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# Innovating routines in the business firm:

# what corporate tasks should they be accomplishing?

by

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**SUMMARY**

One challenge in evolutionary economics is to give greater operational content to the notion of "innovating routines" inside the firm. Historical and contemporary evidence suggests that such routines always have to deal with increasing specialisation in knowledge production, increasing depth in knowledge sources and complexity in physical artefacts, and with the continuous matching of specific corporate competencies and organisational practices to the market opportunities offered by specific technologies. As a consequence, some innovating routines have always been important, such as those dealing with the tasks of co-ordination and integration within the firm, and of reducing uncertainty through learning. Others are becoming more so, such as those co-ordinating technological resources external to the firm, coping with systems and simulations, and adapting organisational practices to the requirements of radically changing technological opportunities.

## 1. WHY THE NOTION OF ROUTINES NEEDS MORE EMPIRICAL CONTENT

The purpose of this paper is to give greater empirical content to the notion, first elaborated by Nelson and Winter in 1982, of "innovating routines". They defined routines in general as the regular and predictable behavioural patterns within firms who are coping with a world of complexity and continuous change that precludes decisions and behaviour that maximise anything of importance. Whilst acknowledging the considerable uncertainties surrounding innovation, Nelson and Winter agreed with Schumpeter that " ….organizations have well-defined routines for the support and direction of their innovative efforts." (p. 134).

Since then, considerable brainpower has been mobilised to dissect the notion of routines, and to compare it with other concepts like "skills", "operating procedures", "capabilities", "competencies", and "distinctive corporate advantage". But we still have only a very hazy idea of what innovating routines are in practice. How would practising managers respond when asked, "what are your innovating routines?" At best, with polite incredulity. How would observant scholars recognise an innovating routine, when (and if) they visit a business firm? At best, by observation and good intuition.

There are at least three sets of reasons why knowledge of innovating routines – especially in large firms – deserves greater attention. The first is practical. It could help identify ingredients for the successful management of innovation, and links with corporate strategy. As we shall see later, it could also improve understanding of the links between private corporate knowledge and public academic knowledge, help identify some of the major implications for the management of innovation of improvements in information and communications technologies (ICT), and provide insights into the effects of technology on industry dynamics and structures.

The second reason is theoretical. The notion of "routines" was first developed by Nelson and Winter (1982) as part of a more realistic interpretation of what managers actually do in a messy and changing world. However, it can be argued that fewer insights of practical importance have been developed since then on the basis of the notion of routines, than on the basis of (say) transaction cost or principle-agent theories. At the same time, other dimensions of evolutionary economics have had more influence: in particular, in strategic management and industrial dynamics, where new theoretical concepts have been successfully combined with rich bodies of empirical evidence.

The third reason is that similar opportunities now exist in relation to innovating routines. Over the past twenty years, business historians, management specialists, sociologists, economists and other scholars have accumulated impressive bodies of evidence on what happens inside the innovating firm, and some have developed explanatory models for parts of the innovation process, including the capacity to distinguish success from failure[1]. This has writer has had two opportunities recently to read and assimilate this evidence: first, together with Ed Steinmueller for a chapter in a handbook for doctoral students on corporate strategy (Pavitt and Steinmueller, 2001); second, together with John Bessant and Joe Tidd

[1] One of the earliest was the distinction, made by Burns and Stalker (1961), between "mechanistic" and "organic" forms of organisation, with the latter better able to deal with changing and uncertain environments.

for textbook for masters students on managing innovation (Tidd et al., 2001)[2]. This paper is a first attempt to synthesise this evidence.

## 2. ASSUMPTIONS: ABOUT THE PRODUCTION AND USE OF KNOWLEDGE, AND ABOUT THE TASKS OF ROUTINES

### 2.1 The three dimensions of knowledge production and use

So far, this writer has been unable to find a simple or elegant theoretical framework to encompass the richness of the empirical material on corporate innovative activities[3]. However, in organising this material, it has proved useful to divide the processes of innovation into three, partially overlapping, processes each of which is more closely associated with contributions from particular academic disciplines.

