business activities become routinised and codified, allowing for stable, formal structures and established codified routines as, for example, in the volume production activities of automobiles or commodity chemicals. In these circumstances, some sort of "steady state" problem decomposition becomes institutionalised, also allowing the establishment of neat organisational structures, and, together, the exploitation of economies of scale and scope. The "Fordist" and "Chandlerian" archetypes of organisation are the classic example. This is also the organisational arrangement which most forcefully highlights potential advantages (and also the in-built rigidities) of division of labour and specialisation. However, even in this stable case there remain many non–routine, complex activities within the firm, including new product design, research and development, new marketing programmes, and so on. In these areas the foregoing properties of search for new PSBs continue to apply and organisational forms take a variety of shapes in relation to these tasks. In addition, under conditions of rapid market and technological change even stable ("Fordist") organisations are often forced to re-assess and re-constitute their structures in order to respond to new market demands and to exploit new technical opportunities (see, for example, the related discussions by Coriat and by Fujimoto in Dosi, Nelson and Winter (2000) on Japanese – "Toyotist" – organisational arrangements and routines.

During the multi-stage product design task, the basic elements to be co-ordinated are characterised by strong inter-dependencies which create many local optima within the search space. For instance, adding a more powerful engine could lead to a reduction in the performance of an aircraft or prevent it from flying altogether if the other sub-systems and components are not simultaneously adapted. Similarly, at the organisational level, the introduction of new routines, practices or incentive schemes which have proven superiority in another context, could also prove counter-productive if other elements of the organisation are not appropriately adapted to suit the new inputs (Dosi, Nelson and Winter, 2000).

A helpful 'reduced form' metaphor of the complex task problem is presented in Kauffman's (1993) model of selection dynamics in the biological domain with heterogeneous interdependent traits. Kauffman considers a model of the selection mechanisms whereby the units of selection are complex entities made of several non-linearly interacting components. Units of selection are combinations of N elementary components (genes or morphological or behavioural traits) which can assume one of an finite number of states and a fitness value is exogeneously assigned to each "gene" producing a fitness landscape on the space of combinations, reflecting the interdependencies among the constituent elements. His model shows that as the number of interdependent elements increases the fitness landscape presents an exponentially increasing number of local optima. In the presence of strong interdependencies (as occurs in many complex products, see Part 3) the system cannot be optimised by separately optimising each element it is made of. Indeed, in the case of strong interdependencies it might well be the case that some, or even all, solutions obtained by tuning "in the right direction" each component yield a worse performance than the current one.

In the presence of strong interdependencies the problem cannot therefore be decomposed into separate sub-problems which could be optimised separately from the others (Marengo, 1999). However, as argued by Simon (1981) problem-solving by boundedly rational agents must necessarily proceed by decomposing a large, complex and intractable problem into smaller sub-problems which can be solved independently. Within the firm this is equivalent to a division of problem-solving labour. However, the extent of the division of problem-solving labour is limited by the existence of interdependencies. If, in the process of sub-problem decomposition, interdependent elements are separated then solving each sub-problem interdependently does not allow overall optimisation. As Simon (1981) also points out, since a perfect de-composition, which isolates in separate sub-problems all and only the elements which are interdependent to each other, can only be designed by someone who has perfect knowledge of the problem, boundedly rational agents will normally try to design 'near-decompositions'. The latter are decompositions which try to isolate the most performance relevant interdependencies into separate sub-problems.

Unlike the biological analogy above, the design space of a problem faced by an engineer or a firm is not given exogenously but, rather, is constructed by them as a subjective representation of the problem itself where, in practice, much of the search takes place. If the division of problem-solving labour is limited by interdependencies, the structure of the latter, in turn, depends on how the problem is framed by the problem-solvers. Sometimes with major innovations, problem solvers are able to make major leaps forward by re-framing the problem itself in a novel way. For example, in the accounts of wireless communications development provided by Levinthal (1998) and the Polaris missile system by Sapolsky (1972) various known system elements were combined and re-combined in creative new ways.

In short, the representation of the problem itself plays a crucial part in determining its complexity. By acting on its representation, decision-makers can make a problem more or less decomposable. The division of problem-solving labour is therefore very much a question of how the problem is represented and its elements encoded.

Given the limits that interdependencies pose to the division of problem-solving labour, an important part of the representation is how agents evaluate the "goodness" of solutions. As already mentioned, the problem of interdependencies amount to a problem of mis-alignement of local vs. global performance signals: local moves in the ‘right direction’ may well decrease overall performance if particular elements are not properly adjusted to the moves. Thus there is room for the design of many alternative methods of performance assessment. In the formal model presented elsewhere (Marengo et al, 1999), for every problem of a given class there can be different performance assessment schemes, providing a set of payoffs to variations of components of the solution which allow for maximum decomposition. This form of performance assessment makes local adaptation and decentralised trial-and-error search effective as strategies.

During the design of PSBs and in the long-term building of the distinctive competence of firms, the architecture of the firm co-evolves with its decomposition schemes. Indeed, any organisational hierarchy may be seen, from a problem-solving perspective, as entailing particular decompositions into blocks of elements (sub-problems and organisationally admissible behaviours and tasks assigned to them) which, together make the overall configuration of the PSBs and organisational governance of the firm. In complex tasks, firms continue to go through step-by-step experiments with groups of elements in order to improve the performance of the overall system. In some cases, activities are more or less decomposable (e.g. finance and manufacturing, or a mechanical and electrical system). Here the firm is able to rapidly find a an appropriate “robust” decomposition.

