Issues in the Adoption of Microelectronics

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Introduction

So much has been written in recent months about the so-called 'micro-electronics revolution' that the first question which we must inevitably face is: why add to the pile? After all, the media have not been slow to exploit the broader implications of microelectronics for society as source material for a host of publications and programmes. How far these have succeeded is difficult to assess, although they have certainly made the majority of people aware of microelectronics technology, which is evidenced by the popular usage of words and phrases based on 'chip'. Much of this exposure has, however, been exaggerated and distorted — particularly in the area of predicted unemployment associated with widespread application of microelectronics technology. The overall impression is of an uneven coverage, which treats some issues extensively whilst leaving others relatively untouched.

We are concerned that the bulk of the microelectronics debate has taken place at a rather high level of generality. Obviously this reflects a genuine lack of comprehensive, empirical data on which to base an analysis but it unfortunately allows many varied yet plausible, macro-level viewpoints to be offered and commentators who speculate in this field are fortunate in having such a broad canvas on which to paint.

This, for us, is an important point: if it is possible to criticize the macro-level of commentary already available, then it must be because of its essentially speculative nature. At its worst it suggests armchair pundits who take up one of two positions. Either they are optimists who see economic revival, renewed growth and a rosy dawn reflecting off the edges of a silicon chip, or else they are pessimists, who are deeply concerned about a gloom-laden future, economic decline, massive unemployment and a drift into depression far worse than that experienced during the

1930s.

The reality of the situation is that the truth lies somewhere in the middle of the continuum suggested by these extremes. Given its considerable technological potential, its relatively low cost and its pervasive nature, it seems reasonable to expect that microelectronics will have a significant impact on industrial society. But the rate and extent to which this will take place are unknowns which it will require considerable research to ascertain. What little research evidence is available does suggest that the speed of take-up of the technology is slower, the level of exploitation lower, the cost higher and the unforeseen problems greater than was anticipated in both product and process innovations.

In the manufacturing sector this has certainly been the case; there is very little information about what is actually taking place – despite the expectation of a new Industrial Revolution associated with adoption of microelectronics technology. What evidence there is (for example, statistics indicating the level of take-up of the government's Microprocessor Applications Project money), suggests that actual implementation of microelectronics is taking place only to a very limited extent. Further analysis of these indicates that, in fact, the level of general awareness (that is, of the existence of microelectonics and the appreciation of some of its more general characteristics) is quite good. This suggests that the problem arises in identifying and implementing *specific* applications in *particular* firms.

Clearly there is a need to understand what influences adoption or rejection of microelectronics at this level – and yet there is very little information to build up this picture with. The purpose of this book is to try and examine some of the important issues in this area. What are the key factors? Do they apply across different sectors? What are the differentiating features? Are there any useful guidelines for successful implementation? What are the policy implications?

We would hope to provide answers to some of these and other questions; at the least we feel that the book offers a useful introduction to this complex field.

The Microelectronics Revolution

Before proceeding further, it will be useful to recap briefly on the 'microelectronics revolution'. We do not, however, wish to go into great detail since there are many useful publications on the subject (see, for example, Forester,[1] Barron and Curnow,[2] Bessant *et al.*[3] and the Conference of

Socialist Economists[4]).

Considerable interest has been shown in microelectronics as a 'revolutionary' technology comparable with, say, steam power in the first Industrial Revolution. Freeman,[5] for example, suggests that it may represent a 'heartland' technology and has used this argument to revive interest in the concepts of Kondratieff and other long-wave cycles in the economy. Several other writers go along with this view (for example, Rothwell and Zegveld,[6] Mensch,[7] Maier,[8] and Ray[9]) in seeing microelectronics as a general rather than a specifically applicable technology offering substantial improvements in labour and capital productivity across a wide range of activities.

Certainly the potential impact of the technology is considerable because of its pervasive nature. Virtually every task involves some element of logical information processing and thus represents a possible application area. When taken in conjunction with progress in fields such as telecommunications and computing, the resulting convergence represents a resource with considerable potential for change.

In this sense microelectronics is a dramatic technology. The encapsulation of so much capability and flexibility in such a small device with no apparent moving parts plus its extensive range of applications is of interest in itself. When allied to the considerable improvements in performance visible in any number of these applications, the result is a public image of the microprocessor (as the most publicized example of microelectronics devices) as 'the miracle silicon chip'. This is a significant distortion of the truth, so much so that it would be useful to put the radical technological changes into perspective.