- *Producing scientific and technological knowledge*: since the industrial revolution, the production of scientific and technological knowledge has been *increasingly specialised*, by discipline, by function and by institution. Here, history and social studies of science and technology have been the major academic fields contributing to our understanding
- *Transforming knowledge into working artefacts*: in spite of the explosive growth in scientific knowledge in this period, theory remains an insufficient guide to technological practice, given the *growing complexity* of technological artefacts, and of their links to various fields of knowledge. Technological and business history has made major contributions here and, more recently, so have the cognitive sciences.
- *Matching working artefacts with users' requirements*: the nature and extent of the opportunities to transform technological knowledge into useful artefacts vary amongst fields and over time, and determine in part the nature of products, users and methods of production. In the competitive capitalist system, corporate technological and organisational practices therefore *co-evolve*. These processes are central concerns of scholars in management and economics.

In sections 3 to 5 below, I shall identify in the light of these three processes, what are the essential managerial *tasks* that innovating routines must accomplish. Given current fashions that everything is changing, I distinguish tasks that innovating firms have been carrying out for some time and still need to do so, from those that appear to be genuinely new.

### 2.2 Tasks and Routines

Whilst we shall see that essential managerial tasks emerge from the features of innovation processes described above, they can be achieved through a variety and a combination of routines, some of which may be formal and explicit, and others implicit and organisationally embedded. Thus, to take the important task of ensuring integration amongst corporate functions (see 3.1 below), this may involve very formal routines imposed by management (e.g. planned flows of information and personnel amongst functions; matrix management; heavyweight project teams) to informal ones emerging from everyday practice (e.g. meetings

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[2] I have also benefited from earlier work with Stephano Brusoni and Andrea Prencipe (Brusoni et al., 2000), by P. Nightingale (Nightingale, 2000), and from reading Coombs and Metcalfe (2000).

[3] Given initial training, first, as a pilot, then as an engineer, I am uncomfortable with analyses that start with (for example) "Let's begin by assuming that metal fatigue does not exist." Subsequent experience in policy-related social science has re-inforced this view.

in bars and sports clubs; bootlegging and misreporting; e-mails). In other words, there are a variety of routines that can help accomplish a task essential for innovation. This paper does not have the ambition to evaluate the relative effectiveness of specific routines in accomplishing a given task. It restricts itself to identifying the tasks that routines must accomplish.

## 3. INCREASING SPECIALISATION IN KNOWLEDGE PRODUCTION

### 3.1 What's the same: Internal Co-ordination, Increasingly Multitechnology Products & Diversification

As Adam Smith rightly predicted, specialisation in the production of knowledge has turned out to be just as efficient as in the production of goods and services (Pavitt, 1997; Pavitt and Steinmueller, 2001). Three interrelated dimensions of such specialisation can be distinguished: - between disciplines in universities, between functions in firms, and between institutions (e.g. firms and universities) in countries. Specialisation requires co-ordination, but to differing degrees. Empirical studies show that some processes of co-ordination can and should be consciously managed and reasonably tightly coupled: like the links within the firm between R & D and other functions, and between corporate professionals in various scientific and technical disciplines. Others require a softer touch: like the establishment between universities and business of partly non-market based networks between like-minded researchers[5]. These findings confirm the notion that the more costly and less uncertain processes of technological selection should be more tightly constrained than the less costly and more uncertain processes of search.
Increasing specialisation in disciplines has also meant that an increasing range of fields of knowledge are being deployed in business firms to solve technical problems and to reach technical targets. Products incorporate an increasing number of fields of knowledge, and so are the firms that make them: compare the exclusively mechanical weaving loom of the late $18^{th}$ century with today's equivalent, which also incorporates electrical, electronic and even aerodynamic technologies. One consequence is that technologies (e.g. computing) should not be confused with closely related artefacts (e.g. computers), since the former is used in many more products than the latter (e.g. computing in automobiles. See also Granstrand et al., 1997). Another consequence has been that new combinations of fields of knowledge[6] have enabled firms based in rich fields of science and technology – like chemistry, and electrical and electronic fields in the past, and ITC today - to diversify by creating and entering cognitively related product markets.

Yet another consequence of specialisation has been the difficulties facing managers in large firms in decomposing their organisation, in order to match unique fields of technology with unique classes of product. Increasingly multi-technology products in diversifying firms have made the pure M-form of organisation impossible to sustain. Some of form of central corporate laboratory or technical competence persistently proves necessary in order to help mix and match changing technologies with changing products and divisions.

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[5] See, for example, Pisano, 1991.
[6] Although Schumpeter spoke extensively of "new combinations", he was not thinking specifically of knowledge (Tunzelmann, 1995, p. 76-78), to which Adam Smith gave more central important in the innovation process (Pavitt, 1997).

