EVOLUTION, TECHNOLOGY, POLICY AND TECHNOLOGY MANAGEMENT*

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This paper outlines recent developments in our understanding of the process of innovation and the implications for technology management. It addresses the puzzle of the interface between technology management (private, for profit, firms) and technology policy (government), and the obvious implication that effective policy must be conditioned by an understanding of the practice of management. Equally important is the view that technology management is to be understood in terms of the systems of institutions which generate and support technology, systems which extend beyond the boundaries of individual firms. Underpinning these themes is a particular subplot, namely the link between technology management and competitiveness.

Keywords: technology, technology policy, technology management, evolutionary economics

INTRODUCTION

A recent issue of the *Harvard Business Review* provoked a lively debate with a paper entitled 'Does America need a technology policy'.[1] This debate is notable for its lack of agreement on the fundamental issues, which is not surprising in the light of the reasons why this is such a complex area. Of some importance here are three issues: that technological innovation is at the core of the mechanisms which define modern capitalism, and these mechanisms are extremely complex; that technology is only one factor in determining competitiveness, and it is impossible to separate it from questions of organisation; and, that technology is itself complex with immense scope for misunderstanding if its dimensions are not properly distinguished. One cannot hope to understand the link between technology, innovation and competitiveness by focusing on the individual firm, an internalist view is simply not adequate. Moreover, a wealth of case studies of individual firms show a bewildering complexity in terms of strategies, practice and performance in technology management. This diversity is the key to understanding the nature of competitive behaviour and it is undoubtedly an error to reduce this diversity by invoking an ideal typology of firms. The importance of diversity in innovative behaviour takes us immediately to the classical conception of competition as rivalry, driven by the differences between firms and ultimately grounded in the idea of entrepreneurial behaviour. Markets provide the framework for a dynamic of economic change and

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it is in this context that the distinctive contribution of the evolutionary approach emerges.

Stimulated by the work of Nelson and Winter,[2] but with many precursors,[3] a growing band of scholars is developing on account of the economic process in which all the components in the jigsaw fit together while representing a continually changing picture. Two aspects of the evolutionary school are important in this context. First, it has always looked to the management literature for insights into the origins of diverse behaviour. Secondly, it combines the strength of economics (the importance of the interactions between individual behaviours) while avoiding the weaknesses (an indifference to the internal operation of organisations and their diversity). All this involves a considerable change in methodological approach to the study of competition. The question is no longer how to characterise the similarities between firms, but rather what sense to make of the differences between them. How these differences arise, how they are contained and limited, and how these differences are resolved into market outcomes, become the central issues in the evolutionary approach. From this, several insights follow: the rejection of essentialist doctrine and its handmaiden, the representative agent; the understanding of behaviours in the context of an evolving population distribution; the importance of history and the significance of small differences in behaviour; and the relativeness of the competitiveness concept in that competition depends on where the firm is located in the relevant distributions of behaviour.

All this leads us to what may be termed the 'technology policy paradox'. Diversity in behaviour drives competition, but competition destroys that very diversity (evolution consumes its own fuel). Thus if competition is to be sustained, some mechanism has to be introduced to replenish variety. Mechanisms in relation to innovation are obviously central to this task and it is this which brings us to the importance of technology management and policy, and to a technology systems perspective on the generation of innovative variety. But first some elaboration of the evolutionary foundations of technological competition is required.

TECHNOLOGICAL COMPETITION

Let us begin with a brief synopsis of the evolutionary mechanisms which drive economic change. They are two in number: mechanisms creating asymmetries in firm behaviour, typically in terms of products and their methods of production;[4] and dynamic selection mechanisms of non market and market types which change the relative importance of the competing behaviours and eliminate the least effective.[5] We should be clear at this point that the equation of evolution with biological science can be the source of many serious misconceptions. In biology, it is random mutation which generates diversity in behaviour, but – without denying the significance of random events – this will not do for our purposes. In particular, economic evolution depends upon the operation of learning mechanisms and the anticipation of possible future states of the world. Far from weakening the evolutionary argument, learning and anticipation (entrepreneurship!) greatly strengthen its application to competition, leading us directly to the central importance of the adaptive, creative firm.

A third aspect of evolution now becomes relevant, that of complexity and its implications for problem solving and decision making. If problems are too complex to be well defined, then so are their solutions. There are natural limits to the application of rational deductive analysis. In a complex world, we expect behaviours to be at best boundedly rational with complex problems solved predominantly by induction on past experience, combined with creative insight. These are essential elements in understanding how firms come to behave differently. They operate in the same world, but perceive different vistas. Even if they could be said to behave rationally, their optimisations would be local, not global, and therefore, in all likelihood, different. How firms construct images of their environment, their paradigms and research programmes is an issue of central concern to the evolutionary perspective. With the behavioural perspective in mind, it follows naturally to think of firms as bundles of interdependent behaviour routines,[6] routines which are the components of corporate competence and which adapt to experience and creative insight, though always subject to inertia.