In a definite technical sense there has been no revolution (save, perhaps, for the invention of the transistor in 1947) but rather a steady evolution since that first invention. Development work, supported in part by military and aerospace involvement has since generated a highly efficient and innovative semiconductor industry with the capacity to produce large volumes of highly complex, integrated circuits. (An excellent account of the history of this industry appears in Braun and MacDonald.[10])

One aspect that is revolutionary is the way in which various characteristics of this technology have behaved. In essence, the cost has fallen dramatically along with the size of the devices, whilst there have been simultaneous rises in circuit complexity, computing power, quality, flexibility and reliability. The outcome of this phenomenon is the availability of enormously powerful computing facilities to accommodate almost all needs and at low cost. It is now possible to place all the required elements of a computer (input/output control, memory, central processing unit, etc.) on a single chip of silicon – although in practice microcomputers tend to be made up of several chips, each dedicated to one of these different functions, on a single board.

Although these rates of change are usually referred to as the basis for the 'revolutionary' claims made for microelectronics, there is a much more pressing candidate information technology. The impact of microelectronics is considerably enhanced when considered in conjunction with developments in other technological areas such as computing theory, systems analysis, telecommunications, and so on. This convergent group ('information technology' as it has been termed) offers major advantages in all aspects of information processing – input/output, storage, handling, transmission, etc. Thus its potential for radically changing operations which involve a high proportion of information (for example, office work) is considerable (see Porat[11] for a detailed breakdown and analysis of the 'information content' of most activities).

In the manufacturing sector the information processing needs fall into two categories: general administration (including ordering, stock control and holding, wages and accounts, invoicing, etc.) and control of actual operations, on and off line. Table 1.1 gives a list of typical manufacturing operations which involve some element of control; from this it can be seen that the *potential* application of microelectronics is great. Even where logic is not the only component of the information loop and some element of judgement is involved, the information processing function is still necessary in the preparation of relevant information in a suitable form.

Table 1.1: Typical Tasks in Manufacturing

1. Controlled movement of materials, components, products.
2. Control of process variables.
3. Shaping, cutting, mining, moulding, etc. of materials.
4. Assembly of components into sub-assemblies and finished products.
5. Control of quality at all stages of manufacture by inspection, testing or analysis.
6. Organization of the manufacturing process, including design, stock-keeping, despatch, machine maintenance, invoicing and the allocation of tasks.

Given this enormous potential for widespread application, the small percentage of actual developments and applications in the manufacturing sector seems doubly hard to understand. Clearly there is a need to take a much closer and disaggregated view of the problems of adoption and diffusion.

Manufacturing Innovation

Our concern in this book is with the application of microelectronics to manufacturing processes. Such implementation can take any one of a number of forms, from simple incremental additions to complete redesign of a manufacturing system.

In our research in the Technology Policy Unit we have used the term 'manufacturing innovation' to describe that particular set of innovations which are adopted by firms to improve their production operations without necessarily changing the overall process (for example, by replacing the control system involved from an electro-mechanical one to a microelectronics-based one). We feel that this is a useful distinction to make since it covers any incremental changes or any 'off-the-shelf' replacement type innovations as well as the more radical instances of new technology implementation.

One of the key points which we wish to make in this book is that microelectronics is not, in fact, a revolutionary technology. So far, in fact it follows a pattern which is, in essence, common to industrial innovation and evidence regarding its adoption supports this view. This is not to say that the *effects* of its adoption will not be dramatic – given such a pervasive technology with potential for widespread application it is possible that these will be significant. There is also the issue, rarely raised but potentially even more powerful in impact, surrounding the shift to higher levels of technological integration which is associated with microelectronics adoption. Essentially microelectronics:

(a) changes the way we think about design and control (that is, a shift towards a systems/holistic viewpoint);
(b) allows faster, more reliable, more accurate control and thus influences design concepts and limits;
(c) is pervasive and thus provides a common denominator for major technological advance. This is the argument behind the convergence hypothesis advanced by many commentators.[12]

As with other innovations, potential applications vary widely and for many sectors microelectronics will mean little change; some idea of the sectorial variation within the UK is given later. This again supports the hypothesis that microelectronics should be viewed as any other piece of new manufacturing technology.

Basis of the Book

As a final point, we would like to comment on the material which provides the basis for the book. The Technology Policy Unit at Aston University was set up to try to improve understanding of the mechanisms, procedures, constraints and interactions which form the practical framework for decisions on technology. As part of the research programme we have a major initiative in the field of manufacturing innovation which has been running for some time and which has been supported by various groups including the Department of Industry and the Anglo-German Foundation.

Inevitably, much of this work has involved studies of microelectronics application; in addition we have worked on a number of consultancy research assignments associated with aspects of microelectronics introduction.

