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The social shaping of technology

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Abstract

This paper reviews the growing body of research that explores 'the social shaping of technology' (SST) – how the design and implementation of technology are patterned by a range of 'social' and 'economic' factors as well as narrowly 'technical' considerations. It shows how researchers from a range of disciplinary backgrounds were brought together by a critique of traditional conceptions of technology (for example, 'linear models' of innovation that privileged technological supply or restricted the scope of social inquiry into technology to assessing its 'impacts'). Though their analytical frameworks differ to a greater or lesser extent in terminology and approach, some explanatory concepts have emerged, and constitute an effective model of the innovation process. Here, it is suggested, SST offers a deeper understanding and also potentially broadens the technology policy agenda. These claims are assessed through a review of recent research into specific instances of social shaping, particularly in relation to information technology. Finally the article discusses some of the intellectual dilemmas in the field. Though the intellectual cross-fertilisation has been creative, points of tension and divergence between its constituent strands have resulted in some sharp controversies, which reflect upon the theoretical and policy claims of SST.

1. Introduction

This paper reviews the body of research that addresses 'the social shaping of technology' (SST) (MacKenzie and Wajcman, 1985). In contrast to traditional approaches which only addressed the outcomes or 'impacts' of technological change, this work examines the *content of technology* and the particular processes involved in innovation. We highlight the growth of socio-economic research falling within this very broad definition of SST. It explores a range of factors (organisational, political, economic and cultural) which pattern the design and implementation of technology.

SST has gained increasing recognition in recent years, particularly in the UK and Europe, as a valuable research focus [1], and for its broader import for the *scientific and policy* claims of social sciences. SST is seen as playing a positive role in integrating natural and social science concerns; in offering a greater understanding of the relationship between scientific excellence, technological innovation and economic and social well-being; and in broadening the policy agenda, for example in the promotion and management of technological change (European Sci-

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[1] For example, in 1992, European research collaboration was established on SST under the COST programme (COST A4: the impact of the social environment on the creation and diffusion of technologies). SST, with human communication, forms one of the nine thematic priorities adopted in 1995 by the Economic and Social Research Council, and is seen as part of the contribution of social sciences to recent UK science and technology policy initiatives: the 1993 White Paper "Realising our Potential" and the 1995 Technology Foresight Initiative (ESRC, 1995; Office of Science and Technology, 1995).

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ence Foundation/Economic and Social Research Council, ESF/ESRC, 1991; Newby, 1992).

However, various analytical frameworks have been proposed, which differ to a greater or lesser extent in their terminology and approach. Considerable confusion remains about the identity and claims of SST: what constitutes social shaping research? what are the differences within SST? what is the relationship between SST and other areas of social analysis of technology? Thus 'SST' is often taken to be synonymous with one particular approach (for example, the social construction of technology [2]) or more generally with the sociological study of technology (see for example Rose and Smith, 1986; Mackay and Gillespie, 1992). This paper attempts to clarify the situation by mapping out our conception of the domain of SST as a 'broad church', indicating its different strands and the relationships between them. We therefore adopt a very broad definition of SST, without implying a particular consensual 'orthodoxy', clear boundaries or claims of ownership to the field. As we hope to show, much of the strength in this area lies in the very diversity of work which it encompasses. Our main focus is on Britain, although SST has emerged to an important extent through international discussion.

We argue that a variety of scholars, with differing concerns and intellectual traditions, find a meeting point in the SST project. They are united by an insistence that the 'black-box' of technology must be opened, to allow the socio-economic patterns embedded in both the *content of technologies* and the *processes of innovation* to be exposed and analysed (MacKenzie and Wajcman, 1985; Bijker and Law, 1992). SST stands in contrast to post-Enlightenment traditions which did not problematise technological change, but limited the scope of enquiry to monitoring the social adjustments it saw as being required by technological progress. SST emerged through a critique of such 'technological determinism'. SST studies show that technology does not develop according to an inner technical logic but is instead a social product, patterned by the conditions of its creation and use. Every stage in the generation and implementation of new technologies involves a set of choices between different technical options. Alongside narrowly 'technical' considerations, a range of 'social' factors affect which options are selected – thus influencing the content of technologies, and their social implications.

Simply establishing that technologies are 'socially shaped' leaves open many important questions about the character and influence of the shaping forces. In seeking to grasp the *complexity* of the socio-economic processes involved in technological innovation, SST has been forced to go beyond simplistic forms of social determinism which, like technological determinism, see technology as reflecting a single rationality – for example an economic imperative, or the political imperative of a ruling élite. For example a critique has been made of the dominant neo-classical tradition of economic analysis, with its assumptions that technologies will emerge readily in response to market demands (Coombs et al., 1987).

In attempting to grasp this complexity, various conceptual frameworks have been advanced both about the nature of the socio-economic forces shaping technology and about the appropriate levels and frameworks for their analysis. These reflect the differing research concerns and theoretical traditions within SST. We will therefore begin by outlining (in Section 2) this diversity of intellectual origins, and its legacy in current theoretical perspectives and debates.

Central to SST is the concept that there are 'choices' (though not necessarily conscious choices) inherent in both the design of individual artefacts and systems, and in the direction or *trajectory* of innovation programmes. If technology does not emerge from the unfolding of a predetermined logic or a single determinant, then innovation is a 'garden of forking paths'. Different routes are available, potentially leading to different technological outcomes. Significantly, these choices could have differing implications for society and for particular social groups. The character of technologies, as well as their social implications, are problematised and opened up for enquiry. We can analyse the social influences over the particular technological routes

[2] The metaphor of social construction has proved attractive to many in the field, and we could have grouped this review under the heading of constructivism, rather than SST. We opted not to use this term because it has a substantial history and intellectual baggage and has acquired multiple meanings (Sismondo, 1993).

taken (and their consequences). This opens up two sets of questions. First SST stresses the *negotiability* of technology (Cronberg, 1992), highlighting the scope for particular groups and forces to shape technologies to their ends and the possibility of different kinds of ('technological' and 'social' outcome). Second it raises questions about *irreversibility* (Collingridge, 1992; Callon, 1993) – the extent and manner in which choices may be foreclosed. Earlier technological choices pattern subsequent development (Rosenberg, 1994). Certain options may be selected and become entrenched (for example as a result of the tendency of new technologies to develop cumulatively, erected upon the knowledge base and social and technical infrastructure of existing technologies) particularly where increasing returns to scale of investment result in 'lock-in' to established solutions (David, 1975; Arthur, 1989; Cowan, 1992). SST points to *closure*, the ways in which innovation may become stabilised (Pinch and Bijker, 1984), as well as the possibility of reversing earlier choices (Latour, 1988). As we shall see below, SST proponents differ over their characterisation of such 'choices', and in their approaches to the stability or negotiability of technologies – with related differences over the rôles and significance of large-scale social and economic structures, as opposed to the activities of individuals and groups. Long-established debates within social sciences have resurfaced in this field, with a number of (often heated) theoretical disputes.

These debates are not merely 'academic': they relate to policy claims and objectives. For SST has been strongly influenced by a concern with technology policy. By rendering the social processes of innovation problematic, SST has opened up policy issues that had been obscured by technological determinism, and by related simplistic models. For example SST criticised established 'linear models', which conceived of innovation as involving a one-way flow of information, ideas and solutions from basic science, through research and development (R&D), to production and the diffusion of stable artefacts through the market to consumers.

Public technology policies underpinned by these linear models are now seen as unhelpful (Fairclough, 1992) because of their division of innovation into separate phases and their privileging of technological supply. In contrast, SST has drawn attention to the close and reciprocal *interactions* between these stages, and the *transformation* of technologies between their initial conception and their eventual application. SST contributed towards the development of public policies which emphasised the role of the user as well as the supplier, and the need for linkages between them (Fleck, 1988a). And it has been claimed that SST could help to broaden technology policy agendas and make them more pro-active: rather than merely conducting retrospective cost–benefit analyses of technology, 'constructive technology assessment' would allow exploration of the possible implications of different choices within and during technological development (Schot, 1992; Rip et al., 1995).

Many SST writers had deeper concerns: to emancipate science and technology – to dismantle their privileging as inevitable, or standing outside or above society; and to view them as areas of social activity, subject to social forces and amenable to social analysis (Bijker, 1993). An important critical strand within SST has highlighted the politics of technology (Winner, 1977; Winner, 1980), arguing that technologies are not neutral, but are fostered by groups to preserve or alter social relations (Hård, 1993); they are 'politics pursued by other means' (Latour, 1988). Thus from the outset SST was influenced by a desire to democratise technological decision-making (or, at least, to subject it to forms of social accountability and control). However, the different approaches within SST reach divergent conclusions about the character of technology, the social mechanisms of shaping and control, and thus about the methods (and indeed the very possibility) of social intervention in technological innovation. And these tensions and contradictions pose a number of dilemmas, particularly in methodology and epistemology.

At a theoretical level, we would argue that the tensions are, at least potentially, creative – requiring continual reassessment both of research methods and interpretation, and of SST's rôle. It may be that these internal differences, and more profound schisms with other disciplines and approaches to the social analysis of technology (particularly mainstream' economics (Stoneman, 1992), have impeded SST's cumulative theoretical growth: yet its empirical work has been remarkably fruitful (ESF/ESRC, 1991). A range of explanatory concepts has recently begun to emerge, constituting an effective model of the innovation process. We briefly summarise some of its elements in Section 3. Since the final test of any research perspective is its ability to yield more adequate understandings, Section 4 reviews, by way of illustration, a range of recent research that addresses specific instances of the social shaping of information technology (IT). Finally we discuss some of the intellectual dilemmas in the field (Section 5, and conclude with some comments on possible future developments.

2. The intellectual origins of the social shaping perspective

2.1. The critique of technological determinism

The social shaping perspective emerged from a long-standing critique of crude forms of technological determinism (Edge, 1988), which held:

1. that the nature of technologies and the direction of change were unproblematic or pre-determined (perhaps subject to an inner 'technical logic' or 'economic imperative');
2. that technology had necessary and determinate 'impacts' upon work, upon economic life and upon society as a whole: technological change thus produces social and organisational change.

It was linked to opposition to ideologies of 'technological imperative', that were particularly prevalent in British government and industry in the late 1970s and early 1980s, which suggested that particular paths of technological change were inevitable. However, the SST perspective was not just a response to a public rhetoric of technology, but also criticised the way technology had been conceived by many academics. Social scientists all too frequently took technology for granted (treated it as a *given*) and sought to assess its social 'impacts'. This failing was even shared by critical theorists, such as early writers from the labour process perspective, who gave a pessimistic account of how information technology would degrade work, displace workforce skills and enhance managerial control. They treated technologies such as 'computer numerical control' (CNC), robotics and 'computer aided design' (CAD), in a reified manner, as if they were an internally homogeneous class of objects, uniform in their characteristics and stable over time (Fleck et al., 1990). In so doing, they accepted the dominant rhetoric of technology – and often took, at face value, suppliers' claims about the efficacy and reliability of their products. They assumed that technology offered a sure vehicle for achieving organisational change, and overlooked difficulties in implementing technologies and their frequent failures to deliver predicted and desired outcomes.