### 3.2 What's changing: External Co-ordination - the 'Third Face' of Corporate R & D

An important and relatively recent manifestation of the increasing specialisation in knowledge production has been the growth of so-called "strategic alliances" between large firms, designed to exchange knowledge in rich technological fields like ICT and biotechnology. One explanation for this growth has been that - as with production - firms have been "outsourcing" R & D in order to reduce technology-related costs, and to concentrate on their core technological competencies. But the evidence shows the contrary: both corporate R & D costs and their dispersion across fields have continued to increase in large firms (Granstrand et al., 1997)

A more plausible explanation is the continuously increasing number of technological fields that firms must monitor and master. These have increased not only with the division of labour in the production of knowledge, but also with the division of labour in the production of goods and services. The latter has led to increasing vertical disintegration (great "roundaboutness") in the production system. Changes and improvements in the production system can be handled satisfactorily through purely market mechanisms, when the links between the various production stages can be made modular, namely, when they have a standardised physical interface *between* each stage, which allows improvements to be made autonomously *within* each stage. Firms are then able to outsource current production of components and sub-systems, in order to benefit from cost advantages arising from competition, as well from changes and improvements still possible within established modular configurations.

However, complete modularity is not sustainable, for two reasons (Brusoni et al, 2000). First, growing product complexity increases the probabilities of unforeseen systemic interactions amongst components and subsystems. Second, rapid technical change and increases in performance in one part of a system can create both bottlenecks and opportunities in other parts. Under such conditions, firms at the centre of complex or fast-changing supply systems - be they physical supply systems as in the automobile industry, or knowledge supply systems as in pharmaceuticals - must also have the means to co-ordinate change in these systems, especially when they are designing and implementing major changes[7].

Empirical studies show that such firms maintain in-house a systems integration capability: first, in order to monitor and stimulate improvements by suppliers within the modular constraints of established systems; and second, in order to integrate major architectural changes periodically into new and improved systems. With increasingly systemic complexity (of which more in section 4.2 below), it is likely that a growing share of corporate technological activities are being devoted to these activities. In addition to innovation and imitation, corporate R & D now therefore has a third face (Cohen and Levinthal, 1987): co-ordinating change and improvement in increasingly complex external product and knowledge networks – often called "systems integration".

### 3.3 What's Changing: "Useful" University Research - Opportunities not Incentives

[7] For theoretical explorations of this phenomenon, see Franken et al., 1999; Marengo, 2000.

Another (perhaps related) recent change has been in the role of university-based research in underpinning corporate innovative activities. Here it is particularly important to distinguish rhetoric from reality. Much current rhetoric - mainly from government sources - is that university research has in the past been too "blue sky" and "academic", and should now be focussed more closely towards application. The current reality - based on statistical studies and surveys - shows that the research appreciated most by corporate practitioners is publicly funded, undertaken in high prestige research universities, and published in high quality academic journals (Mansfield, 1995; Narin et al., 1997). It also shows that the training of high quality researchers is generally more appreciated by practitioners than direct inputs of knowledge to corporate practice (Martin and Salter, 2001).
However, there is scattered evidence that university research is beginning to make more direct inputs into corporate technological activities, but not because of government-led policies and exhortations to be more "useful". For example, a recent study shows that licensing income from research in major US universities has increased dramatically in the past 20 or more years (Mowery et al., 2001). The rise began before the Bayh-Dole Act in biotechnology, suggesting that the increase has been opportunity-rather then incentive-driven. There have also been related increases in university-based spin-off firms, not only in biotechnology, but also in fields benefiting from improvements in large-scale data processing like speech recognition and computational chemistry (Mahdi and Pavitt, 1997; Koumpis and Pavitt, 2000).

One possible explanation for this apparently greater involvement is that, whilst large firms previously explored the opportunities emerging fast-moving fields from their central laboratories in direct contact with university departments, they are now doing so increasingly through "loose-coupled" arrangements to explore potential fields of application through university spin-offs firms. This may be linked to another change, namely the increase in the range of technological opportunities emerging from university-based research in certain fields, because applied experiments have become much cheaper, following improvements in fundamental understanding, in measurement, and in computation and simulation (see section 4.3 below). Given the high uncertainties involved, companies prefer to stimulate developments through loosely coupled arrangements rather than close integration (Pisano, 1991).