However, in many cases (e.g. product design and systems integration) notwithstanding the ubiquitous search for "modularity", tasks are highly interdependent, leading to indeterminacy in PSBs and governance arrangements and many different solutions to chose from. When building a decomposition scheme, firms might ideally search for perfect decomposability, so that all groups of elements can be optimised in a totally independent way from the others. However, near-decomposability is more common as many problems cannot be divided into neatly isolated groups of components which can all be solved independently.

Problem-solving design does not only involve search within a given space but also, and very importantly, a re-framing of the problem itself by the agents within the firm. Changing the frame or representation of the particular problem is a powerful form of PSB. Indeed, as argued in Marengo (1996), the establishment of collectively shared representations and problem-solving frames is one of the fundamental roles of top management. Equally important, when the organisational architecture allows it, groups within the firm, by experimentation, are able to collectively evolve new representations, possibly yielding more effective decompositions. In the formal model presented by Marengo et al (1999) the construction of shared representations allows for the simplification of complex problems, offering a more powerful strategy than attempting to optimise any particular given representation. Experience and learning provide the agents with knowledge of probable viable decompositions as well as probably ‘well-behaved representations’.

In the real world of decision-making, agents rarely hold a full representation of the overall problem and can only control a limited number of elements involved. Firms have to proceed by roughly defining an architecture for various blocks of elements to be integrated (e.g. electronic hardware and software systems), assigning the blocks to individuals and groups, co-ordinated by a project manager or equivalent. This way they try to achieve decomposability and, where not possible, effective communications and interactions between agents across the various blocks of sub-tasks. Note that top-down assignments of sub-problems and formal tasks rarely match perfectly the actual decompositions achieved via "horizontal" self-organising adjustments (for a fascinating longitudinal story of these dynamics throughout the establishment of a major telecom company see Narduzzo, Rocco and Warlglien (2000)). Indeed, the mismatches between "formal" representations and decompositions and actual (emergent) ones, are at the same time a major drawback on organisational performances but also a potential source of organisational learning. These processes are endemic to most activities involved in the production of CoPS, as discussed in the following sections.

4. PSBs in complex products and systems

Complex product systems (CoPS) are high value artefacts, systems, sub-systems, software packages, control units, networks and high technology constructs.[10] As high technology customised capital goods, they tend to be made in one-off projects or small-batches. The emphasis of production is on design, project management, systems engineering and systems integration. Examples include telecommunications exchanges, flight simulators, aircraft engines, avionics systems, train engines, air traffic control units, systems for electricity grids, offshore oil equipment, baggage handling systems, R&D equipment, bio-informatics systems, intelligent buildings and cellular phone network equipment.

There are many different categories of CoPS, ranging from relatively traditional goods (e.g. train engines) to new IT networks (e.g. internet super-servers) to established goods which have been radically transformed by IT (e.g. integrated mail processing systems and printing press machinery). They can be categorised according to sector (e.g. aerospace, military and transportation), function (e.g. control systems, communications and R&D), and degree of complexity (e.g. as measured by the number of tailored components and sub-systems, design options and amount of new knowledge required).

The physical composition and production processes of most CoPS have changed due to the diffusion of IT and embedded software. As software becomes a core technology, many CoPS are becoming more complex and difficult to produce partly as a result of the human, craft design element involved in software development.[11] Technical progress, combined with new industrial demands have greatly enhanced the functional scope, performance and complexity of CoPS throughout, from jet engines to nuclear power simulation systems.

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[10] This section draws from Hobday (1998). The term CoPS is used, as 'capital goods' fails to capture the diversity and range of systems involved. CoPS are, in fact, a subset of capital goods (and might eventually include sophisticated consumer goods). Somewhat similar issues, related to the variety and complexity of knowledge emerge in connection with products which are relatively simple as such but require complex search procedures to be discovered. Pharmaceutical are an archetypical example: cf. Orsenigo, Pammolli and Riccaboni (1999).

[11] The effect of software can be interpreted as shifting the emphasis of production from a relatively predictable 'engineering' task to a much more imprecise design-intensive 'development' process, increasing the degree of uncertainty and learning involved in the production of each system.

CoPS have at least three defining characteristics which distinguish them from mass produced goods. First, as high cost, capital goods they consist of many interconnected, often customised elements (including control units, sub-systems and components), usually organised in a hierarchical manner and tailored for specific customers and/or markets. Often their sub-systems (e.g. the avionics systems for aircraft) are themselves complex, customised and high cost. Second, they tend to exhibit emergent properties during production, as unpredictable and unexpected events occur during design and systems engineering and integration (Boardman, 1990; Shenhar, 1994). Emerging properties also occur from generation to generation, as small changes in one part of a system's design often call for large alterations in other parts, requiring the addition of more sophisticated control systems and, sometimes, new materials (e.g. in jet engines). Third, because they are high value capital goods, CoPS tend to be produced in projects or in small batches which allow for a high degree of direct user involvement, enabling business users to engage directly into the innovation process, rather than through arms-length market transactions, as normally the case in commodity goods.