The SST perspective, as we show below, has drawn upon a range of academic traditions: these share some analytic concerns, and also a critical perspective. SST research investigates the ways in which social, institutional, economic and cultural factors have shaped:

1. the *direction* as well as the rate of innovation;
2. the *form* of technology: the content of technological artefacts and practices;
3. the *outcomes* of technological change for different groups in society.

It thus goes beyond traditional approaches, concerned merely to assess the 'social impacts' of technology, to examine what shapes the technology which is having these 'impacts', and the way in which these impacts are achieved (MacKenzie and Wajcman, 1985). [3] SST research could, it was hoped, identify opportunities to influence technological change and its social consequences, at an early stage – moments at which accountability and control could be exercised. [4] SST broadens the policy agenda: no

[3] Some writers have, we feel mistakenly, interpreted SST as exclusively concerned with the form of technology and not its social implications (see for example Winner, 1993; Bijker, 1995). SST, however, goes beyond the design of artefacts to address how social outcomes are achieved in the implementation/consumption and use of technology.

[4] See, for example, the work by Donald MacKenzie and others on how missile guidance systems stabilised over time, which was, in part, motivated by a concern to interrupt the spiraling arms race (MacKenzie, 1986, MacKenzie, 1988, MacKenzie, 1990; MacKenzie and Spinardi, 1988a, MacKenzie and Spinardi, 1988b; MacKenzie et al., 1988). Studies of defence technology raise interesting issues in SST which we do not have space to discuss in this paper. For a consideration of the influence of defence agency funding on technical development, see Harbor (1989) and Smit (1994); for studies stemming from SSK and actor-network theory, see Law (1988) on the TSR 2, and (from Holland) Elzen et al. (1990) on the B-1 bomber and European fighter aircraft.

more mere tinkering at the margins of technology policy, seeking to grapple with its products but leaving unaltered the direction and goals of innovation. SST allowed people to get inside science and technology themselves (Latour, 1986, Latour, 1988). It offered the prospect of moving beyond defensive and reactive responses to technology, towards a more pro-active role. In this respect, there are strong resonances between the social shaping view and the model of 'constructive technology assessment' (CTA) being articulated particularly in the Netherlands (Schot, 1992; Rip et al., 1995). The policy utility of conventional TA is limited by its concern with the retrospective assessment of the costs and benefits of technologies already designed and developed (Kranakis, 1988). In contrast, CTA holds out the prospect of strategic intervention from the early stages of innovation – highlighting both the possible consequences of different technological routes, and the problems and opportunities of controlling them to meet societal goals.

This critique of technological determinism is perhaps less controversial today than when the SST banner was first erected. The challenge now is to go beyond a simple critique, and elaborate a model for analysing processes of technological change. In Section 3 we shall attempt to do this, drawing upon the first round of research projects, informed by this perspective, which are beginning to deliver results. [5]

But first we shall trace the intellectual origins of the SST perspective in Britain. This approach has brought together four broad academic traditions – the sociology of scientific knowledge (SSK), the sociology of industrial organisation, technology policy studies (particularly those from a 'political economy' background) and certain approaches within the economics of technological change (in particular, evolutionary economics). These traditions exhibit some common analytic concerns – for example, examining processes by which power is achieved and exercised, and highlighting the rôle of knowledge in this process. However, there are important differences. In particular, although they each draw attention to the choices inherent in technological development, they differ in their approaches to such choice – in relation to 'closure' (i.e. the emergence of stability), the inherent flexibility of technology and the apparent presence (or absence) of choice. By emphasising these differences, we point to the diversity of research in Britain, and the creative tensions between its various centres. We will briefly summarise the four participating traditions in turn.

2.1.1. *The sociology of scientific knowledge (SSK)*

SSK emerged at several centres in Britain during the 1970s – notably the Universities of Edinburgh, York and Bath (see Pickering, 1992, pp. 1–4; Nye, 1992 pp. 233–35). Its extension into the sociology of technology (Woolgar, 1991) took place at all three centres and elsewhere, albeit with differing emphases.

SSK exploits an approach widely used in the history and sociology of science (Shapin, 1982). Essentially, it consists of studying the development of a scientific field, and identifying points of 'contingency' or 'interpretative flexibility', where, at the time, ambiguities are present. Having identified such 'branch' points, the researcher then seeks to explain why one interpretation rather than another succeeded. The influential 'strong programme' of SSK insists that such explanation, to avoid teleology and judging veracity in terms of what is currently accepted as true, must be impartial to the truth or falsity of the beliefs under investigation; it must treat all knowledge claims symmetrically, explaining their creation or acceptance in social terms, rather than by reference to the natural world (Bloor, 1973, Bloor, 1976).

Having established the social construction of scientific truths, researchers from SSK have extended this approach to the study of technological artefacts. They have sought to identify instances where technologies could be designed in more than one way, with choices between different technical options, and to explain why one way of designing the artefact triumphed. This is rarely a simple 'technical' issue,

[5] Here we will be drawing heavily upon approaches developed in the SST research programme at Edinburgh University. In illustrating our argument with work which we know well, we are not implying either primacy or centrality for the Edinburgh approach: we will also draw on other examples, and intend to reflect and exemplify all work in the SST broad church, in Britain and, occasionally, from wider afield.

but is patterned and shaped by the particular 'selection environment': in other words, social factors enter into such explanations. The analysis proceeds 'outwards', from the technology to the context shaping it. This approach has been presented as offering a 'new sociology of technology', summed up by the phrase *social construction of technology* (SCOT) (Pinch and Bijker, 1984). These writers have also been strongly influenced by actor-network theories – in particular, by the research programme led by Michel Callon and Bruno Latour at the École des Mines in Paris. Together they have engaged in a vigorous programme of debate and publication (see e.g. Bijker et al., 1987; Pickering, 1992). SSK has often been taken (unhelpfully, we would argue) to be synonymous with the SST approach.

The SCOT approach tends to have difficulty in accounting for closure. The possibilities of 'interpretative flexibility' (i.e. of 'choice') seem endless. Actor-network studies remain sceptical about the nature and influence of broader social and economic structures of power and interests, insisting that actors create the world anew (Latour, 1983, Latour, 1986, Latour, 1988), and implying that technologies (and social systems generally) are highly malleable to local actors. It has been noted that much of their early research has involved micro-level studies, focusing upon the scientific or R&D laboratory, and tending to examine nascent technological fields, in which the broader institutional context is fluid (Russell and Williams, 1988; Rosen, 1993; Russell, 1994). More recently, researchers from this tradition have shown more interest in the relative stability of certain larger scale structures, practices and the context of innovation (Law and Callon, 1992; Callon, 1993). This concern with the stabilisation and 'obduracy' of sociotechnical systems signals an attempt to engage with other traditions in the field (Law and Bijker, 1992).

2.1.2. The sociology of industrial organisations

In contrast to SCOT, industrial sociology has focused on an arena of technological change characterised by clear, and often conflicting, socio-economic interests. Here, the starting point is not a particular technological field, but a particular social context within which technical change takes place. The analysis proceeds 'inwards': the social processes, interests and goals typical of the context are identified, and attempts are then made to trace their influence on evolving technology.

Much of this research has been stimulated by the work of Braverman (1974), who 'rediscovered' Marx's analysis of the 'labour process'. In his analysis, technological change was designed to appropriate and displace workforce skills, and thus to enhance the control of capital over the production process. Though initial studies supported this view (see for example Zimbalist, 1979), later work from the 'labour process' perspective emphasised the contradictory nature of this endeavour, pointing to the complex web of interests within the organisation amongst diverse professional and occupational groups, and the range of managerial strategies (Wood, 1982). Researchers explored the mobilisation of interests and processes of conflict and accommodation in the innovation process; the diverse forms of technical and other knowledge involved, and the interplay between knowledge and power; and the influence of labour and product markets and of broader social and political structures (e.g. of gender or industrial relations). The industrial workplace is particularly well studied, demonstrating the tight interconnection of technological change with changing patterns of industrial relations in, for example, the British engineering (Wilkinson, 1983; Jones, 1988), printing (Cockburn, 1985; Smith, 1988) and textile industries (Lazonick, 1979). However, many labour process studies failed directly to interrogate the *development* and *content* of technology. An important exception here was the classic study by Noble (1979) of the history of automatic controlled machine tools.

A large body of empirical research has been stimulated by the labour process debate, though not following all its tenets. This work has highlighted the choices surrounding the selection and design of new technology (Jones, 1983, Jones, 1988; Wilkinson, 1983; Child, 1984; Webster, 1990; Murray and Knights, 1990) and the influence of managerial and workforce strategies and structures, culture, labour markets and the like.

2.1.3. Critical studies of technology policy

Within British technology studies, a group of scholars has carried out research informed by a broad 'political economy' approach (a perspective shared by many industrial sociologists). In contrast to 'orthodox' technology policy studies, which simply seek to inform the policy process, their work attempts to understand the underlying political, economic and other forces shaping the development and implementation of that policy itself. They thus address the values and interests of those individuals and organisations directly involved – the 'sociotechnical constituency' (Molina, 1989a) which underpins the development of any new technology. But the scope of their investigations goes beyond those organisations directly involved in innovation, to examine the broader institutional and societal context (including market structures and dynamics, culture, legislation and politics) in an attempt to explain both particular instances of technology and 'the general characteristics of a society's technological ensemble' (Russell and Williams, 1988, p. 11). Cross-national comparisons provided a means of assessing the influence of particular social formations upon the characteristics of technology. Much of the initial research highlighted the rôle of the state – for example, in the regulation of industrial hazards (Doyal et al., 1983; Williams, 1984), and in promoting technology in the context of energy policy (Russell, 1986).

There are a range of approaches within this tradition, and related work in industrial sociology (see Powell, 1987), which, however, share a common problematique: in many cases, the issue is not to reveal available choices and analyse the forces determining which designs are eventually adopted – instead, the situation is often characterised by an apparent *absence* of choice, and the problem is to account for this 'absence'. In doing so, attention is focused on the 'real' limitations on choice which are located in the wider social system, and which bear in upon the specific context in which technical change is taking place. Again, choice is a key focus of research – but in a very different sense from the work in the economic or SSK traditions!