## 4. INCREASING COMPLEXITY IN ARTEFACTS

### 4.1 What's the Same: Coping with Uncertainty – Rules *vs.* Judgement

Schumpeter was right about the growing predictability of corporate *inputs* into innovative activities, but wrong about *outputs*. Specialised R & D and related activities have certainly become institutionalised and predictable source of discoveries, inventions, innovations and improvements. But technologists and managers are still not able to make accurate predictions about the emergence and acceptability of major new products, about the technical performance of newly designed artefacts, about the costs or time to develop them, or about the size of market for specific innovations. This is because the world of innovation is complex, in that it involves many variables, the properties and interactions of which are understood only very imperfectly. As a consequence, we are not able to explain fully and predict accurately either the technical performance of major innovations, or their acceptability to potential users (or even who the potential users are).

Corporate management therefore continues to have difficulties in deciding how to deal with innovative activities, which have some of the elements of conventional investments activities, but which are also uncertain and therefore require continuous feed back from experience and experiment to learning. The broad differences between search and selection activities has been recognised for a long time in practice with the distinction between corporate and divisional R & D activities, and in theory with the distinction between "knowledge building" and "strategic positioning" on the one hand, and "business investment " on the other (Mitchell and Hamilton, 1988).

However, as the recent history of corporate R & D shows, maintaining balance and linkages between the two is not an easy task. Briefly stated, there is no one best way of evaluating corporating R & D expenditures *ex ante*. Rule-based systems fail because they inevitably simplify, and may therfore neglect what turn out to be important factors in a complex system. Judgement based systems fail because of the impossibility of quickly distinguishing good judgement from good luck. As a consequence, there are periodic swings in fashions and management practices, with attempts - often following "failures" or examples of "waste" - to "manage" R & D more effectively through "better" techniques forecasting, more "rigorous" methods of personnel management, and of project selection and control. These are often subverted by practice and by evidence of missed opportunities. Professional judgement and experience then displaces management technique as the main basis for decisions, and the co-ordination of learning across organisational and professional boundaries becomes paramount. This style of innovation management is likely to be more successful, but more difficult to achieve, since it depends on the person-embodied skills and informal networks, rather than on codified techniques and procedures. So failure can start off the whole cycle again.

### 4.2 What's the same: Increasing Scientific Understanding & Increasing Technical Complexity

One interesting paradox in the development of new technology is that, despite the massive increase in scientific understanding in the past 200 years, technological practice stills runs ahead of what scientific theory can predict. Most expenditure in business firms is still on the development and testing of specific artefacts rather than on the development of underlying theory. The sheer combinatorial complexity of useful artefacts precludes accurate predictions of practice based purely on theory (Girin, 2000). This is why technology advances through the practices of scientists and engineers that Constant (2000) has recently described as recursive, involving "alternate phases of selection and of corroboration by use. …… The result is strongly corroborated foundational knowledge: knowledge that is implicated in an immense number and variety of designs embodied in an even larger population of devices, artefacts, and practices, that is used recursively to produce new knowledge." (p. 221).

However, there are grounds for thinking that technical complexity cannot run too far ahead of scientific understanding. The feedback loops in both directions between improvements in scientific understanding and improvements in technical performance have been well documented by historians and others[8]. More specifically, increases in technical complexity and associated increases in combinatorial complexity will by themselves increase the risks and costs of search and selection. One factor that can reduce them is improved scientific understanding of cause-effect relations, very often emerging from advances in the technologies of measurement and manipulation of the increasingly small. This has been the case in the past decades in molecular biology and materials, both of which have opened major new opportunities for technical change[9].

### 4.3 What's changing: ICT in improving understanding and increasing complexity

A second factor reducing the costs of search and selection has emerged from ICT. Major advances in large-scale computing and simulation technology are reducing considerably the costs of exploring alternative technical configurations. Nightingale (2000) has shown that experimental techniques in the pharmaceutical industry have in the past ten years seen major changes resulting from all the mechanisms described above: first a shift towards more fundamental science, for example, linking biochemical mechanisms to the expression of genes; second, using simulations and data banks to conduct virtual experiments complementary to real ones; third, using high throughput screening techniques. His findings tend to corroborate the recent suggestion by Perkins (2000) that improved search strategies involve both "code" (i.e. theories) and "construction" (i.e. prototypes)[10].