There are many different dimensions of product complexity, each of which can confer task complexity and non-routine behaviour to production and innovation tasks. These dimensions include the numbers of components, the degree of customisation of both system and components, multiple design choices, elaborate systems architectures, breadth and depth of knowledge and skill required, and the variety of materials and information inputs. Users frequently change their requirements during production, leading to unclear goals, uncertainty in production and unpredictable, unquantifiable risks. Managers and engineers often have to proceed from one production stage to the next with incomplete information, relying on inputs from other suppliers who may be competitors in other multi-firm projects. Project management often involves negotiating between the competing interests, goals and cultures of the various organisations involved in production.

Many CoPS are produced within projects which incorporate prime contractors, systems integrators, users, buyers, other suppliers, small and medium sized enterprises and sometimes government agencies and regulators. Often, these agents collaborate together, taking innovation (e.g. new design) decisions in advance of and during production, as in the case of flight simulators (Miller et al, 1995). Projects consist of temporary multi-firm alliances where systems integration and project management competencies are critical to production. The project represents a sort of focusing device which enables the problems of design and production to be addressed. It is also responsible for realising the market, co-ordinating decisions across firms, enabling buyer involvement and matching technical and financial resources through time. Because production is oriented to meet the needs of large business users, the project management task is fundamentally different from the mass production task. As Joan Woodward (1958, p23) already put it in her research into UK project-based companies in the 1950s:

“those responsible for marketing had to sell, not a product, but the idea that their firm was able to produce what the customer required. The product was developed after the order had been secured, the design being, in many cases, modified to suit the requirements of the customer. In mass production firms, the sequence is quite different: product development came first, then production, and finally marketing”.

5. Designing organisational forms for CoPS

Although vast and diverse bodies of literature exist on organisational forms, there are not many studies which examine in any depth the project-based organisation or forms suited to CoPS.[12]

[12] Works germane to our analysis include Gann and Salter (1998) who provide a rare account of how project processes relate to wider organizational activities within a project-based organization, and Middleton (1967)

Certainly, the relation between organisational form and the problem solving nature of the firm is at the heart of "competence-based" and, largely overlapping, evolutionary perspectives (e.g. Dosi, Nelson and Winter, 2000, Dosi and Marengo, 1994, Kogut and Zander, 1992 and 1996, Nelson and Winter, 1982, Nelson, 1991, Teece, Pisano and Schuen, 1994, Teece *et al.*, 1994, Conner and Prahalad, 1996, Leonard-Barton, 1995, Winter, 1988). The competence view in fact focuses on organisations as repositories of problem-solving knowledge and analyses some salient properties of knowledge accumulation and the ways the latter co-evolve with organisational structures and practices (including, of course, routines but also managerial heuristics and strategies).

Organisational specificities and persistently different revealed performances, are thus interpreted also on the grounds of path-dependence in knowledge accumulation and inertial persistence of organisational traits. Bounded rationality, in its broadest meaning, is the norm. Its general sources include the "complexity" and procedural uncertainty associated with problem-solving procedures and the intrinsic "opaqueness" of the relationship between actions and environmental feed-backs, so that it is seldom obvious, even ex-post, to state how well one did and why (March, 1994).

Taking all that as a (quite sound, in our view) point of departure, one must acknowledge, however, that one is still far from having comprehensive taxonomies mapping discrete organizational types into diverse forms of knowledge distributions and problem-solving behaviours, even if one find suggestive exercises in this direction.
So, for example, Mintzberg (1979), partly building on the work of Burns and Stalker (1961) attempts to derive a classification contingent on the nature of markets, tasks and technologies (A somewhat extreme notion of "contingency" of organizational forms upon environmental characteristics is, of course, in Lawrence and Lorsch (1971).
He describes five basic organisational forms: (a) the "machine bureaucracy" with highly centralised control systems, suited to a stable environment; (b) the divisional form suited to mass production efficiency; (c) the professional bureaucracy made up of flat organisational structures, useful for delegating complex, professional tasks (e.g. in universities); (d) the simple or entrepreneurial structure, valuable for its informality and flexibility; and (e) the 'adhocracy', which is a temporary project-based design, suited to complex tasks and turbulent and uncertain markets. Somewhat similarly largely building upon a competence-based view of organizations, Teece (1996) proposes six categories of firm: (1) stand-alone entrepreneur inventor; (2) multiproduct integrated hierarchy; (3) high flex, Silicon Valley type; (4) "virtual" corporation; (5) conglomerate; and (6) alliance enterprise.[13]

Other observers of organisation form (e.g. Galbraith 1971, 1973; Larson and Gobeli 1987, 1989) describe a range of alternatives from pure functional form through to pure "product form", where management structures are centred upon each product.

A general conjecture lurking through many such taxonomic efforts is the positive relation between some form of organizational flexibility, on the one hand, and complexity and variability of tasks, on the other. In that vein, Burns and Stalker (1961) make the famous distinction between "organic" and "mechanistic" organizational types. They argue that the latter is more suited to stable environments

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on the establishment of projects within functionally-based organizations. See also Miller et al. (1995). Research on new product development and project success factors also illustrates the importance of the project form (Clark and Wheelwright 1992; Pinto and Prescott, 1988; Shenhar, 1993)

[13] On this see also Miles and Snow (1986), whose formulation of network brokers and partners is similar to Teece's virtual firm and alliance enterprise respectively.