In terms of technology management, the relevant categories of routines are three in number: routines to create the agenda for innovation, the list of alternatives from which firms make choices about future technologies; routines to select from the agenda; and routines to manage the process of technological development. Taken together, these routines determine how good the company is as an experimental institution. Thus, from this evolutionary perspective, the company's creativity is as central to its competitive performance as its efficiency. Much of the management literature tells us that creativity and efficiency are often in conflict, that they require different managerial and organizational styles[7], and that there is much more to the management of innovation than R&D based activity. Moreover, we now realise that there is considerable diversity across firms in the routines they employ, and their routines to change routines. It is this diversity which provides the foundation for the market process of competitive selection, the dynamics of growth and change in market share which provides the evidence for evolution at the economic level. As an aside, we can note now that mathematical tools are now available to handle these complex processes in a way not possible with conventional optimising techniques and their associated equilibrium-dependent dynamics.

TAKING TECHNOLOGY SERIOUSLY

To understand more fully the origins of diverse innovation behaviour, it is clearly necessary to take a more serious attitude to technology. New views have emerged in economics, in strategic analysis and in the historiography of technological change, with a number of excellent histories of corporate creativity.[8] One hesitates to say that an all encompassing view has been reached for novelty creativity and entrepreneurship are not obvious candidates for Cartesian analysis. It is indeed a mistake to think that the only useful questions are those with precise answers.

Consider, for example, the relationship between science and technology. A wealth of historical work has established that science and technology differ in the nature of the knowledge they seek and in terms of the underlying patterns of discovery.[9] While science is important to technology, the relationship is subtle. That science leads and technology follows is a thoroughly discredited viewpoint. Quite crucially, three different dimensions of technology need to be distinguished: as knowledge, as practical skill and as artefact. Each is accumulated by different mechanisms and in different institutional contexts. Moreover, while it is economic to codify much knowledge, substantial portions of technological knowledge remain tacit and accessible only through the development of individual skill. This tacit knowledge is communicated by personal contact and demonstration; it is accumulated by experience gained in specific contexts. We should note carefully that the tacitness of knowledge depends to a considerable degree on the economics of writing codes, with both coding and decoding costs being important determinants of tacitness. Two important points follow from these distinctions. First, publicly available information is not automatically absorbed in a costless fashion. Economists may claim that science is an international public good, but it is not a free good. Indeed, much corporate R&D can be understood as an attempt to listen-in and participate in the open scientific debate.[10] Secondly, technology transfer is a nontrivial problem. When codes are written by different organisations, it is hardly surprising that communication can be a particularly intractable and costly business.[11]

While it is the artefact dimension of technology which is always at the cutting edge of technological competition, it is the knowledge and skill dimension of technology which raises some of the most complex issues for technology management. There is, for example, the appropriability problem, which can effectively undermine the incentive to invest in skills and knowledge. That others can reap where the innovator sows may be competitively efficient, but it is not competitively creative. As Downie and Richardson point, out competition works dynamically only if there is sufficient sand in the wheels of commerce.[12] Thus, innovative competition depends on the existence of information asymmetries which make competition imperfect, but which certainly cannot be termed market failures. In short, a dynamic, innovation-based economy will fail all the tests of static market efficiency. Schumpeter clearly understood this, as did Hayek, with their insistence that static efficiency is not the proper basis for evaluating the institutions which underpin economic progress.

Because markets for knowledge and skills are necessarily imperfect, one would expect a variety of different co-ordination mechanisms to emerge, and they have. Vertical control of innovation within organisations, networks for the formal and informal exchange of knowledge, and collaborative innovative activities across independent organisations are all examples of necessarily non-market co-ordination. Each involves difficult questions of technology management; for example, in relation to the differences in operation between scientific, technological and industrial networks.

Any evolutionary theory has to have a clear view of what it is that evolves, and thus a concept of an appropriate unit of selection. It is now apparent that the single innovation perspective is seriously deficient. Rather, what evolves and is selected is a sequence of innovations related by their origins in a common set of technological principles, a design configuration. The design configuration provides the framework which shapes the day to day activities of innovators and technologists, a heuristic, a set of guideposts or focusing devices, with paradigmatic qualities.[13] The configuration identifies possible paths of advance, it constrains what can be done, it is the framework for learning within which knowledge builds cumulatively. Now the crucial point is that each distinct business unit (not co-terminous with the firm) is built around a particular design configuration. This provides strength by focusing activity and weakness by limiting the capacity to read changes in the external environment. Configurations are fully compatible with the product cycle perspective and help us understand the difficulties business units have in shifting to different design configurations, and their inability to appreciate the significance of apparent minor changes in a competitor's technology.[14]

In terms of economic evolution, design configurations are subjected to two distinct kinds of selection process: internal selection processes in business units and their umbrella firms to decide which configurations to adopt and how to develop these – the prerevelation stage – and external selection processes in which the market selects between competing artifacts - the post revelation stage. While this is straightforward enough, matters are necessarily made more complex by the fact that technologies are not developed by firms in isolation; rather they operate in the context of a wider innovation support system.