However, Perkins' (and others') use of "Fitness Landscapes" does not grapple with most of the central features of corporate activities for technological search and selection that can be found today in sectors as different as aircraft and pharmaceuticals: namely, the design, testing and re-design of hierarchical and interdependent systems, subsystems and components, based on bodies of increasingly specialised knowledge and practice, that are continuously improving, and at different speeds.

Finally, whilst reducing the costs of search, advances in ICT are also increasing opportunities for greater systemic complexity.. Advances in network and digital technologies are opening major new possibilities of products and services with much greater systemic interdependence , involving not just the spheres of production and exchange, but also those of distribution (e.g. logistics, sales and deliveries in retailing) and of domestic consumption (TV, computing, messaging and photography).

## 5. THE CO-EVOLUTION OF TECHNOLOGY AND ORGANISATION

### 5.1 What's the same: Matching Specific Technologies and Specific Organisational Practices

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[8] See, for example, Rosenberg and Nelson (1994) on the origins of the engineering disciplines in US universities.

[9] A similar conclusion has been reached by Becker and Murphy (1992). They argue that the degree of specialisation in tasks is limited not by the extent of the market, but by the costs of co-ordinating specialised activities. These co-ordination costs are reduced by increases in general knowledge.

[10] Without any such theoretical codes, and without any cheap method of constructing and testing prototypes, the costs of search and selection can become prohibitively high. See Martin on why Japanese swords did not improve over a period of more than 5000 years.

It is a commonplace today to argue that technologies and organisational practices co-evolve. It is less common to expose oneself to accusations of "technological determinism" by arguing that, on the whole, corporate organisational practices adapt, in order to exploit emerging technological opportunities. On historical grounds, Chandler (1977) has shown that the rise in the USA at the end of the nineteenth century of the large, multi-unit firm, and of the co-ordinating function of professional middle managers, depended critically on the development of the railroads, coal, the telegraph and continuous flow production. Similarly, the later development of the multi-divisional firm in part reflected the major opportunities for product diversification in the chemical industry opened up by breakthroughs in synthetic organic chemistry.

Technical advances normally precede organisational advances, because of their firmer knowledge base and the lower costs of experimentation. This does not mean that technology imposes one organisational "best way": variety in the characteristics of technologies, their continuous change and uncertain applications lead to variety and experimentation in organisational practices. But it also does not mean that "anything goes" in organisation. For example, a firm practising conventional cost-benefit analysis and strict cost controls with all its investment decisions will not prosper in the long term in a competitive market governed by the exploitation of a rich, varied and rapidly advancing body of technological knowledge[11].

Based on the empirical literature, the first two columns in Table 1 identify the key features of technologies that must be matched with corporate organisational practices. The richness of the technological opportunities and the scale of technical experiments will determine the appropriate share of resources allocated to technological search, as well as the degree of centralisation and fluidity in organisation structures. Supporting skills and networks will define the specific competencies to be accumulated, professional networks to be joined and key functions and functional interfaces within and across which learning must take place within the firm. And the strategic position of the firm will determine which the technologies are supported as part of its distinctive core advantage, or as necessary background technologies.

[11] See, for example, the history of the UK General Electric Company under Arnold Weinstock (Aris, 1998)

**TABLE 1 MATCHING CORPORATE TECHNOLOGY AND ORGANISATIONAL PRACTICES**

| CORPORATE TECHNOLOGY ➔ | MATCHING ORGANISATION PRACTICES➔ | DANGERS IN RADICAL TECHNOLOGICAL CHANGE |
|---|---|---|
| ***INHERENT CHARACTERISTICS***<br>1. Richness of opportunities | 1a. Allocating resources for exploring options<br><br>1b Matching technologies with product divisions | 1a. Greater opportunities not matched by resources for exploring options<br><br>1b. Matching opportunities missed |
| 2. Costs of specific technical experiments | 2. Degree of centralisation in decision-making | 2. Reduced cost of experiments not matched by decentralisation |
| ***SUPPORTING SKILLS AND NETWORKS***<br>1. Specific sources of external knowledge<br><br>2. Accumulated knowledge of specific customers' demands, distribution channels, production methods, supply chains. | 1. Participation in specific professional knowledge networks.<br><br>2. Learning and improving in key functions and across key functional interfaces. | 1. Difficulties in recognising & joining new knowledge networks<br><br>2a. Difficulties in recognising & responding to new customers' demands, distribution channels, production methods, supply chains.<br><br>2b. Difficulties in recognising new key functional interfaces<br><br>3. Scepticism and resistance from established or potentially obsolescent professional and functional groups |
| ***STRATEGIC POSITION IN THE FIRM***<br>1. Core technologies (Central to sustained competitive advantage. Difficult to imitate)<br>OR<br>2. Background technologies (Necessary for use of outside technologies in supply chain and pervasive applications) | 1. Strong commitment of technical resources to maintain state of the art<br>OR<br>2. Commitment of technical resources sufficient to monitor and assimilate technologies developed outside the firm | Inability to distinguish core from background:<br>1. Excessive outsourcing of core technologies;<br><br>OR<br>2. Inability to sustain competitiveness with background technologies |