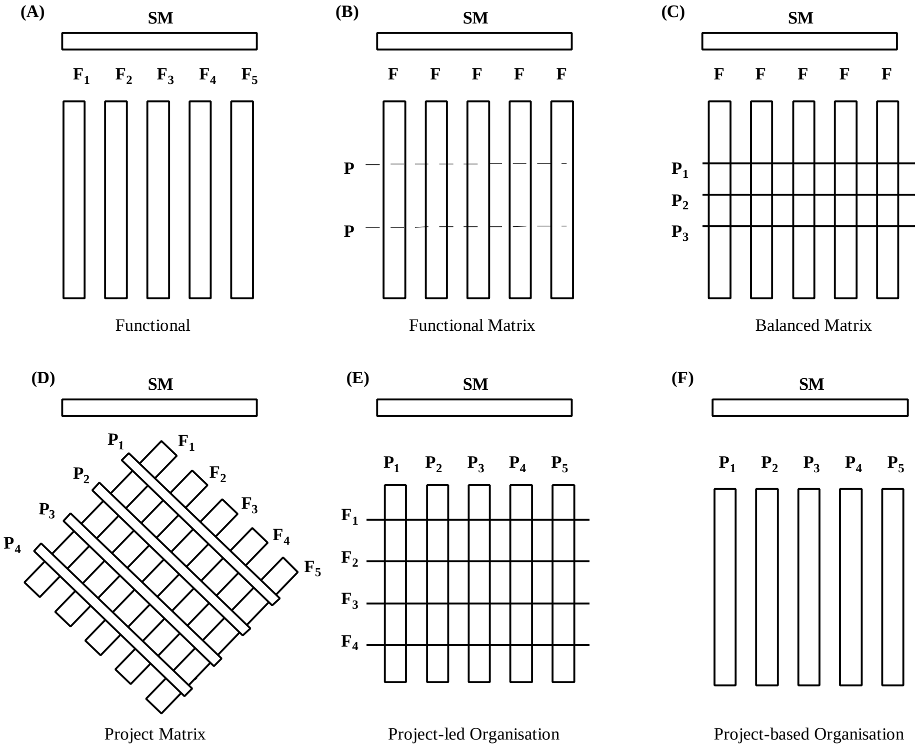
and routine PSB, taking advantage of e.g. clearly defined job description, stable operational boundaries and tayloristic work methods. Conversely, they suggest, under rapidly changing technological and market conditions, open and flexibile ("organic") styles of organization make for easier coordination between different organizational functions - such as R&D and marketing, etc. The spirit of most of the foregoing studies tend to be either *prescriptive* (i.e. focused on how to design suitable organizations) or *cross-sectionally* descriptive (comparing different sectors, technologies, etc.). That makes an interesting contrast with long-term historical studies, *in primis* the path-breaking investigations by Chandler (1962), hightlighting a secular trend form the rather simple owner/manager firms of the eighteenth century, all the way to the 20th century divisionalized/matrix form. This is not to say that the two views are necessarily at odds with each other. For example, it could well be that profound inter-sectoral variations (nested into different problem-soling tasks, as mentioned) happened to go together with an overall average increase in organizational complexity[14]. We cannot tackle the issue here. Let us just mention that diverse "cross-sectional and "historical" patterns are all nested into diverse forms of division of cognitive and manual labour which in turn is reflected in diverse PSB and learning patterns.
In the perspective of the interpretation outlined above in this work, diverse organizational forms map into diverse

(i) problem *representations*;
(ii) problem *decompositions*;
(iii) task *assignments*;
(iv) *heuristics for* and *boundaries to exploration and learning*;
(v) *mechanisms for conflicts resolution over interests*, and, equally important, over *alternative cognitive frames* and *problem interpretations.*

With respect to these dimensions, to repeat a telegraphic caricature we are rather fond of, one might think, at one extreme, of an archetype involving complete, hierarchical, ex ante representations, precise task assignments according to well defined functions/tasks, quite tight boundaries to exploration - "learning" being itself a specialized function - and, if all that works, no need for ex-post conflict resolution.
The opposite extreme archetype might be somewhat akin university departments, with a number of representations at least as high as the number of department members, fuzzy decompositions, little task assignments and loose boundaries to exploration, fuzzy conflict resolution rules, etc.
Clearly, Taylorist/Fordist organizational forms tend to be nearer the former archetype, which to repeat have never been experienced by COPs, for all the reasons mentioned above. However, they do display a quite large variety of arrangements, and with that equally diverse PSB.

[14] And some scholars further speculate that the future "archetypical" firm might be somewhat different from the classic "M-form": cf. among others, Miles et al. (1997) on the prediction of "cell-based" organizational structures.

Figure 1: Positioning the Project-based Organisation



Key:

* $F_{1-}F_5$ = various functional departments of the organisation (eg Marketing, Finance, Human Resources, Engineering, Manufacturing, R&D)

* $P_{1-}P_5$ = major projects within the organisation (eg CoPS projects)

* SM = senior management

Note: The number of functions and projects will vary according to the organisation in question. Various permutations are used here for illustration.

Figure 1 provides a description of six ideal-type organisational forms ranging from the pure functional form (Type A) to pure product/project form (Type F).[15] The various functional departments of the organisation (e.g. marketing, finance, human resources, engineering, R&D, and manufacturing) are represented by F1 to F5, while notional CoPS projects are represented by P1 to P5. Type B is a functionally-oriented matrix, with weak project co-ordination. Type C is a balanced matrix with stronger project management authority. Type D is a project matrix, where project managers are of equal status to functional managers. Type E, is a 'project-led organisation', in which the needs of projects outweigh the functional influence on decision-making and representation to senior management, but weak co-ordination across project lines occurs. Finally, Type F is the pure project-based form where there is no formal functional co-ordination across project lines and the entire organisation is dedicated to one or more CoPS projects.