2.1.4. The economics of technological change

The various schools of economic thought differ in their approach to theorising technology, and in its importance as an explanatory variable. As already noted, neo-classical economics has an 'instrumental' approach – tending to assume that technologies will just 'appear to order', in response to the demands of the market at any one time (Coombs et al., 1987). This approach, in other words, treats technology as if it were highly flexible in its development, and available equally to all. They ignore discontinuities in innovation. The form and content of technology do not receive detailed consideration. This work, based as it is on unrealistic and unhelpful assumptions, has little to say to SST researchers (David, 1975; Coombs et al., 1987; MacKenzie, 1992; Lundwall, 1993; Rosenberg, 1994).

However, other approaches have given more weight to 'supply-side' issues, and to technical development. In particular, we can see a convergence amongst a group with economic backgrounds but, in their approach to technology, lying outside the mainstream of economists. These writers share an historical approach to the analysis of industrial and technological development, and emphasise the unevenness of that process, its discontinuities and qualitative shifts. Changes in basic technologies have played a key rôle in their accounts. Among them we would highlight the work of Freeman and others at the Science Policy Research Unit, operating within a 'post-Schumpeterian' framework. Much of this work has been at a very generalised level, seeking to explain long-term patterns (e.g. Kondratiev long-waves) in innovation and economic activity (see e.g. Freeman et al., 1982; Perez, 1983), and borrowing ideas from the sociology of science (in particular the Kuhnian notion of 'paradigm') to explain such patterns in terms of shifting 'techno-economic paradigms'. Some of this work has been criticised, from an SST viewpoint, for its tendency to treat technology in an over-generalised way, and sometimes to see technological change, deterministically, as the motor of socio-economic change. [6] However, the main thrust of this analysis emphasises the interaction between 'supply' (e.g. 'science-push') and 'demand' – conceived as a contradictory process,

[6] The early work of Freeman and Perez (see for example Perez, 1983; Freeman, 1987) involved the rather global, and ultimately deterministic vision, of a new techno-economic paradigm which called for structural change in the Western economies to adapt to its new requirements. The later work of Freeman and the Science Policy Research Unit has moved on to a less deterministic formulation.

rather than as a deterministic triumph of one over the other.

A closely related group of economists are developing an 'evolutionary' model of innovation. They have been strongly influenced by the analysis of Nelson and Winter (Nelson and Winter, 1977, Nelson and Winter, 1982) in the USA. They inherit from the Schumpeterians a concern with radical, as well as incremental, changes in products and processes and have also emphasised behavioural characteristics of the firm, underpinning for example stability and change in decision rules (Saviotti and Metcalf, 1991). They conceive the market as a socially constituted selective environment which favours the survival of particular types of technology (Walsh, 1993).

Drawing upon these frameworks, writers such as Dosi (1982) have attempted to address the detailed pattern of innovation. Particular economic and social contexts create selection environments which pattern a series of innovations. This results in periods of broad stability within a *'techno-economic' paradigm*, in which the innovation process conforms to a common set of criteria, and the design of technological artefacts changes in an incremental, evolutionary manner, described as *technological trajectories*. Technological trajectories represent the unfolding of a paradigm over time. The model also accounts for discontinuities in development and periods of radical innovation, as shifts in the basic techno-economic paradigm.

Though few of these writers would probably see themselves as part of any 'SST school', the evolutionary model has been very influential in British SST research. It allows both for the stability of technologies over long periods of time (i.e. the effective suppression of choice), and for periods of instability associated with fundamental shifts in technological capabilities. However, Dosi's concept of paradigms and trajectories remains problematic.

In particular, it is predicated upon the maintenance of a stable set of social, economic and technical forces, which serve to generate the necessary uni-directionality of technological development. For example, in their study of the extent to which particular paradigms of work organisation were embedded in the design and implementation of industrial applications of IT, Fleck et al. (1990) found neither a simple technological trajectory, nor a single paradigm. Even where clear-cut principles appeared to underpin the *design* of a particular technology, there were forces which served to frustrate the expected trajectory in its *implementation*. The complex forces shaping these technologies were not stable and in harmony, but were contradictory and changed over time. In particular, there were tensions between the conception and implementation of technology. Initial technological trajectories failed, became fragmented, or were reversed. Thus the existence and continuation of paradigms and trajectories cannot be taken for granted. Though the early development of a technology might be informed by shared visions of a new technology, by particular objectives for its use and by the requirements of specific users, as a technology becomes more widespread, these conditions are liable to become more diverse and generalised. In this way, SST has raised questions about the factors giving rise to trajectories, suggesting that they may be sought in locally shared objectives and expectations (Latour, 1988; Molina, 1989a; MacKenzie, 1992) as much as in 'objective' structures (for example, in particular techno-economic logics of competition).

2.2. The economic and the social

The influences of the social and of the economic have often been counterposed – an unhelpful and surprising dichotomy, since the economic is also, surely, social. Indeed economic shaping is one of the most salient features of the social shaping of technology (Weingart, 1984). The limitations of some economic perspectives have already been discussed. However, sociology can also be criticised for its failure to engage effectively with questions of price and profit (MacKenzie, 1992). In part this reflects weakness or bias in the concerns of early SST studies. 'Social shaping' theorists have been criticised for an undue emphasis on instances of innovation within localised networks characterised by strong and visible interactions between different players (such as the early stages of development of new enabling technologies; Russell and Williams, 1988), where the 'political' character of the actions of different players is writ large, and their neglect of contexts where the relationships between players are weak, indirect, impersonalised and, in particular, where they are mediated through markets and where conflicts take an economic form (Hård, 1993). The latter applies particularly to the large-scale diffusion of established technologies such as mass-produced consumer goods (Miles, 1988; Mackay and Gillespie, 1992; Rosen, 1993). Although SST theorists are divided in their willingness to address broader economic and market structures, some recent SST research has begun to highlight the close interaction between economic and other social factors in patterning technological development.

Ultimately, we suggest that what is seen as 'economic', and what as 'social', may consist of different ways of describing the same sets of processes. MacKenzie (1992) has argued that although the economics of technological change and the sociology of scientific knowledge make different presumptions (for example, where SSK and actor-network analyses of technology find it difficult to account for 'closure' and the stabilisation of technological artefacts, economic analyses start from the presumption that technologies have stable characteristics that can be subject to a rational economic calculus), they are approaching essentially the same topic (the creation of stable networks) from directly opposite points of view. Markets can be seen to be socially constructed and shaped by legal, political, cultural and knowledge processes (Green, 1992). Indeed, the market is itself a form of social organisation – a particular type of network between actors. Though the theoretical pure market is impersonal, and the only information that must be exchanged concerns the identity of the product (the utility of which is presumed to be known) and its price, real market situations do not conform to this stereotype in practice. For example even where technological artefacts are obtained through the market, they are often not available as finished commodities; their development and implementation involves processes of collaboration between supplier and user – a hybrid between the ideal-type market relationship and a social, inter-organisational interaction (Brady et al., 1992; Lundwall, 1993). Markets take a variety of forms, more or less personalised, and are influenced by industrial and occupational structures (Newell and Clark, 1992; Fincham et al., 1995). The dichotomy between market and non-market relationships thus breaks down. The pure market form is one extreme on a spectrum of differing forms of social network that create and shape technology.

3. A model of social shaping

The SST perspective draws upon a broad stream of economic and social analysis. Though we have highlighted differences between traditions, there has been extensive interchange between the various schools of thought. These approaches to technology have, with differing emphases, established that the form and content of technology are important, and are amenable to (and require) social analysis. They highlight and 'problematise' the *innovation process*.

Innovation is thus seen as a contradictory and uncertain process. It is not just a rational-technical 'problem-solving' process; it also involves 'economic and political' processes in building alliances of interests (amongst, for example, supplier firms, technologists, potential users, funding bodies regulators) with the necessary resources and technical expertise, around certain concepts or visions of as yet unrealised technologies. Several, broadly homologous, frameworks have been advanced to describe this process – described variously as building 'sociotechnical systems' (Hughes, 1983), 'sociotechnical constituencies' (Molina, 1989a) and 'sociotechnical ensembles' (Bijker, 1993, Bijker, 1995) or creating/mobilising an actor-network (Law and Callon, 1992), and the particular strategies it involves, of, for example, 'enroling' local players in a broader network (Law and Callon, 1992) and 'aligning' their expectations around realisable objectives (Molina, 1994a). The process is characterised by imperfect knowledge and bounded rationality. Success in developing a technology is not just a matter of 'having the money' or of achieving good technical solutions. There may be difficulties, for example, in ensuring the flows of information between the various expert and specialist groups, with their differing perspectives and knowledge bases, needed to create new technologies (Fincham et al., 1995). It may also be necessary to enrol a range of other actors, including users, and, on occasions, competing suppliers, to participate in developing markets (Green, 1992; Walsh, 1993). However, too close alignment of players can cause problems (for example of blinkered, inflexible approaches; Collingridge, 1992), and a balance must be struck between cooperation and competition (see for example Howells and Hine, 1993).

The shaping process begins with the earliest stages of research and development. Though 'invention' is at least partially an unpredictable process, extensive studies by historians of technology have suggested systematic patterns within it. There are cases where a quite specific social influence can be traced – where, say (as in Noble, 1979) inventions are responses to perceived problems of industrial relations. In other cases, inventive attention focuses on a particular technical issue because it is strategic for an expanding technological system. Thus Edison's work on the high resistance electric light filament followed his identification of the filament as central to electricity's economic struggle with the existing gas light industry (Hughes, 1983).

Much British SST research concerns the *generation* of new technologies, which may arise in academic or industrial laboratories. There is particular interest in how technologies developed in the 'laboratory' reflect specific local concerns and priorities. These technologies must then be *transformed*, as they move from research to commercial production and widespread use (i.e. as they become 'commodified'). This is not uniformly the case. Certain instruments and techniques ('instrumentalities') do indeed conform to conventional ideas about technological diffusion which treat technical products as largely fixed entities, and can be simply transferred without modification and applied in different contexts. Attempts at commercial exploitation of artificial intelligence (AI) provides a case in point here (Cornwall-Jones, 1990). The most widely diffused products are 'expert systems' shells, which can be applied in a wide variety of circumstances, but which arguably amount to little more than devices to assist in programming. [7] However, where more general technical systems are transferred, they may need to be reconfigured, 'translated' and redesigned to meet the new requirements.

This highlights an important theme in SST, which (as we briefly outlined in our opening section) stems from criticism of the conventional 'linear model' of innovation.

This model traditionally describes technologies as 'applied science', emerging through a sequential flow from basic science, through applied R&D to commercial production and use/consumption: it conceives the cycle of invention–innovation–diffusion as separate 'stages' in an essentially linear process (Pinch and Bijker, 1984; Edge, 1988; Fleck, 1988b). At the 'invention' stage technologies are presumed to arise as 'fixed' or 'black-boxed' solutions. These established artefacts are then diffused through the marketplace, to have 'impacts' upon society, work organisation, production systems, skills and so on. However, empirical study of technological development highlights the serious limitations of this linear model. In particular, SST research emphasises *feedback* from the later stages of innovation to the 'upstream' sites (see, e.g. Edge, 1988).