Differences amongst technologies are therefore reflected in differences in organisation practices. Thus, given rich technological opportunities, both pharmaceutical and consumer electronics firms devote substantial resources to technological search; but given the much higher costs of experimentation, the former tends to have centralised and formal procedures for launching new products, whilst the latter is more likely to be decentralised and informal. Similarly, both pharmaceutical and automobile companies have centralised decision structures, but the former will stress interfaces between corporate R & D and public research in bio-medical fields, whilst the latter will stress links between R & D and production.

### 5.2 What's the Same: Widespread Adoption of Revolutionary Technologies

The past 200 years has seen periodic step-jumps in technological understanding and performance in specific fields, based increasingly often on major scientific breakthroughs. These have reduced considerably the costs of key economic inputs, and have therefore been widely adopted and become the catalysts for major structural changes in the economy. They include steam power, electricity, motorization, synthetic materials and radio communications (Freeman and Louca, 2000). The contemporary example is of course the massive and continuing reductions in the costs storing, manipulating and transmitting information brought about by improvements in ICT.

Each wave of radically new technologies has been associated with the emergence of firms that have mastered the new technologies, and that have led in the development and commercialisation of related products, processes and services. In the current jargon of corporate strategy, these firms have developed *core competencies* in the new technologies, which have become a distinctive and sustainable competitive advantage. They must be distinguished from the far more numerous firms who adopt and integrate the new technologies with their current activities. For these firms, in-house competencies in the new technologies are *background*: in other words, necessary for the effective adoption of advances made outside the firm.

Paradoxically, the very fact that new technologies allow step-jump reductions in the costs of a key input simultaneously makes their adoption both a competitive imperative, and an unlikely source for the adopting firms of their own distinctive and sustainable competitive advantage. For example, in the past many factories had no choice but to adopt coal and steam - and later electricity - as a source of power, given their cost and other advantages. The same is true today for many ICT-based management practices. In neither case were - or are - these revolutionary advances by themselves a source of sustainable competitive advantage for the adopting firms. This means that much of the emphasis by writers on corporate strategy - like Barney (1991) and Porter (1996) - on the importance of establishing a distinctive and sustainable advantage does not, and cannot, apply to the major transformations now inevitably happening in many companies through the adoption of ICT. Their framework helps understand *CISCO* (a major US supplier of equipment for the Internet), but doesn't help much with *TESCO* (a major UK supermarket chain, increasingly using the Internet).

### 5.3 What's changing: Creative Destruction in Organisational (not Technological) Practices

Ever since Schumpeter associated the advent of revolutionary technologies with "waves of creative destruction", there has been debate about the relative role of incumbent large firms and new entrants in exploiting them. Over the past 20 years, most of the analytical writing has been stacked against incumbents, although recent empirical studies can point to evidence in favour of both (Methe et al., 1996). Over time, the weight of the arguments against has shifted. Earlier studies emphasised the difficulties facing incumbents in mastering new fields of technological knowledge (Cooper and Schendel, 1976; Tushman and Anderson, 1986; Utterback, 1993). More recently, there has been a shift towards emphasising the difficulties in changing and matching established organisational practices to the opportunities opened by revolutionary technological changes: examples include the organisational consequences of changes in product architectures (Henderson and Clark, 1990), resistances from groups with established competencies (Leonard-Barton, 1995; Tripsas and Gavetti, 2000), and of the unexpected emergence of new markets (Christensen, 1997; Levinthal, 1998).