The positioning diagram helps to contrast many of the various forms of organisation available for dealing with complex tasks, accepting that a mixed organisational structure is possible even within a single business unit. Forms A to C tend to be unsuitable for CoPS, because they are inappropriate for performing non-routine, complex project tasks in an uncertain and changing environment. CoPS projects typically require 'super-heavyweight' professional project managers (or directors), capable of integrating both commercial and technical business functions within the project and building strong lines of external communication both with the client (often the source of the innovation idea) and other collaborating companies. The collaborators may well have different goals, structures and cultures and the task of the project director is to skilfully negotiate a path towards successful completion.

The pure project form (F) appears to be well suited for large innovative projects and single project firms, where resources have to be combined and shared with other firms in the project (i.e. a large multi-firm project such as the Channel Tunnel). The project-form is suitable for responding to uncertainty and changing client requirements, coping with emerging properties and learning in real time. By contrast, the project form is weak where the functional and matrix structures are strong: in co-ordinating resources and capabilities across projects, in executing routine production and engineering tasks and achieving economies of scale for mass markets.

To illustrate the problem–solving advantages of the project-based form for CoPS, Figure 2 contrasts the project management task within a functional matrix (Type B) with that of a pure project form (Type F). Figure 2A shows the position of the 'weak' project manager within the functional matrix, involving multiple lines of communication, control and command, and the sub-ordination to various department managers. Here project co-ordination embodies a linear or sequential model of project management, in which the project passes through various stages and departments in turn. Client and suppliers are external to the project and the project manager has to perform a highly complex internal task of balancing various internal interests and meeting different demands (e.g. in terms of reporting and quality control) of the departments. There are many lines of communication with project team members (TM 1 to TM 6) who also report to functional or departmental managers (FM 1 to FM 6) to whom they owe their career allegiance.

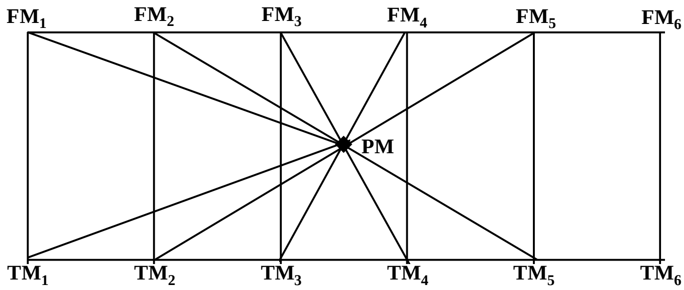
Throughout the problem-solving process, project managers in the functional and matrix forms also face many difficulties in external co-ordination. To reply to customer requests they often have gain information and commitments from engineering, purchasing and planning departments. The larger and more complex the project, the more difficult the task of keeping the client informed and responding to requests for changes.

[15] This section draws heavily on Hobday (2000).

Figure 2: Comparing the Project Management Function in functional and project-based organisations

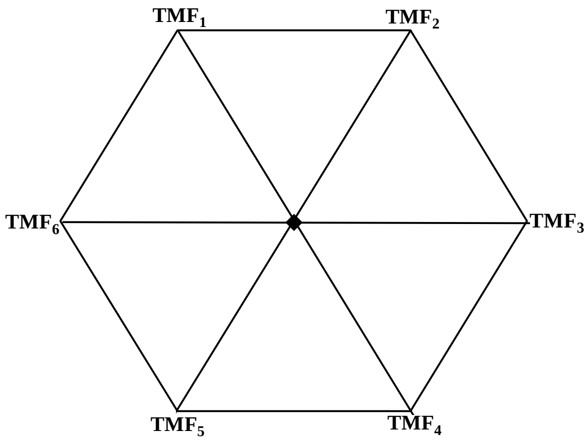
2A

Functional Matrix



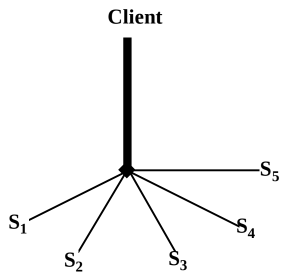
2B

Project-based organisation (internal co-ordination)



2C

Project-based organisation (external co-ordination)



Key:

- FM = Function Manager
- TM = Team Manager
- PM = Project Manager
- TMF = Team member/function
- S = Supplier

By contrast, Figure 2B shows the position of the project mangers in a project-based organisation in relation to the specialist functions within the project. The project manger is the main channel of communication and can exercise control to co-ordinate and integrate specialist functions, focusing on the needs of each project. Because there are few internal lines of command and communication to interfere with project objectives, the internal co-ordination task becomes simpler and the ability to react to emerging properties is enhanced.

Similarly on the external front, clear strong lines of command and communications can be built up with the client (Figure 2C). In principle, the project manager is able to quickly assess and react to changes in client needs and learn from feedback from the client and major component suppliers (S 1 to S 5). The project manager has both the responsibility and power to react to unexpected events, negotiate changes with the client and, if necessary, put suppliers of sub-systems together with the customer to resolve difficult problems.