Another part of this 'interactive' model of innovation has emerged from analysis of the implementation of new technology. This shows that *implementation* is an important site of innovation: Fleck has coined the term 'innofusion' to describe the kind of 'learning by struggling' which is involved (Fleck, 1988a). Fleck's alternative model of technological development stresses

... the possibility of the development of technologies which are at the outset intrinsically constituted in terms of user needs and requirements – that is, in terms of the characteristics of demand. This is achieved, not through some esoteric, arbitrarily plastic, "black box" of technology which responds to market signals conveying information about demand, but through determinate processes of technological design, trial and exploration, in which user needs and requirements are discovered and incorporated *in the course of the struggle to get the technology to work in useful ways, at the point of application* (1988a, p. 3, our emphasis).

In this approach, technological development is a spiralling rather than a linear process: crucial innovations take place both at the design and at the implementation stages, and are continually fed back into

[7] The artificial intelligence (AI) based systems which have actually been implemented are very restricted compared to the broad range of developments and claims of AI. What is applied is often cut down, simplified elements of AI (such as intelligent knowledge based systems (IKBS) or 'expert systems') which are barely distinguishable from conventional computer tools and techniques (Cornwall-Jones, 1990).

future rounds of technological change.

This focus on implementation counteracts the traditional privileging of technology supply and instead highlights the contribution of 'users' to innovation and the importance of supplier–user interactions. Particularly in relation to information technology (IT), implementation is the arena in which supplier offerings interact with user needs. Powerful 'universal' information processing techniques, embodying computer science principles, are customised for use, drawing upon the contingent local knowledge of the various user groups. This provides a test ground, a site for learning about the utility of (and problems in using) technological products and about user requirements. This knowledge is fed back to the suppliers, and can inform further innovations. The importance of supplier–user interactions has been demonstrated in a range of ITs, including robotics (Fleck, 1988a), computer systems in the finance service sector (Fincham et al., 1995) and computer aided production management systems in manufacturing (Clark and Newell, 1993; Webster and Williams, 1993).

Taken together these observations constitute an alternative to traditional linear models of innovation as reflecting a simple rationality (Lundwall, 1993). The emerging *interactive* model conceives innovation as a complex social activity: an iterative, or spiral process that takes place through interactions amongst an array of actors and institutions involved and affected. Innovation is a process of struggle (Hård, 1993) as well as a technical problem-solving process, involving interest articulation as well as learning processes. This framework highlights the types of expertise possessed by different actors in the innovation process and the flows of information between them (Fincham et al., 1995).

The characteristics of these interactions may vary between sectors and types of technology depending for example on the kinds of knowledge inputs (Pavitt, 1984; Faulkner et al., 1995), the maturity of the technology, as well as between different nodes in the technological system, most closely involved in different 'innovative moments' of design/development, production and consumption (Molina, 1989a). These features will have a bearing upon the range of players (and the relative importance of local players and broader networks and institutions) and the way they are involved. Here SST places particular emphasis upon the 'meso-level' of interactions between organisations as well as the 'micro-' or firm level (Sørensen and Levold, 1992).

In the rest of this section, we examine particular aspects and sites of social shaping in more detail: first, the technology/organisation relationship in the implementation of technological change within organisations); second, the consumption of technology (including the construction of markets) as a dimension in the shaping of technology; finally, 'gender and technology' (which constitutes a pervasive feature of SST, in the design, production, consumption and use of technology).

All this work has, as its main aim, an understanding of technological change as a *social process*. While early work highlighted the close interplay between the technical and the social in a 'seamless web' (Hughes, 1983) that lacked clear boundaries, today the consensus is emerging that the distinction between the socio-economic and the technical is increasingly hard to sustain.

3.1. The technology / organisation relationship

When we begin to examine the implementation of technologies within organisations, we find that 'technology' and 'organisation' cannot be treated as entirely separate categories. Their social settings shape technologies just as much as vice versa: the mutual relationship between the two becomes more apparent (MacKenzie and Wajcman, 1985; Edge, 1988). It is therefore clearly unhelpful to treat technologies and their social contexts as separate phenomena in the way that traditional conceptions have tended to do; the definition of technology itself must incorporate the social arrangements within which it emerges and becomes embedded (Hill, 1981; Clark et al., 1988).

This implies abandoning the preoccupation with technology as 'equipment' alone. Instead, we require a schema which acknowledges all those institutions, artefacts and arrangements within which the adoption, configuration and use of those technologies takes place – including the knowledge and expertise which have created technologies and are embedded within them (Dosi, 1982), and the processes of learning and experience which inform innovatory activity (Sahal, 1981). Technologies, therefore, are inclusive phenomena. Their development proceeds by interaction of various social and technical elements. These different components cannot be separated from one another, or treated as distinct variables; they are in constant mutual tension. Just as there is no linear effect of technologies upon society, so too the conditioning of technologies by social factors is not a simple one-way process. Technologies, once developed and implemented, not only react back upon their environments to generate new forms of technology, but also generate new environments (Clark and Staunton, 1989; Fleck, 1993, Fleck, 1995; Webster and Williams, 1993).

Technologies are in part prefigured by existing forms of work organisation: they come to embody elements of earlier divisions of labour and expertise (Fleck et al., 1990). [8] At the same time, technical change is frequently motivated by particular ideas about the organisation and how it should develop, and technical systems may be designed and implemented with particular objectives of transforming work. Analysis of the development of technology and of work organisation must thus proceed in tandem. Furthermore, the development of complex production and administration systems (and their implications for work) can only be understood if we see them as complex configurations of automated and non-automated activities (Fleck, 1988b). These observations are particularly relevant to industrial applications of IT, which we discuss in more detail in Section 4.

However, it is useful at this point to consider the idea of complex technologies as 'configurations' (Clark et al., 1988). Fleck (Fleck, 1988b, Fleck, 1993, Fleck, 1994) characterises integrated IT systems as examples of *configurational technology*. Whereas most contemporary applications of IT have automated *discrete*, well-delimited functions, which can be standardised and readily obtained through the market, *integrated* applications of IT to conduct a range of activities, can rarely be obtained in the form of standard solutions. [9] Instead, firms must 'customise' solutions to fit their particular structure, working methods and requirements. They may be forced to select, and link together, a variety of standard components from different suppliers. The result is a particular *configuration* – a complex array of standardised and customised automation elements. Moreover, no single supplier has the knowledge needed to design and install such complex configurational technologies. Instead, this knowledge is distributed amongst a range of suppliers (of different technological components) and a range of groups within the firm. Configurations are highly specific to the individual firms in which they are adopted – and local knowledge of the firm, its markets, its production and administration processes, its information practices and so on, are at a premium (Fleck, 1993). This local learning and innovation may have broader significance. Suppliers may discover opportunities to adapt them into more-or-less generic technological applications that can be sold to a range of other companies. Indeed, some important new technologies (such as robotics) have evolved and become technically viable and commercially successful in particular applications through close collaboration between supplier and user companies, each contributing important knowledge (Fleck, 1988a).

We thus see the development of industrial technologies in terms of a double dynamic. On the one hand, we identify processes of sedimentation within the ferment of innovative activity, whereby certain technical artefacts become stabilised and standardised, and may be available to the user through the market as 'black-boxed' solutions, as 'commodities' with well-established attributes. On the other hand, the dynamic development of both technological opportunities and user requirements may open up new application possibilities, and undermine existing solutions. By creating greater complexity and uncertainty in system development this may reverse the trend to stabilisation (Brady et al., 1992). A fuller understanding of this process must consider the range

[8] For a precursor, see what has been called 'Conway's Law': "systems resemble the organizations that produce them" (Yourdon and Constantine, 1979, p. 400, footnote).

[9] The distinction between discrete and integrated technology is discussed in more detail in Section 4.3 – Industrial applications of IT.

of relevant knowledges, both of technologies and of the user domain, and their distribution between supplier and user firms (Fleck, 1995), and the extent to which this knowledge remains local and contingent or can be appropriated and centralised, and even embodied in 'black-boxed' technical solutions, reducing the knowledge needed by the local user.

3.2. Social shaping of consumption and the rôle of markets

Although SST research often started from the design of artefacts, the interactive model highlights the need to look at whole 'circuit of technology' (Cockburn and Furst-Dilic, 1994, p. 3), from design and production through to consumption and use, to understand how technologies and the social implications are shaped.

This first draws our attention to the interactions across a network of actors involved in innovation and the creative tension between supply and consumption. Certain groups, such as marketing personnel, may occupy crucial interfaces. Thus Webb (1992) has analysed their role in the relationship between supplier and user firms in a variety of new, mainly IT-based, products. She emphasises that product development is not simply a question of deploying technical know-how, but involves other types of expertise – for example, in marketing. Social interactions amongst particular occupational groups within and between firms, their cultures and orientation, all influence product design and choice.

In his study of the commercial exploitation of monoclonal antibodies in biotechnology to create techniques and products for medical diagnosis, Green (1992) has examined interactions of this kind across a broader network of players. He notes that for a new technology to realise its 'commercial potential', where there is no existing market, "the 'market' may have to be created to go with the product" (Green, 1992, p. 165). Green found that biotechnology firms were relatively successful in selling those products which were, in effect, merely incremental innovations of existing products – for example new diagnostic tools which emerged from the templates of existing product markets. More radical innovations, such as new medical treatments, had to contend with a number of institutional, as well as technical problems, and made less headway. The institutional complications included regulatory controls, resistance from the medical profession, and the need to diffuse the knowledge required to understand the utility of new products, and to use them. A separate study by Walsh (1993) reaches very similar conclusions.

This work draws attention to the very different forms of 'coupling' (Freeman, 1984) that may exist between suppliers and users of technology. In emerging product areas, where products and markets are developing rapidly, with high levels of uncertainty, close forms of coupling are likely, including collaborative development. Vertical collaboration between supplier and user allows an exchange of information about technological opportunities and user needs. Horizontal collaboration allows players to share the risks in development. The former occurs in the development of strategic IT systems in the finance service sector (Fincham et al., 1995), and the latter in microelectronics (see Fransman, 1992, Fransman, 1995, below) and the commercial exploitation of biotechnology (Green, 1992; Walsh, 1993).