This has provided us with a useful perspective which we feel lends value to the book as a practical document. We have attempted to pass on this experience in the form of case examples which we hope will provide suitably descriptive illustrations of the way in which particular issues arose and were handled. Inevitably there are some limitations to this approach – not the least of which is the need to preserve confidentiality – but nevertheless we hope that it will serve to ground the discussion in the 'real world'.

Overall, our aim is to take a much closer look at the actual pattern of adoption within the manufacturing sector. In doing so we hope to address several questions; for example:

(a) What influences a firm to adopt or reject microelectronics technology?
(b) What problems does this raise?
(c) Which agencies are involved?
(d) What are the typical success criteria?
(e) How well does the innovation fit in with other operations?
(f) What adaptive responses are necessary?
(g) What, if any, is the role of outside agencies?

These and similar issues form the framework of the book, with each chapter constructed around a particular field.

We have attempted analysis and explanation of the various phenomena observed but would be the first to admit that much of this remains speculative. By presenting case examples it may be easier for the reader to judge for himself and to add his own interpretation. We have an aversion to prescribing solutions for dealing with issues arising out of microelectronics adoption; instead we hope that our description and analysis will provide a useful route map; how the reader actually drives the car is still very much up to him!

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2. ENVIRONMENTAL INFLUENCES

Introduction

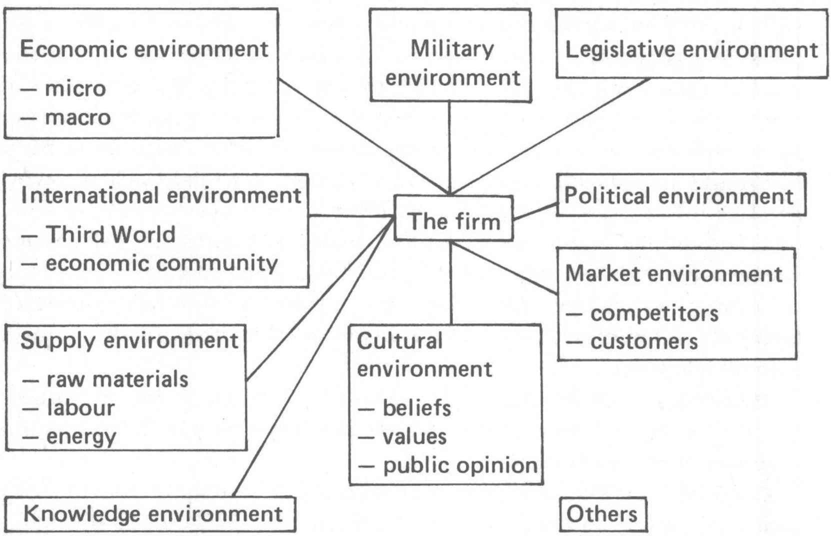
The first group of factors we wish to consider are those which originate outside the organisation – the pressures and demands placed upon it by events and influences in the environment. Microelectronics adoption is, like any innovation, sensitive to the economic climate in the world outside, and the present outlook for any investment in manufacturing (at least in the UK) is extremely gloomy. But there are other, more specific, influences as well; for example, concern has been expressed about shortages of suitably trained manpower to support and maintain a shift to sophisticated manufacturing technology. Another area of concern is the pressure arising out of the behaviour of competitors – their prices and product ranges and the way in which they are changing, the emergence of new competitors (for example, the developing countries), their investment policies, and so on. Adopting microelectronics (with its implicit advantages in reducing costs, improving quality, etc.) may well represent an effective response to this type of threat. On the positive side there are other promoting factors like the Department of Industry's MAP scheme which is designed to support exploration and implementation of microelectronics technology. Also there are a number of other sources of financial, technical and other aid available to help firms in their moves towards adoption.

However, before we proceed to a detailed discussion of these influences it will be useful to review briefly the role of environment in the innovation processes of an organisation.

Companies do not operate in a vacuum but as systems interacting with their environment in a series of exchanges and interchanges. The characteristic elements of the particular environment are many and varied; Fig. 2.1 indicates some of these. In addition, the environment is changing, often in discontinuous fashion; this means that the firm must be constantly adapting in order to maintain an advantageous relationship with the environment (A detailed discussion of the systems theory underlying this argument lies outside the scope of this book, but see Ansoff,[1] Emery and Trist[2] or Duncan[3] for examples).

One of the possible adaptive responses which a company may make is technological innovation – either in the form of new products or processes. That is, it may change the nature of the outputs it exchanges with the world outside or it may change the way in which it makes those outputs. Considerable evidence exists to support the view that product innovations are triggered by environmental needs – in particular, market forces – much more often than by 'pure' inventions. Figures suggest that the ratio of 'need pull' to 'knowledge push' may be as high as 4:1; (see Langrish *et. al.*,[4] Freeman,[5] and others). A similar argument can be advanced for process innovation, although there is little explicit mention of this in the literature on innovation; some variation in the ratios might also be expected. Nevertheless, it is clear that the role of environmental factors is of signficiance in determining adoption.