The project-based organisation embodies a concurrent model of project management in which tasks are integrated as required by the project. In principle, the project-based form boasts several advantages over the functional and matrix forms for CoPS. Producing a CoPS is often a creative task, requiring innovation at both the product and organisational levels. Production typically involves many knowledge-intensive, non-routine tasks and decision-taking under conditions of uncertainty. These uncertain processes cannot easily be codified within routine procedures as learning during production is required to complete the task. Because the project-based form is able to create and re-create organisational structures and processes around the needs of each product (and customer) it contrasts sharply with the anti-innovation bias which are likely to be displayed by large functional organisations with their semi-permanent departments and rigid processes. The challenge of managing CoPS is one of ensuring responsiveness to the changing needs of customers, and dealing with the emerging properties which arise in production. It is also a challenge of anticipating future client needs and convincing buyers of the firm's competence to deliver new systems in the future. On the other hand, the looser the structure is the more difficult it is also to codify past learning achievements into some organizational memory; together, mobility employees might have a greater impact on organizational capabilities and performances. There are indeed subtle trade-offs in all the foregoing organizational arrangements – and together unexploited learning opportunities – of which most often the actors involved are only partly aware.
Symmetrically, "diagnostic" techniques and heuristics for organizational design might be surprisingly effective in the improvement of decision-making processes and PSB.

6. Heuristics for organisational design and collective action in complex task environments

In this respect, let us briefly report on how the foregoing framework on problem-solving can be combined with work from organisation development field to produce a method to assist in the real world of problem-solving, at least in the case of the design and the production of complex products and systems. We have been discussing above, from a theoretical point of view, the crucial step of decomposition of complex problems into nearly independent sub-problems and the difficulties thereupon. Indeed, a first operational task in a practical, diagnostic, exercise is to help identify alternative representations and, relatedly, decompositions of the problem at hand. Second, the exercise ought to be aimed to elicit the differences between formal vs. informal processes (and structures) for each project. Third, and relatedly, it provided mechanisms for a sort of endogenous benchmarking. This technique avoids the need for conventional benchmarking which, in any case, cannot be applied to one-off, non-routine tasks, but rather tries to elicit the very representation of such a benchmark and feeds back this data to the 'actors' in a structured manner in order to help them design and develop the complex product and ensure an appropriate organisational structure. The outcome tends to be a re-combination of tasks and structures in the companies in which the intervention was made and, in general, a reduction of the difficulties inherent in complex one-off tasks, through a narrowing of the gap between formal and actual practices and processes.

To operationalise the theory, an experimental attempt was made to develop and apply an action research technique to collective decision-making in six large multi-project CoPS suppliers in Europe.[16] The approach is partly based on intervention techniques developed within the field of organisation development (a sub-field of organisational behaviour), which spans both management strategy and implementation (Schein, 1990; Mullins, 1994; Handy, 1993; French and Bell, 1973; Tyson and Jackson, 1992), and tends to treat strategy, management, learning and innovation as iterative processes rooted in working practices, which are 'crafted', informal and sensitive to organisational forms (Mintzberg, 1989; Seeley Brown and Duguid, 1996). Using research data, selective outside interventions can sometimes be helpful in surfacing issues, identifying problems and stimulating new working practices (French and Bell, 1973).

The method was initially developed for the analysis and improvement of PSBs in complex software projects in collaboration with process analysts in a large French corporation. The purpose of the method (or 'tool') is to assist collective decision-making in order to arrive at effective PSBs and appropriate organisational forms for projects and specific tasks within projects (e.g. design, bidding and sub-contractor management), in the common situation where each product and project is different and processes are, to a large extent, uncodifiable.[17] The method involves generating benchmark data on behaviours, routines and structures and feeding this back to company teams in real time in order to assist problem-solving under conditions of bounded rationality and task complexity, by promoting more effective collective action by 'shining a mirror' on the organisation.

A distinctive feature of the method is that it focuses on the tacit, informal side of the PSB and informal organisations, comparing these systematically with formal processes and organisational structures. In other words it compares 'what should be and what should happen' with real, actual practices ('what actually happens'), in order to identify variance (for explanation and discussion) problems, their causes and strategies for improvement. The tool complements other formal procedures which exist in most large firms by delivering a 'bottom up' practitioner view of real processes in action.

The method is applied by decomposing the CoPS project roughly into tasks, which include not only the main technical activities, but other functions such as finance, manufacturing and scheduling. To carry out a minimalist intervention in a large firm, typically two projects are identified, to allow for comparability and contrast. Within (and above) the projects, twelve or so individuals at three or four levels of seniority are selected across the project tasks. The researchers then carry out the intervention with the members of the 'slice group' for each project, according to the five standard steps in Figure 3), each with more detailed sub-processes and outputs (Hobday and Brady, 1998).

Step 1 involves agreeing with management and practitioners the scope, aims, outputs and timing of the exercise, and identifying the slice group of interviewees (this focuses especially on practitioners

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[16] This work is carried out by one of us (M. H.)within the CoPS Innovation Centre at SPRU. Hobday and Brady, (1997; 2000) provide full details of the method, one in-depth case study, and the results of the six applications mentioned briefly below.