In the IT sector (as we shall see in more detail in Section 4 we find a complex pattern of stabilisation and destabilisation. The emergence of industry standard products (black-boxed solutions) 'creates' markets. These offer cheaper products, and give users both a greater choice of suppliers, and confidence that a product will not become obsolete (Swann, 1990). This creates an incentive for suppliers to collaborate in creating larger and more stable markets. Increasingly, firms are coming together, with competitors and suppliers of complementary products, to agree standards for emerging technologies (Cowan, 1992; Collinson, 1993). Future technologies/markets are being pre-constructed in a virtual space constituted by the collective activities of players! However, there is not, of course, a unidirectional shift away from competition. For example, these markets may attract new entrants (e.g. the proliferation of vendors of IBM PC 'clones'). Where accommodation or collaboration is not favourable, firms may promote proprietary solutions. Dominant players may seek to destabilise solutions and erode industry standards, to monopolise their links with users – for example the recent, largely unsuccessful, attempt by IBM to tie in existing users to their next generation of personal computers by launching the new OS2 operating system in place of the industry standard DOS.

The extent to which artefacts can be obtained as commodified 'black-boxed' solutions varies across the IT system. In hardware and its components, and in some types of software (computer operating systems and programming languages), black-boxing is well-advanced, but in application software it is poorly developed. This is perhaps unsurprising. The former type drives machine-related functions, potentially generalisable to a wide range of situations; but in local *applications*, software must be individually tailored to the specific needs and activities of a diverse range of users. The scope for commodification partly reflects market structure, but is equally a function of the kinds of knowledge deployed: 'black-boxing' implies that substantial parts of the knowledge required to create it can be appropriated and incorporated into a generic solution.

With mass consumer products and services, a very different pattern of coupling arises, since the supplier does not have direct links with all its customers. The consumer may be represented 'by proxy' – for example, through market research on panels of potential customers. However, the supplier has to take a major rôle in prefiguring, or indeed constructing, the customer and the market (Collinson, 1993). This remains a rather difficult and uncertain process for many suppliers – particularly where the technologies are consumed in the private sphere of the household (Silverstone, 1991). Studies of telematics products and services by Miles (1990) and Thomas and Miles (1990) have pointed to the complexities surrounding the design and uptake of technologies. Drawing on the examples of electronic mail, videotex and fax, they conclude that the success of new telematics services does not simply reflect their functionality and price, but also the extent to which they are compatible with the skills, understandings and habitual practices of potential users. Fax represents an extremely interesting case; though conceived in 1843 and commercially launched in 1865, it did not take-off until the last decade, when its explosive growth was attributed to the success of Japanese suppliers in 'manufacturing a superior machine' (cheap and designed into an easy-to-use package) and 'creating users' (Coopersmith, 1993, p. 48). Silverstone and Morley (1990), exploring IT-based technologies in the home, pursue similar concerns. In analysing consumption, such technologies cannot be treated simply as objects; one must also address the 'meanings' attached to artefacts, and the ways in which they are appropriated within (e.g. family) structures. The final consumer may have little opportunity to engage upon the design and development of such artefacts (e.g. domestic goods) other than the 'veto power' to adopt or not (Cockburn, 1993). However, even in this setting it is important to acknowledge the scope for these actors to articulate their own representations of technologies and uses which may differ from those articulated by technology suppliers (Akrich, 1992; Sørensen and Berg, 1991; Cockburn, 1993). In this sense, closure is never final.

3.3. Gender and technology

Another issue that any SST model must accommodate is the influence of gender (Wajcman, 1991; Sørensen, 1992). The creation and consumption of technologies are subject to pervasive and often extreme sexual divisions of labour. With a few notable exceptions, however, much UK socio-economic research on technology, including social shaping research, has been 'gender-blind' (Liff, 1990). The virtual exclusion of women from most areas of technological research and design, and the fact that it is principally men that shape modern technology went largely ignored. Within SST, actor-network and SCOT approaches had particular problems in addressing this sexual division of labour; their analyses start from the actors directly involved with innovation, and have difficulties explaining the influence of broader social structures, and why some actors are excluded or marginalised and why some actors and outcomes may be absent. Their preoccupation with the powerful and pro-active groups has led to a neglect of marginalised and subordinate groups (Russell and Williams, 1988; Radder, 1992). Though they have focused selectively upon the largely masculine world of technology design, the predominance of men has gone unremarked. They have moreover failed to see women's involvement in production and in the consumption of many technologies (Cockburn, 1993; Winner, 1993).

In the 1980s, the focus of feminist interest extended from science to technology, and from the position of women in technological professions to wider question – such as the gendered nature of technology, and women's rôle in the production and consumption of technology, as well as its design. Feminist research draws our attention to the mutual shaping of gender and technology (Cockburn and Furst-Dilic, 1994). One the one hand it raises questions about how the gendered nature of society influences technological development: how the sexual division of labour and control in the production and consumption of technologies (and the gendered cultures and value systems thereby constituted) are reflected in the *form* of technologies? On the other hand it explores ways in which the use of these technologies may reinforce particular gendered social relations. Much of the early 'gender and technology' research tended to focus upon the differential *impacts* of technological change on the sexes (primarily on women) and on the sexual division of labour, in the workplace, in the home and in the global economy (Huws, 1982; Cockburn, 1983; Cowan, 1983; Mitter, 1986). A range of studies charted women's *exclusion* from, or concentration in, particular areas. Thus Cockburn (1985) and Hacker (1990) consider the systematic exclusion of women from technological know-how, the consequent 'maleness' of certain occupations (such as skilled printing crafts and engineering) and their associated technologies.

Extending this analysis, it was argued that women and men have fundamentally different relationships to, and therefore experience of, technology, with men more actively involved in design and construction and women primarily on the receiving end of its products – at work and home (Cockburn and Furst-Dilic, 1994), and even the intimacy of giving birth (Faulkner and Arnold, 1985). Technology had been appropriated as part of masculine culture; both shared an emphasis on instrumental rationalities and control over nature ('hard mastery'). This seemed far removed from the world of women, whose strategies (of 'soft mastery') towards technology were more holistic and did not exclude the affective and sensual (Cockburn, 1985; Hacker, 1990; Kirkup and Smith Keller, 1992).

Initial feminist writings tended to be pessimistic about the implications of technological change for women. They shared with much contemporary critical analysis a rather deterministic concept of the ways in which social values became incorporated in artefacts and then were reproduced as these were used (Wajcman, 1991). Thus the exclusion of women from technology was seen to both reflect and reinforce the imbalance of power and material benefit between women and men. This research pointed to a serious lack of regard to women's needs and priorities in technological innovation and design. Indeed, many feminists argued that the strong military–industrial orientation of modern technology reflects male dominance in this area, and raised the prospect that different technologies might emerge in a non-patriarchal society. Today, such essentialist interpretations of technology as patriarchal have been criticised (Wajcman, 1991). Recent writing highlights the difficulties of making direct links between (e.g. gendered) social values and the content of science and technology, and between the latter and social outcomes (Sørensen, 1992). Some feminist researchers have drawn upon SST concepts of 'interpretative flexibility' to insist upon the potential of even marginalised consumers/users of technologies to be 'actors', since the intentions baked into technology may restrict the flexibility of a given artefact but they cannot altogether determine its use or meaning' (Berg, 1994a, p. 95). This has opened up a new area of enquiry. Empirical research on this has focused on new technology at work, and domestic technologies.

In relation to the former, Webster (1993) has examined the historical evolution of a workplace technology traditionally associated with women – the word processor. There is a mutual shaping process between the (gendered) distribution of typing skills and office tasks and word-processing technologies. The subsequent shift from dedicated machines that mimic typewriters to all-purpose personal computers has opened up the potential for further reshaping of social relations (for example, male managers are losing their inhibition about using keyboards with computers – for spreadsheets and electronic mail and, latterly, even for text processing). Another set of projects has sought to address and alter these strongly gendered patterns. These projects have been concerned to intervene in the very process of IT systems design to develop different, and more 'human-centred' technologies. The objective is to empower users (particularly where these are women in 'low-grade' occupations, such as clerical work, who are usually totally disenfranchised from the process of systems design) and make fuller use of their skills and capabilities (Hales, 1988; Green et al., 1993). However, the sexual division of labour has proved remarkably persistent, maintained is it is by a range of interlocking factors – of which technology design is but a part.

A major study of the gender relations of technology focuses upon domestic technologies, and seeks to overcome weaknesses in existing design-focused study by examining the whole life cycle of a technology including manufacture, distribution and consumption as well as design, and the linkages between them (Cockburn and Furst-Dilic, 1994). Cockburn (1993) examines the struggles over the gender character of the microwave oven, which was initially characterised as 'masculine' electronic goods and only later, and incompletely, labelled as 'feminised' 'white goods'. Gendered social relations and technologies were caught up in a complex interaction of mutual shaping. Though largely absent from design, women figured in microwave assembly, in shops selling them, in writing recipe books and buying. Designers incorporated real or imputed women into the design process, often on the basis of limited knowledge. In their attempts to get the artefact to carry a message about how the product should be used there is an imperceptible shift 'from describing the user to configuring the user' (Cockburn and Furst-Dilic, 1994, p. 11).

The interaction between feminist research and SST, despite its difficulties, appears to have been mutually fruitful. Feminist perspectives have made an important contribution to SST, broadening the range of actors and influences under consideration and in this way also provoked discussion about appropriate epistemologies. SST has provided tools to analyse the complexity of the relationship between (gendered) technology and (gendered) society, which has, for example, improved understanding of the scope for and limits to human intervention.

4. Review of research into the social shaping of information technology

As we have shown, SST research is engaging with a wide variety of social settings of innovation (from the initial design and development of technologies, through their industrial production to their application and use): of social and economic forces which may shape technology (e.g. the division of labour and expertise within and across organisational structures; industry and market structures; and so on); and has highlighted the rôle of a broad range of involved and affected groups (including not only technologists and decision-makers, but also final users). We have examined some of the concepts that have been advanced for analysing the innovation process and its complex social setting. As we have argued, the value of these concepts will be demonstrated in their contribution to a better understanding of innovation in particular technologies. We therefore turn now to reviewing some recent empirical research findings in the field. SST has informed an enormous, and rapidly growing, body of research in Britain and beyond. We cannot summarise it all here. We have therefore chosen to present some research findings on just one technology – information technology (IT).