Contrary to a widely made assumption, the nature and directions of radical new technological opportunities are easily recognised by the technically qualified: for example, miniaturisation, compression and digitalisation today in ICT. The technological consequences of these trends can be explored in corporate R & D laboratories: thus, a growing number of large firms in a growing number of industries are now technically active in ICT (Granstrand et al., 1997; Mendonca, 2000). However, the difficult, costly and uncertain task is that of combining radically new technical competencies with existing technical competencies and organisational practices, many of which may be threatened or need to be changed. Experimentation and diversity is therefore necessary, not in exploring the directions of radical technological changes, but their implications for products, markets and organisational practices.

The third column of Table 1 tries to identify some of the reasons why such experiments may fail in incumbent firms. Some are a consequence of the need to modify competencies or organisational practices, and some of the inevitable uncertainties in the early stages of radically new technologies. The likelihood that established firms will fail increases with the number of practices and competencies that need to be changed. Here a comparison between the conclusions of two recent industry studies is instructive. Klepper and Simons (2000) have shown that firms already established in making radios were subsequently the most successful in the newly developing colour TV market. On the other hand, Holbrook and his colleagues (2000) have shown that none of the firms established in designing and making thermionic valves were subsequently successful in establishing themselves in semiconductors. With the benefit of hindsight, we can see that success in semiconductors required more changes in both technological competencies and organisational practices amongst incumbents than success in colour TV. The valve firms required the new competencies and networks in quantum physics, a much stronger interface between product design and very demanding manufacturing technology, and the ability to deal with new sorts of customers (computer makers and the military, in addition to consumer electronics firms). For the radio firms, the shift to colour TV required basically the same technological competencies, augmented by well-known screen-technologies. Otherwise, the customers and distribution channels remained unchanged, as did the key networks and linkages both inside and outside the firm.

# 6. CONCLUSIONS

## 6.1 Achievements so far

This paper has argued that innovating routines in business have to deal with three fundamental features of technical change in modern societies: increasing specialisation in knowledge production, the tendency for technological practice to run ahead (but not too far ahead) of scientific theory, and the continuous matching of the specific features of changing technologies and specific organisational practice that transform technology into useful artefacts.

It emerges from our analysis that some of the tasks of innovating routines are long established, and continue to be important: for example, co-ordination and integration of internal knowledge sources and functions; technology-based product diversification; coping imperfectly with uncertainty; learning by analysing and by doing. Other tasks are growing in importance as a consequence of increasing specialisation in knowledge production: co-ordination and integration of external as well as internal knowledge sources; anticipating the dangers of creative destruction in corporate organisational - rather than technological - practices. And yet others are changing - at least in part - because of the effects of rapid improvements in performance in ICT: increasing technical complexity; reduced costs of technical experiments; more direct links in university research to practice.

The paper has (hopefully) one achievement. It has made at least some progress in its initially stated purpose to give more operational content to the notion of innovating routines. Based on the corporate tasks identified above, it should be possible for academics to ask questions about how they are accomplished in business firms, to get meaningful answers, and thereby identify innovating routines. It also opens a rich research agenda on the efficacy of various routines – and combinations thereof – in accomplishing the corporate tasks in specified circumstances.

## 6.2 Next Steps: Checklists, models or recipes?

However, the paper has two very obvious limitations. The first is theoretical. Although it proposes the three fundamental features of innovation process repeated above in the opening paragraph of the Conclusions, it offers no testable model of the innovation process. This is because, in this author's view, a comprehensive and testable model dealing with all the important factors identified above cannot yet be built[12]. In such circumstances, it is probably better to keep things simple, and start from a checklist of important tasks and related routines. Thereafter, it will possible usefully to model and predict delineated parts of the innovation process, provided boundary conditions are carefully and realistically defined. For example, one would justifiably be sceptical about the explanatory power of a model of a supplier-user alliance, established to develop new and radically improved product components, if it assumed that the alliance was a zero-sum game.

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[12] In a recently published book about technological change, contributing scholars from a variety of disciplines concluded that " its categories and their interactions are too imprecise and contextual to be represented realistically by a computable algorithm. ……. A mathematical simulation can never be true to life. It …is a metaphor in its representation of a real system with complex unquantifiable structural relationships between its elements" (Ziman, ed., 2000, p.312).

The second, more practical, limitation is that the paper offers no obvious simple recipe for managerial action to promote successful innovation. Here we can be more categoric: there is none. As we have seen, well established tasks often still matter, new ones emerge, and their precise nature varies between technologies, and changes often unpredictably over time. Given these conditions, we can at best offer a checklist of important innovation-related tasks on the basis of which corporate practitioners can use their judgement and experience. This presumably is what they are paid to do.

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