[17] In such cases, firms cannot apply normal benchmarking or improvement techniques (e.g. total quality management, continuous improvement, statistical process control or business process re-engineering) as these presume routine codifiable procedures, determinate tasks and established forms (usually departments), rather than temporary project forms.

who understand best the informal project processes). In step 2 data is collected on formal codified practices as usually contained in toolkits, manuals, flow charts, formal procedures (and a few interviews with senior managers), on how the process 'should' proceed. If the firm does not have formal codified procedures for the project, then senior management views or any 'best practice' model of project management can be used.[18] Using a standard questionnaire, qualitative data is gathered from practitioners on how processes actually proceed in the two projects and in the wider organisation (inputs, activities and outputs are described and informal flow charts are drawn). Step 3 involves comparing the formal ('should be') practices with informal, uncodified activities to generate key differences (e.g. by comparing formal and informal flow charts). This represents a rapid form of real-time benchmarking (comparing actual with codified practices) for complex tasks.[19]

Variances tend to fall into two categories: major problem areas and best practices (or solutions to problems). Often solutions consist of engineers resolving problems caused by the formal processes! In step 4 the findings are presented back to practitioners for verification, which involves feedback on the accuracy of the data collected, omissions, the extent and depth of problems identified and the nature of the solutions. At this stage, quantitative data can be gathered if needed (using Likert scales, for example, on the extent of particular problems in the organisation). Step 4 also includes an analysis of the causes of problems, a discussion of possible solutions and proposals for implementation, as applied both to project processes (including PSBs) and organisational structures. Step 5 involves reporting back to senior management (who have agreed to act on the findings) and the agreement of a plan for improvement. The actual format depends on the culture of the company. In some, the practitioners are happy to have senior managers involved closely in all steps. In others practitioners are inhibited in the presence of functional and project mangers.

Figure 3: Process Analysis and Improvement Method: Five Basic Steps

set up programme; identify structured group for interviews and workshops

❷ data collection: codified processes (management) *vs* actual informal processes (practitioners)

benchmark analysis: identify key variances (a) problem areas (b) best practices - prepare workshop 1

❹ workshop 1: (a) verification (b) establish causes of problems (c) identify solutions (d) proposals on implementation

❺ workshop 2: report back to senior management - agree actions/support for implementation

Although the method was initially developed for complex software projects, it has subsequently been modified and applied to other domains and other non-routine, complex processes. However, the approach remains the same - the application of an outside intervention to benchmark codified against actual processes in order to provide data to question, assess and sometime re-compose organisational

[18] Formal procedural models are presented in many project management and software engineering texts (including Boehm, 1988; 1989; Kellner, 1996), most of which are rationalist in that they do not recognise or deal with informal processes, structures or emerging properties.

[19] The aim is not to gather comprehensive data, but sufficient information to run the verification and improvement workshops.

structures and processes. The following six examples give some idea of the scope of the intervention technique.

Company A is a producer of complex embedded software for flight simulators. Here, the purpose was to improve software processes within a new change programme. The group discussions led to the questioning of (redundant) software tools and a reconfiguration of parts of the software process, contributing to an upgrading of the latter according to the official international quality standard 'CMM'. The intervention enabled software practitioners to shape work processes by contributing new more appropriate tools and training programmes aligned with real, rather than formal work processes, with the consequence of reducing also variances between initial software estimates and actual outcomes in terms of budget and costs. In the language introduced above, the objective was achieved by the identification of a closer alignment between formal problem decompositions/ task assignments and actual, "informally learned", ones.

Company B is a supplier of components for naval equipment organised along lines established lines in the 1960s. The task was the improvement of product development processes for a new generation of nuclear submarine cores. The two main technical groups involved - design engineering and manufacturing engineering - organised separately along traditional lines, were brought together during the intervention, enabling them to analyse, question and re-configure the 'normal' linear sequence of design and production. By introducing more concurrency into the design-build cycle, re-work was reduced as a result of closer engineering-manufacturing integration: more "fuzzy" decompositions, broader "spans of exploration" and faster information exchange cycles have been key organizational modifications.

Company C is a producer of synchrotron particle accelerators and large scale magnetic equipment for scientific research. This intervention focused on the assessment of the relative merits of two different organisational structures (one project-based and one functionally-based) in the company. The data gathered from practitioners during the interviews showed that the functionally-based structure was largely unsuitable for large one-off projects, although it operated well for batch production and standard product lines with little new technology. By contrast, the project-based structure revealed a close matching between formal and informal processes and an ability to cope with emerging properties in design and production, by virtue of project team coherence and strong leadership. The data were used to design and implement a new project-based structure for all major projects as an alternative to the functionally-based system. Together, some functional co-ordination was also introduced to promote learning and technical leadership along the lines of the project-led organisation (see Figure 1).

Company D is a producer of base stations for mobile phone systems. The intervention focused on the installation and extension of new turnkey systems for a mobile telecommunications network. The work, which compared formal project management processes with what actually occurred during the first implementation phase, captured major problems in the formal project management procedures and revealed many differences between formal and actual practices, - some of which hindered the project, others which helped -. The data were used by the company to develop a "best practice" 'Turnkey Project Start-up Guide' which formally embodied many of the informal practices and excluded unnecessary procedures. This was placed on the company intranet to be updated with new experiences as learning occurred in new projects.