First, a general observation: the very structure and architecture of contemporary information technology is itself a product of historical processes of social and economic shaping. Different elements of the IT system have become differentiated, starting with the separation between hardware and software (Pelaez, 1990). [10] Software itself has become hierarchically segmented (OECD, 1985) between on the one hand *systems / utilities*: such as operating systems, programming languages, which are closely related to the functionality of computer machines; *application tools*: generic data management systems and tools and, at the other extreme, *applications solutions*, such as accounting and payroll systems which con-

[10] As Pelaez (1990) has pointed out, the creation of the sofftware market was itself a direct consequence of a political action. Regulatory intervention to prevent IBM from bundling together software with its hardware sales created the basis for the establishment of an independent software supply sector.

cern the use of computers for example in organisations including industry specific applications such as electronic funds transfer systems in banking. This segmentation marks out a degree of autonomy between the development of different components of the technological system, whereby interaction between each set of components is restricted, for example by stabilising the interfaces between components. It can be seen as reflecting a strategy for managing the growing complexity of the IT infrastructure; a process of 'black-boxing': stabilising certain elements while segmenting the knowledge involved in their development and use. At the same time, it reflects a process of differentiation in the industrial sectors engaged in its supply. So whereas industrial *users* of automatic data processing machines, such as Prudential Assurance and Lyons, were heavily involved in the construction of the earliest commercial computers (Campbell-Kelly, 1989), and in the creation of the first operating systems (Friedman and Cornford, 1989), today these technologies are developed almost exclusively by specialised IT suppliers (Brady et al., 1992).

This review groups research on the social shaping of information technology according to its primary focus. First we address work which addresses the influence upon the content of computer technology per se: both hardware and software, where the focus is upon the factors shaping development of artefacts within the laboratory and as they moves out of the laboratory into commercial production and use. We next examine the large body of work which explores the industrial application of IT. Given the importance of 'innofusion' this focuses upon a nexus between diverse players: not only those involved in IT supply, but also, significantly, various groups of organisational 'users'; finally we address the small but rapidly growing area of research into IT in the home and community.

4.1. Hardware

There has been relatively little research to date on the social shaping of IT hardware (but see Kidder, 1982, for an interesting account of the influence of organisational culture, and Edwards, 1995, analysis of the role of the military). MacKenzie and others studied the evolution of parallel computing technology as it moved from initial development to commercial exploitation and use. They found that its development could not be explained simply in price:performance terms (MacKenzie, 1991a, MacKenzie, 1991b). For example, the technology was supported because of its perceived importance for national strategies, and as a means by which firms could demonstrate their technological competence. Noting the tension in the further development of this field, between the short-term commercial success of 'grainy' machines (based on small numbers of processors) and the longer term prospects/more obdurate technical problems (particularly in relation to programming) of more radical solutions, MacKenzie predicted the emergence of 'hybrid' machines, which combine a fast conventional processor, for parts of programs that are hard to parallelise, with a massively parallel processor.

Molina (Molina, 1989b, Molina, 1990, Molina, 1992, Molina, 1994a, Molina, 1994b) has examined the recent development of the European microprocessor industry, starting with the development of the transputer. This microprocessor, designed for parallel applications, was launched with a programming language (OCCAM) which, though sophisticated, was not used in industry. Commercial exploitation was held up until compilers were developed in more standard industry languages. Molina observed that the designers' emphasis on the technical elegance of their solution, neglected users' needs; the transputer's future, he argued, would depend on the ability of its promoters to engage with users – and thus to broaden the 'transputer-constituency'. Subsequently the transputer became one of the core elements of a much larger technological effort – the European Open Microprocessor Initiative (OMI). This was a collaborative initiative, bringing together many competing suppliers and users – and other institutions, with a view to creating an autonomous European microprocessor capability that could challenge the market dominance of Intel and Motorola. Molina highlights the interplay between the detailed design of artefacts (in this case the use of open standards for collaborative development) and the commercial strategies and prospects of different technologies.

Given the pace of innovation in IT, coupled with the need to maintain inter-operability between the offerings of different players, some distinctive strategies for managing innovation have become particularly marked. These are particularly marked in relation to hardware, where the huge R&D costs of new products, coupled with massive potential economies of scale bring great uncertainties: huge losses for those that fail and potentially enormous returns for successful products. For example in microprocessors, or the IBM PC (personal computer), competitive strategies of 'architectural technology' have emerged – where some elements of a product remain constant through several different generations (Morris and Ferguson, 1993) providing some guarantee of compatibility over several product generations for consumers and producers of complementary products.

Most existing research on hardware focuses on economic and policy aspects of its development and production. This work does not, in general, address the content of technologies and their social shaping. Some work, however, has attended to flows of technological information between suppliers and users in the innovation process, highlighting the importance of collaborative networks amongst actors and the broader policy context. Thus Fransman (Fransman, 1990, Fransman, 1991) has examined the development of digital electronic switches for telephone exchanges in Japan, as an example of the Japanese 'national system' for innovation. He notes the creation of stable, long-term relationships between Nippon Telegraph and Telephone (NTT) and its main suppliers – involving close collaboration (in joint research and development of new switches), semi-competitive tendering to NTT and full competition for outside markets (Fransman, 1995). This solution offered benefits to firms (sharing the risks and costs of development), compared with the competitive relationships that prevailed, for example, in the UK. Fransman (1992) suggests that these distinctive arrangements were related to areas of relative technological failure, as in the case of central office switches, as well as Japanese success.

4.2. Software

Software represents the critical layer in IT systems – it forms the interface between the 'universal' calculating engine of the computer, and the wide range of social activities to which IT is applied. For IT systems to be useful, they must, to some extent, model and replicate parts of social and organisational activity. Earlier applications of IT focused on routine and simplified information processing activities, such as payroll and account-keeping. These could readily be described in mathematical terms, converted to algorithms and implemented in software. But currently, IT is being applied to more complex organisational activities. IT systems must therefore articulate with higher-level human information processing activities (of decision-making, planning and communication) that are inherently more difficult to describe in formal mathematical terms. Human beings are adept at dealing with poorly defined problems (of problem recognition, of decision-making in contexts of uncertainty, of dealing with ambiguity) which are extremely difficult to replicate on computers. Here people deploy a wide range of experience and (often tacit) knowledge which is difficult, if not impossible, to formalise and appropriate within software systems. The problems in applying IT thus often appear in the production of software. Moreover, it is through software that the purposes of an IT application become realised; software is designed to achieve particular purposes; its design embodies particular values and social relationships. The various social groups involved in or affected by IT may have different objectives and priorities. Software is thus a potential site of conflict and controversy (Dunlop and Kling, 1991). Software development involves a wide range of obdurate social problems, and it is not surprising that it has attracted considerable attention from social scientists (Quintas, 1993). Interestingly, this is an area in which technologists have highlighted the potentially important contribution of social research in helping to resolve 'technical' problems (Randall et al., 1993).

Three major strands of social research on software are directly concerned with 'social shaping' issues: (1) the organisational sociology of software, (2) the 'social constructivist' analysis of software and (3) studies of the commodification of software. We will give examples of each.

4.2.1. The organisational sociology of software

The first, and probably largest, part of social research has involved studies of the organisational setting of the production and use of software, drawing upon industrial sociology and organisation theories. Kraft (1977), following Braverman, saw the labour process of *software workers* (that is, the occupational and organisational division of labour and expertise, and the manner whereby this expertise is deployed and managed) as becoming fragmented, routinised, deskilled and subject to increasing managerial control through structured programming techniques which embodied principles of 'scientific management'. Friedman and Cornford (1989), drawing upon an international survey of software occupations, have criticised this conclusion. They note a historical change in the balance of costs and of effort invested by user organisations in developing the different components of IT systems. Though the rapidly falling price of hardware initially focused attention on the high costs and poor reliability of software, this 'software crisis' has been replaced by a crisis of 'user-satisfaction', as IT systems become pervasive and form a central part of organisational activities. The need for increasing engagement between technical specialists and organisational users offsets tendencies towards functional specialisation and detail supervision in software production.

Other research has also looked at the interface between technical and other specialist occupations – focusing more upon the management of IT functions within the firm. As IT comes to be seen as a strategic resource for companies, conflicts emerge between technical specialists and other managerial groups (such as accountants or industry specialists) as to who will control it (Murray and Knights, 1990; Fincham et al., 1995).

Software design is seen as of particular importance, insofar as it is becoming increasingly bound up in the design of work. A large body of social research on technological change in the workplace over the last 2 decades has addressed this. A major concern was to determine whether computer systems were, as Braverman (1974) had suggested, a vehicle for 'Taylorist' models of work organisation based on the centralisation in management hands of skill and autonomy. We review this work in the following section on the industrial application of IT. It shows that there is a complex and uncertain relationship between social values and objectives motivating design, their embodiment in systems and the achievement of these outcomes when software is eventually implemented. For example, Green et al. (1993) have examined the sexual division of labour in developing software applications for clerical activities. Although arguing that system design is a major arena for the perpetuation of gender inequalities (because of the exclusion of women and clerical end-users from decision-making) control of systems design is by no means clear cut, but constantly open to informal redefinition and renegotiation.

4.2.2. The 'social constructivist' analysis of software

The software development process has been has been an attractive site for researchers studying the scientific or technology laboratory. For example, MacKenzie has investigated attempts to improve the reliability of software – which is becoming a major concern as computerised systems become more pervasive, complex and are increasingly used in applications where safety is critical. Formal mathematical methods are being proposed as a more reliable means than current empirical testing practices to assure that software performs in the manner intended. However, the sociology of scientific knowledge suggests that mathematical proof is not an absolute matter, but rests upon agreement as to which mathematical arguments are to be counted as proofs. Extrapolating from this, MacKenzie predicted that there would be differences of interpretation about what constituted a valid proof of a programs or hardware design, and moreover that such controversies might ultimately be tested in a court of law as these methods came to be applied in commercial settings. A range of disputes has been revealed, including litigation over the veracity of claimed proofs, confirming this prediction (MacKenzie, 1991c) together with general divergences in the meaning of 'proof' amongst different groups in the field (MacKenzie, 1993).

A rather different approach has been adopted by Woolgar and his co-workers. Low and Woolgar's study (Low and Woolgar, 1993) of a software development project explores how certain issues are characterised as 'technical'. From a discourse theoretic perspective they argue that "the 'technical', rather than being the opposite of 'social' is a thoroughly social accomplishment" (Low and Woolgar, 1993, p. 54), whereby particular specialists used jargon to create an arcane, private space, in their attempts to establish control over the project, and allocate responsibility and rewards for its success. Similarly, Cooper and Woolgar (1994), in their study of what constitutes software quality, explore the metaphor of 'technology as text' to highlight the scope for different readings. Again, the constitution of 'preferred readings' is explained as a social achievement – rather than a consequence of particular 'technical' features. Indeed, for this approach, 'the nature and capacity of the technology remain essentially indeterminate' (Woolgar and Grint, 1991, p. 370).

Whilst practitioners in the field may not have been convinced by the epistemological claims of discourse theory (Kling, 1992), ethnography has been accepted as a potentially valuable method – that could provide an important input to systems design (Suchman, 1987; Randall et al., 1993; Cooper et al., 1995). In particular it offers a *rich description* of how work is done, its social setting and the understandings of different players. This resource could help systems designers overcome the problems with their conventional methods, which have all-too often only produced an incomplete account of 'the user' (perhaps unduly focused on formal and overt roles and functions) leading to flawed and unsuccessful designs.