Fig. 2.1: Simple 'black box' representation of a company and its environment.



Environmental Threats and Opportunities

Examining Fig. 2.1 in more detail, we can attempt to categorize environmental elements into threats and opportunities. Under the first heading we might list factors like competition, legislative constraints and regulations, shortages of various resources – both human and material – and so on. Under the second would come emergent new technologies, new markets, promotional legislations, etc.; Table 2.1 outlines these in a little more detail. (Such a distinction between threats and opportunities is a little arbitrary since one of the roles of strategic management is, in fact, to turn threats to opportunities; however, our concern here is with *influence* of this class of variables on adoption decisions rather than as part of the wider company management framework.) The lists themselves are by no means exhaustive, but represent those factors which we have found relevant to the adoption or rejection of microelectronics technology; it may well be that a different list would be generated if we were to consider another technology (for example, biotechnology). This tends to support our view that there is a need to disaggregate when considering factors of this kind.

Table 2.1: Threats and opportunities in the environment (relevant to microelectronics adoption)

Threats	Opportunities
(a) Economic factors	
General recession. High interest rates. Strength of sterling. Lack of available capital. Alternative investment options are more attractive (all of the above lead to low levels of investment and poor incentives to invest in equipment or new technology). Investment cycles which prohibit new technology investment until the correct point on the cycle is reached – applies to capital intensive industries in particular.	Microelectronics offers fast payback times, capital savings, reduction in operating costs, etc. Some micro-based systems are becoming available as add-on items for the control of existing plant (i.e. there is no need to wait for the investment cycle). Also, programmable nature means that micros can be used more flexibly (economically) than conventional equipment.

Table 2.1 (contd.)

Threats	Opportunities
(b) Political/legislative	
Constraining legislation (for example, Health and Safety Acts, emission controls, etc.) Political pressure surrounding key issues (for example, employment displacing technology during a time of high unemployment). Pressure groups (for example, trade unions, political lobbies etc.).	Promoting legislation (for example, financial aid schemes, technical resources, information and advice, etc.). Specific aid for microelectronics technology, under MAP, MISP, etc. Political pressure (for example, on grounds of international competition etc.).
(c) Markets	
Early adoption by competitors can quickly change market patterns in a dramatic fashion (for example, the cases of watches and cash registers). Problems of breaking into new markets, particularly those involving higher technology products. Erosion of traditional markets and/or maturity of those markets means that there is little room for manoeuvre with conventional new products or new manufacturing technology, which cuts costs, improves quality or in other ways restores a competitive edge.	Micros open up new markets via new products, better differentiation of existing ranges, improved quality etc. Large potential for products using micros indicated by many recent market surveys, especially in instrumentation, toys, cars, robotics, office systems, etc.
(d) International competition	
Increasing competitive threat from the Third World is already attacking many sectors (textiles, basic metal castings, etc.) and this is particularly true of the NICs. Usually this is on	Comparative advantage of the Third World has been based on low wage rates and operating overheads. Micros offer possibilities in capital savings, labour-savings, etc., which

Table 2.1 (contd.)

Threats	Opportunities
the basis of high volume low quality products but increasing sophistication is posing a growing threat. Since microelectronics is essentially a 'black box' technology, it might well be adopted quickly in these countries (with considerable implications for the developed world). Developed-nation competition is increasingly on the basis of quality and performance sophistication and there is a growing gap between countries like West Germany, Japan, Sweden and those like the UK which are technologically in a state of decline. Micros could exaggerate this position.	could restore this advantage to the developed world. Alternatively, micros could facilitate the shift into up-market products, services and production methods. This would give the developing world a market opportunity at the lower end (as has been recommended by the Brandt Commission and others). Micros could redress the balance by offering the chance to 'leapfrog' in a technological sense in both products and processes.
(e) Supply and availability	
Shortage of skilled human resources is a major limitation in the take-up of micros. Cost and other factors tend to exclude smaller firms, and to favour 'glamorous' firms and areas.	Shortage/problems of external supplies can be improved through the use of micros in areas like stock control, improved monitoring of process conditions etc. Shortage of certain skills (for example, maintenance staff) can be eased through the use of microelectronics due to their improved reliability, ease of maintenance etc.
(f) Technological environment	
Lack of suitably developed technological infrastructure may impede adoption through lack of suitable peripherals, software, transducers etc.	Opportunities for diversification into new areas to provide this infrastructure.