Company E is a large telecommunications service provider introducing a new business line of 'integrated system and service solutions', involving several areas of network technology new to the company. The intervention helped practitioners decide which new processes and routines would be needed in bidding for new business contracts and which were only appropriate for traditional business lines. Eventually, this led to the setting up of, first, a consultancy wing of the company and, then, a New Projects Division, largely independent of the main organisation. This re-composition of the organisation turned out to be a valuable way of capturing and accelerating learning and rapidly expanding the new business.

Company F is a supplier of high value equipment for monitoring and measuring large scale (rolling mill) steel production. The intervention, which focused on both research and the development of prototypes for in-house use and for sale to external users, revealed that the main total quality programme (TQP) in place was suited to routine manufacturing activities, but unsuitable for the needs of R&D. In this case, the intervention was a rare opportunity for R&D staff to review internal procedures and external relations with university and sub-contractor partners. Eventually, the TQP was modified to recognise the uncertainties involved in R&D and the emerging properties expected in prototype development. Some modifications were made to the formal systems to bring them closer in line with real practices especially where sub-contractors and universities needed to be more closely integrated into the project teams.

To sum up, the diagnostic and benchmarking technique helped to analyse and re-combine processes and structures for one off, non-routine activities. In terms of scope, as the above cases indicate, the method has been applied to various complex tasks, cutting across sectors, technologies and different stages of the project life cycle, contributing to project processes and wider organisational structures. The above examples cover R&D, prototype development, design, engineering, production and installation of CoPS, as well as bid phase and new business development activities. In describing impacts and benefits, it is important to emphasise that the cases above represent experimental, small-scale interventions and that much depended on management follow through and, in some cases, on the success of the wider change programmes in which the interventions were embedded. It is also difficult to disentangle the effects of the interventions from the impact of other changes taking place (for example, three companies underwent mergers and restructuring during our work). However, each of the firms claimed that the de-composition and questioning of processes and structures, based on the foregoing heuristics had a significant impact on organizational learning and performances.

7. Conclusion

In this work, we have proposed and tried to make operational an evolutionary perspective for understanding firms as imperfect, collective problem-solving entities, suggesting an interpretative framework for the patterns by which firms deploy and match problem-solving activities with organizational structures. The paper applied these concepts to a broad class of high value capital goods (or ‘complex product systems’) which are inherently complex and non-routine in nature, conferring extreme task complexity throughout many stages of production and innovation.

The paper focuses on the processes through which problem-solving and creative knowledge co-evolve with organisational form in complex, non-stable, non-routine and complex task environments. Following Simon (1981), problem-solving and organisational structure are viewed as a type of design activity, where elementary physical and cognitive acts (or ‘elements’) are tested, combined and recombined to arrive at solutions. Because of bounded rationality, firms de-compose problems into manageable, but interdependent, and most likely “sub-optimal” blocks of elements. Within the firm, this is equivalent to a division of problem-solving labour, where the extent of the division of problem solving labour is limited by the existence of interdependencies. If, in the process of sub-problem decomposition, interdependent elements are separated, then solving each block interdependently does not allow overall optimisation. Since perfect decompositions with perfectly independent sub-problems rarely exist, boundedly rational agents normally try to design ‘near-decompositions’ which try to isolate the most performance relevant interdependencies into separate sub-problems. Problem-solving design does not only involve search within a given space but also, and very importantly, a re-framing of the problem itself by agents within the firm. By such re-framing the organization and groups within it arrive at more powerful representations, which often (but not always) allows also greater decentralisation and decomposability.

While the approach was applied to non-routine complex tasks and environment, the 'spirit' of the model also applies to routine, decomposable tasks. Here, however, the de-composition problem is, so to speak, resolved 'once-and-for-all', as for example in the Fordist/Taylorist archetype where the organisation is thoroughly designed and tasks are unequivocally assigned. Notice however that, even here, many activities remain by nature non-routine and complex, including strategy formulation, R&D, marketing and new product design and the de-composition approach to PSB and organisational governance is likely to apply. Furthermore, even the Fordist archetype eventually confronts technological and market changes which force organisational and task re-composition.

The application of the approach to complex products and systems showed how the various dimensions of product complexity can confer extreme task complexity and difficult problems of organisational design. For CoPS, one highly innovative form is the project-based organisation. While traditional functional and matrix structures embody a linear or sequential model of project management, the project form provides a concurrent model for integrating various complex technical and marketing functions under conditions of high uncertainty, emerging properties and changing user requirements.

To operationalise these ideas, an experimental attempt was made to facilitate collective decision-making for the purposes of process and structure analysis and re-composition in six large multi-project firms supplying CoPS in Europe. The method used is partly based on intervention techniques from the field of organisation development, which tends to treat problem-solving as iterative processes rooted in both formal and informal working practices and structures. The intervention method was designed to assist firms re-frame problems using research data which compares formal, codified processes with "real"/informal ones. The aim was to re-compose PSBs and structures to arrive at more appropriate organisational forms at the levels of projects and specific sub-tasks within projects (e.g. design, engineering, production, bidding, sub-contractor management, etc.), and wider organizational arrangements.

The apparent success of such heuristics – notwithstanding their simplicity and subject to the caveats mentioned above – is in our view an encouraging evidence of the rich *operational* implications of an evolutionary view of organizations centred on their changing problem-solving capabilities.
Adding more explicitly incentive – and power – related dimensions will certainly refine the analysis. However, as we tried to show, disentangling the processes of knowledge generation within firms is an activity of paramount importance in its own right – at both levels of theory and managerial practices. And one is only at the beginning of such an enterprise.

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