Sociology of knowledge has particular pertinence to a technology concerned with the appropriation and communication of knowledge and information. For example, Harry Collins (Collins, 1990, Collins, 1995) has sought to distinguish different kinds of human behaviour, and the forms of knowledge entailed, to assess the extent to which these could be performed by machines. He contrasts the nature of the knowledge articulated within an 'intelligent knowledge-based system' (IKBS or 'expert system') to the depth of human knowledges applied in dealing with apparently well-demarcated activities, to illustrate the *implausibility* of developing machines that can effectively replicate competent, socialised human action.

4.2.3. Studies of the commodification of software

SST has begun to examine the processes whereby software becomes available through the market, as a 'black-boxed' commodity. Swann (1990) has examined the economics of software standardisation. Lotus adopted a collaborative strategy, enabling other software houses to develop compatible products. When Lotus 1-2-3 emerged as an industry-standard spreadsheet package, it could be sold at a higher price than would be expected from its specifications, due to 'network externalities' – namely, its ability for use as a standard platform for other applications (Swann and Lamaison, 1989). Other suppliers had adopted different competitive strategies – developing proprietary spreadsheets that had better specifications, but were incompatible with competitors' products. These firms' strategies and mutual interactions are thus reproduced in the form of the software, and in the standards industry then adopts. Brady et al. (1992) examined the ways in which user companies acquire software (as bespoke software, turnkey packages, or customised applications) and the source of supply – from external suppliers or in-house development. The study highlights tensions between the cost advantages of providing standard packaged solutions, and their lack of fit with the unique circumstances of particular user organisations. In the short-term, such standard packages often fail; in the longer-term certain tasks may become standardised around the templates of particular applications, particularly where there are positive 'network externalities' from interoperability of technologies, or standardising skills and training. This is reflected in a double dynamic: the stabilisation and commodification of certain generic applications (word-processing packages; payroll systems) on the one hand is countered by the differentiation of new applications as firms seek competitive advantage through the development of unique and novel applications. Two new supply-strategies are becoming more marked: user-configurable software, and the creation of standard technology components that can be configured together on a 'pick-and-mix' basis to meet user requirements.

4.3. Industrial applications of IT

In analysing the industrial application of IT, it is convenient to distinguish between (i) 'discrete' or stand-alone applications of IT; (ii) 'integrated applications', involving databases and computer networks within the user firm; and (iii) 'inter-organisational networks'. These types of application differ in terms of the problems of system development and the structure of the constituencies of actors involved.

Whereas most applications of IT to date have been *discrete technologies* applied to specific or closely related functions, there is now a shift towards *integrated technologies* which link together increasingly diverse activities (for example, of design, administration and production). Discrete applications tend to automate well-defined functions, and can thus be standardised and readily obtained through the market place; they typically involve a single supplier and a single department/group of workers within the organisation. Integrated applications, when applied to internally intricate and diverse activities in manufacture, can rarely be put together by a single supplier as a 'packaged solution'. Instead, suppliers must select a range of components, and link them together in a network. This will involve some customisation to allow different components to operate together (insofar as interfaces are not yet standardised). Moreover, since standard technological offerings operating at the level of the whole organisation are unlikely to fit the precise requirements, structures and operating practices of any individual firm, this will require more extensive customisation (Fleck, 1988b).

4.4. Discrete applications of IT

Research into the implementation of 'discrete' technologies has uncovered a wide range of factors shaping the design of industrial technologies and associated forms of work organisation. These factors include the economic and political objectives of suppliers and managers in user companies, the occupational strategies of different groups in the user firm, their skills and negotiating strength and specific features of the tasks being automated. As well as the immediate features of the labour process, the broader context, including the industrial relations system, and national culture, have all been shown to be important.

These can best be illustrated in the case of 'numerical control' (NC) machine tools, which have been extensively investigated, following Noble's classic study (Noble, 1979) of its initial development after the Second World War. Noble showed that the design of NC was patterned by an explicit objective (shared by a localised constituency of machine tool suppliers, managers in the aerospace companies using NC and the United States Air Force sponsors) of increasing managerial control by reducing reliance on craft metal-cutting skills. However, this attempt to obviate manual skills was only partly successful. As machine tool suppliers sought to sell their equipment to a wider range of firms, the NC sociotechnical constituency grew larger and more diverse, and different requirements came into play. With the development of 'computer numerical control' (CNC), in which the programming computer is attached to the machine tool, more pragmatic approaches emerged. Better interface design meant that CNC could be implemented with fewer technical skills and a lower division of labour. The operational advantages of shop-floor programming resulted in the design of control systems to facilitate 'manual data input'. CNC's adoption was subject to a complex web of interests and concerns. The design of CNC jobs (and the distribution of programming, setting, operating and coordination functions between groups) has been powerfully shaped by processes of negotiation and accommodation between engineering managers, different groups of manual and technical workers, their trade unions (Jones, 1983; Wilkinson, 1983; Williams, 1987; Burns, 1988). A wide range of ways of working with CNC has emerged – depending upon the organisational context and the particular traditions and strategies of the players. A lower level of division of labour between CNC programming, supervision and operation was, for example, associated with smaller companies and with smaller batch sizes (Hartmann et al., 1984). Other things being equal, a higher division of labour tended to be adopted in the UK than in Germany: this was attributed to differences in their industrial relations systems and culture. These differences in industrial culture have in turn reacted back on the form of technology: in Germany, Japan and Norway CNC control systems have emerged designed for shop-floor programming (Anderson, 1988; Spur, 1990). The story has come full circle!

Similarly, research has shown that the introduction of discrete IT systems into office work brings about no single pattern of work organisation. Despite predictions that techniques of office automation (such as word processing) would bring assembly-line regimentation to the office (Braverman, 1974), office-work organisation remains much the same, after implementation as before (Webster, 1990). The key influence on work organisation seems to be the prior division of labour in the workplaces. And this, in turn, is a function, not of IT, but of broader organisational imperatives: managerial objectives and practices, traditions of corporate behaviour, strategies for the control of female workers and responses to local labour market conditions, for example (Webster, 1990).

This body of research demonstrates that 'discrete technologies' have been socially shaped. In particular, they have been designed around templates of existing jobs/tasks, coupled with specific objectives for social and organisational change – not only economic objectives, but also political conceptions of how jobs could be redesigned. [11] In practice, these expectations have only been partially fulfilled. The radical improvements promised by a range of technologies have often not materialised – either in productivity and economic efficiency, or in profound organisational change. Their implementation involves a typically painful learning process that has, to date, been repeated for each new technical offering as it emerges (Senker, 1987). User firms and suppliers have consistently underestimated the difficulty of implementing new technologies, and the need to invest in developing the organisation, training and so on.

This points to a more general aspect of SST: the repeated search for a 'technological fix' to organisational problems, on the assumption that technological change will readily deliver appropriate organisational change. Suppliers (claiming that their products will fulfil the organisation's needs), consultants and government agencies (promoting technical solutions to industrial problems) and user managers (readily won over to accepting these visions), have all been enrolled in this search: technologies have been developed and promoted in the image of current concerns about production. However, conceptions of the problems that technology would solve have changed substantially over time. Thus, in the late 1970s, a rationalising model of technology prevailed: new technology was seen as a way of bringing the economics of mass production and Taylorisation to small and medium-sized batch methods, which had hitherto been largely exempted. In the 1980s, faced with popular perceptions of 'the Japanese challenge', new models of firm behaviour were articulated. Technologies began to be promoted and assessed on the basis of flexibility rather than just productivity. Initially, the priority was flexibility at the point of production, through, for example, programmable equipment. More recently, with the emergence of integrated applications (see below) attention has shifted to the level of the firm and its strategic responsiveness to its environment (Jones, 1988; Zuboff, 1988; DTI/PA Consultants Group, 1990).

Overall, studies of the social shaping of discrete automation emphasise the fluidity and uncertainty of innovation – and thus, also, the potential malleability of new technical systems. Various initiatives seek to exploit this malleability in the design of 'human-centred systems' – alternative approaches to IT applications, explicitly informed by a desire to abandon the traditional presumption that technologies should displace workplace skills. Early attempts (for example the 'human-centred lathe' designed by Professor Howard Rosenbrock at UMIST) started by generating an alternative system specification. Focusing on the allocation of functions between operator and machine, the team tried to retain human conduct of those tasks best suited to human skills and capabilities – aiming for a system which combines maximisation of operator skills, quality of working life and the performance and flexibility of the production system. Later approaches start by examining the social shaping of current technology and jobs (Green et al., 1993), exploring inherent contradictions in job and systems design to identify opportunities to change power relations in the design process (to enhance involvement and influence by lower-graded staff), and to challenge, rather than reinforce, traditional divisions of labour. In this way, human-centred technologies have been seen as a way of socially shaping (and indeed reshaping) technology and working relationships (Rauner et al., 1988).

4.5. Integrated applications

The sociotechnical constituencies involved in the emergence of integrated IT systems tend to be more complex and diverse than with discrete technologies.

[11] For example, Fleck (1988a) and Fleck et al. (1990) show how the design of robots was conceived in terms of a universal replacement for repetitive manual labour – which in turn presupposed the existence of routinised, 'Taylorised' mass-production work and was partly informed by visions of robots drawn from science fiction.

Many suppliers may be involved, together with a range of members from different departments within the user organisation, with distinctive sets of interests, working practices and types of expertise. Clearly, the development of integrated information technologies is even more fluid than that of discrete technologies.

Integrated systems tend to be directed towards the overall performance of the organisation, rather than the conduct of particular tasks. Ideas about how integrated technologies will proceed are closely paralleled by concepts of industrial organisation (Clark and Staunton, 1989; Webster and Williams, 1993). For example, in the financial services sector, integrated databases and new methods of service delivery based on IT were seen as allowing banks and building societies to become 'financial supermarkets' (Fincham et al., 1995). Similarly the concept of 'computer-integrated manufacturing' (CIM), in which the diverse kinds of information involved in manufacturing are centralised on an integrated database, had an organisational correlate in emerging notions of the 'flexible firm', which has close linkages between its sales, marketing, design and production functions, as well as with its suppliers and customers (Fleck, 1988b). Production and inventory control systems (PICS) were projected as a stepping-stone towards this vision of CIM. This coincided with a growing emphasis on the success of organisational practices of Japanese firms ('just-in-time' (JIT)) which also stressed flexibility of production, but through rather different means. These changing concepts of good industrial practice influenced the development of CIM technologies: JIT modules and other elements were added to PICS software systems.