A TECHNOLOGY SYSTEMS PERSPECTIVE

This idea, central to current thinking about innovation, has a long history. In the early 1970s, Chris Freeman and colleagues at the Science Policy research Unit at the University of Sussex stressed the importance of institutional coupling devices in the innovation process. Different kinds of knowledge, located in different organisations, have to be combined to achieve significant improvements in technology. Here there is a strong division of labour, with many institutions, universities, research institutions and professional societies supporting the activities of firms. The different institutions accumulate and disseminate knowledge in different ways, and operate with different incentive mechanisms, geared to different time horizons. How they fit together as a community of interdependent practitioners is a crucial question in understanding the creativity of firms.

The extent to which the various institutions constitute a national system of innovation has been extensively investigated.[15] The identification of boundaries and the nature of institutional bridging mechanisms are major research tasks which indicate significant inter-country differences. Innovation systems are, of course, national by virtue of customs, language, legal framework and policy domain, but how viable is a national viewpoint? Science is international, multinational corporations are significant generators of innovation, and there are important inter-nation collaborative attempts to develop technology. On the other hand, significant groupings of institutions may operate at a sub-national level in terms of local networks, or, as Marshall would have termed them, industrial districts.[16] Rather than prejudge the appropriate domain, it is simply enough to recognise that each technology has its own institutional arrangements and dynamics of accumulation. Nelson has distinguished technologies according to how close they are to a science base,[17] and Pavitt has developed an influential taxonomy of different types of technology innovation support system.[18] Malerba, in his study of post-war Italy, finds two independent innovation systems, one composed of networks of small firms, the other of large firms and university complexes.[19] Finally, Carlsson has shown in the Swedish case how different technologies have different support systems, some of which are international in scope.[20] From all this it is clear that the understanding of the generation and operation of technology systems will be an important theme in future innovation research.

A brief illustration of the importance of the system perspective is provided by collaborative R&D arrangements to couple together different sources of technology.[21] From an evolutionary viewpoint, these constitute examples of group selection – the participating firms intend to derive competitive advantages not available to nonparticipants in collaboration. The significance of any such venture lies in increasing the creativity of the participants, in particular through the sharing of complementary knowledge bases. However, collaborations are not costless and raise some complex issues for technology management concerning choice of partner, exit routes and the valuation of foreknowledge brought to the venture.

THE EVOLUTIONARY PERSPECTIVE ON TECHNOLOGY POLICY

Collaborative R&D ventures lead neatly to the final topic of technology policy. The traditional view within economics is of the optimising policy maker (the omniscient social planner), correcting for market failure and allocating optimum resources for innovation. While there is much to commend in this market failure perspective, it fails to address the dynamic process issues relevant to innovation. Instead, evolutionary approaches postulate an adaptive policy maker subject to the same considerations of bounded rationality as the firms and other institutions which are the targets of policy. Several general principles underlie this shift in perspective. The central concern is to support creative, discovery processes operating across a range of institutions. In part, this involves the question of incentives, but with an emphasis on the greater innovation pay-offs from close institutional couplings. Policy is built around the creation and support of bridging institutions. Support of small firms also plays a central role in evolutionary policy, as does the realisation that duplication of effort is not *a priori* wasteful in an uncertain world. Most significant of all, the policy maker requires a clear understanding of the broad design configurations which underlie the innovation process and the relative importance of knowledge skills and artifacts as foci of policy. Like any evolutionary endeavour, one needs a clear taxonomy of technology if policy is to be pursued effectively and linked to the activities of firms.

CONCLUSION

This brief note has surveyed some rapidly developing areas of understanding. New tools and new perspectives are becoming available which allow us to think of economies as evolving, emergent structures in which the creative activities of firms play a powerful role. But no firm acts in isolation; the wider institutional matrix is of vital importance to a clear understanding of innovation performance. As this field of enquiry develops, the management literature will play a full role in identifying relevant sources of variety in behaviour and the inherent imperfections and grains of grit which typify all real world decision processes. Taken together, we can expect to gather a much greater understanding of perhaps the fundamental question, 'Why does the world change in the way it does?'. Not least to benefit from this will be public policy makers and corporate strategists, hopefully not in isolation from each other.

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