Packaged systems were promoted as a 'technical fix' to the problems of UK manufacturing organisations. However, the initial supplier offerings often had their roots in large US corporations manufacturing complex assemblages and with very formalised information and decision procedures. The requirements of this software was far removed from the haphazard data collection and idiosyncratic planning practices of many of the UK firms who tried to adopt them. Initial implementations often proved unsuccessful (Fleck, 1993; Clark and Newell, 1993; Webster and Williams, 1993).

Integrated IT systems are complex configurations of technical and organisational elements, which must be customised to the conditions into which they are introduced. Though integrated technologies were promoted alongside a vision of the transformation of organisations, in practice it was the former which was more immediately changed. Users were forced to reconfigure these technologies to suit their own particular local circumstances. This process threw up technical and organisational innovations, some of which could be applied elsewhere (Fleck, 1994). So although expectations of dramatic improvements in organisational performance were not immediately fulfilled, despite substantial levels of investment (Freeman, 1988), this 'innofusion' process may provide the basis for further technological and organisational development.

4.6. Inter-organisational networks

Attention has shifted towards the development of IT networks that link different organisations ('inter-organisational network/systems'(IONS)). The constituencies underpinning the development of IONS have a very different structure to those in company-level computerisation, where the user organisation ultimately retains control over the interface between the various components and the overall system operation, and has a direct contractual relationship with all the players (e.g. external suppliers). With IONS, the number of organisations linked to the network may be very large – indeed, notionally infinite. Organisations may thus be affected by the actions of others in the network with which they have no immediate contact. It is therefore essential to develop and agree standards for interfaces and protocols for data exchange to maintain the integrity and functioning of such networks. Organisations need to cooperate to agree these standards.

The first IONS thus emerged where relatively homogenous, and closely aligned groups of players were trading together intensively – for example Electronic Data Interchange (EDI) in the UK retail sector. This oligopolistic industry was also able to exploit the product/producer identification systems already established for bar-coding. Existing cheque clearing system similarly provided an informational template for the development of 'electronic funds transfer at point of sale' (EFTPoS) (Kubicek and Seeger, 1992; Williams, 1995). Once established, these networks tend to grow, due to powerful network externalities – whereby their value to each player increases with the number of players. The cost and inconvenience of catering for multiple, proprietary system has motivated the search for open systems [12]. There has been considerable success in agreeing protocols for transmitting data between different kinds of machines. It has proved more difficult to agree the content of messages, as these relate to the aims and practices of organisations that vary substantially between firms, industries and nations.

IONS, like the other organisational technologies we have reviewed, were conceived as enabling radical organisational change, by allowing firms to change their strategic relationships with other players in the supply chain, securing competitive advantage, changing power relationships or even by-passing other players altogether. However, the immediate need for competing firms to collaborate in agreeing the information to be exchanged has meant that many IONS reproduce existing commercial relationships, or change them only incrementally (Spinardi et al., 1996). Similarly, electronic markets, which could have dramatic affects on competition within a sector, have often been designed to provide 'a level playing field', that balanced the interests of existing players while preventing any one player gaining undue control. There is a complex interplay between collaboration and competition. This has, for example, shaped the design of EFTPoS systems (Kubicek and Seeger, 1992; Howells and Hine, 1993). Today, attention is beginning to focus upon the emerging 'information superhighway' and the Internet. By providing cheap and flexible tools for new kinds of networked business communication and services, the Internet opens up IONS to a much wider range of providers and customers, potentially enabling more dramatic change. However, a range of 'social' and 'technical' problems must first be resolved surrounding access, security, reliability, usability, intellectual property rights etc. (Dutton et al., 1994; Kahin and Keller, 1995).

4.7. IT in the home

The widespread societal application of information technologies started in the workplace. The organisation provides a semi-public forum for innovation, with opportunities for direct engagement between organisational users and its suppliers. As the price of microelectronic-based goods has fallen suppliers have sought to exploit the huge market of domestic consumers. However, the consumption of IT in the home remains a largely private sphere, with only weak and predominantly indirect linkages between supplier and user (Cawson et al., 1995). This constitutes a challenging terrain for research. However, a relatively small group of researchers has been addressing the development and adoption of information and communication technologies for use in the home, including videotext, the home computer and home automation products, e.g. the smart house (Silverstone and Hirsch, 1992; Berg and Aune, 1994; Cawson et al., 1995).

Given the paucity of links between designers and potential users (especially in the case of large organisations geared to mass markets), designers are forced to rely primarily upon their own experience and expertise; starting from their understanding of technological opportunities and imagining how these might be taken up their own households – which may be far from typical (Cawson et al., 1995). For example, suppliers' lack of understanding of 'the housewife' as a possible user, and of 'her' needs, means that technologies in the area of the smart house reflect technology-push rather than user-need; they have not really addressed the realities of domestic labour and have had little appeal to many customers (Berg, 1994b).

This may be one reason why the adoption of domestic IT has often fallen far short of expectations – as instanced by the uneven success of videotex (Bruce, 1988; Thomas and Miles, 1990). Where products are embraced by households, research has stressed the active nature of consumption, involving decisions to purchase the technology and incorporate it within family routines. This 'domestication' often involves innovation by the consumer – using tech-

[12] The European Commission has been significant player in the search for global EDI standards (which was a technological correlate of its vision of a single European market) to ensure that incompatible national EDI standards did not constitute a barrier to international trade.

nology in ways not anticipated by the designer (Berg, 1994a). Perhaps the most striking example is the telephone, which was originally conceived and promoted as a business communication tool for conveying price information to farmers, but which was re-invented by people in rural areas, particularly women, as a medium for social communication (Fischer, 1992).

The case of the home computer provides an illustration of how technologies are appropriated by domestic users (Silverstone and Hirsch, 1992). The evolution of this technology became subject to a web of competing conceptions articulated by various players: government, suppliers, parents, children. Though initially promoted as a means of carrying out various 'useful' activities (word processing, educational programmes), this was largely subverted by boys, whose enormous interest in computer games has shaped the evolution of home computers, leading to the creation of a specialised market for these products (Haddon, 1992). However, domestic users (and refusers) are not homogeneous; their responses are differentiated by gender, generation and class, and shaped in the complex social dynamics (or 'moral economy') of the family (Silverstone and Morley, 1990; Silverstone, 1991).

Today we see a new generation of products and services being envisaged around the development of 'multimedia' technologies (Collinson, 1993; Cawson et al., 1995) and the 'information superhighways' that could bring computerised video and sound, as well as text messages, into the home. Huge markets are anticipated for new products that are interactive, easier to use and more engaging – but there is little understanding of what the products that will eventually prevail will look like (Dutton et al., 1994; Kahin and Keller, 1995). This has redoubled interest in the domestic consumption of IT and the highly dispersed learning process through which family members will come to adopt, redefine and even perhaps re-invent some of these new offerings.

5. Some dilemmas for SST

We have noted a number of points of tension and divergence between the constituent strands of SST. Some of these differences are relatively modest – deriving perhaps from idiosyncrasies of emphasis or tradition which could be readily resolved. We would include under this heading criticism of SST for its relative neglect of the consumption of technology, and the character and rôle of markets and culture/ideology in shaping technologies (Miles, 1988; Mackay and Gillespie, 1992; Cockburn, 1993; Cockburn and Furst-Dilic, 1994). However, other differences have provoked sharp controversies, which reflect upon the theoretical and policy claims of SST. Their intensity will probably seem surprising, and their relevance may not be clear to those outside the field. However, it may be helpful to attempt the (perilous) task of briefly summarising the key points of cleavage and dispute, and their implications for the theoretical and policy development of SST.

Let us first note the different approaches to empirical research within SST, in its selection of instances of innovation. One key difference lies in the choice of focus between 'macro-', 'meso-' and 'micro-studies'. There are now some signs of convergence here. Thus investigators from a background in macro-theory (e.g. neo-Marxist and many feminist approaches) have sought to go beyond drawing simple relationships between technologies and large scale economic and political interests (e.g. of social class, race, gender) and have sought to account for the fine-scale and local processes in influence. Conversely, 'micro-theorists' (e.g. from ethnomethodology and actor-network theory including many from SSK) have started their analyses from the level of interactions amongst individuals and groups, and have then 'scaled up' these processes to obtain broader explanations. These two groups then find themselves offering conflicting explanations at the meso-level of social activity (Russell and Williams, 1988). However, there are objections to seeking simply to meld these two types of explanation. These differences are only partly the result of differing research foci, and of the respective methodological strengths of particular approaches. They also touch, importantly, upon epistemological objections from different schools. Thus actor-network theorists (Callon, 1980; Latour, 1988) are remorselessly sceptical about the nature and influence of pre-existing, large-scale social structures such as class and markets – and, in particular, in the prior attribution of social interests (Callon and Law, 1982; Latour, 1988). And they, in turn, have been criticised for eschewing existing social theory, leaving them poorly equipped to explain particular developments, and open to criticism for 'empiricism' – offering mainly descriptive work and post-hoc explanations. To their critics, they run the risk of ceding too much power and autonomy to individual actors, rather than to existing structures of power and interests (MacKenzie, 1981; Russell and Williams, 1988; Radder, 1992; Cockburn, 1993). This debate reproduces, often well-rehearsed, epistemological cleavages from elsewhere in social science – for example, debates about empiricism, and the relationship between structure and action (though often the discussions within SST appear to replicate, rather than move on from, them).

Two further major areas of debate within SST surrounded the related questions concerning 'realism' and the status of 'the technical', and about 'relativism' and 'how we know about technologies'. The SST critique of determinist assumptions about the process of technological change and its 'impacts' or outcomes leads to the view that the behaviour and properties of technologies are always mediated through particular social settings. Some writers, particularly from SSK, go further, insisting that we never directly 'know' the character of technologies, and of 'the technical'. Tests of the 'successful performance' of technologies are always mediated through socially rooted theoretical constructs (instruments and assessment criteria), and must thus remain provisional (Mulkay, 1979; MacKenzie, 1990), a position described as methodological relativism (Radder, 1992; Collins and Yearley, 1992). A more radical variant, stemming from the SSK strong programme, which can be termed 'epistemological relativism', argues against the invocation of some objective external reality in sociological explanation (Barnes, 1974). For example, according to the 'social realism' of Collins and Yearley (1992) we can never talk of the nature of the technical, but are always dealing with beliefs about the character of the natural world. Methodological and, in principle, epistemological relativism are, however, compatible with *realist* notions of the world.

Others have taken the deconstructivist project much further, to articulate a more profound 'ontological relativism'. Writers with roots in discourse theory and ethnomethodology have argued that the world does not exist independently of human existence and discourse. They reverse traditional positivist and realist assumptions about science and technology; for them *representations constitute objects* (Radder, 1992; Cockburn, 1993; Sismondo, 1993). Thus Woolgar (1991), applying the principles of SSK's strong programme to its own products, argues that SSK/SST must be reflexive about the knowledge it has produced. He further insists upon the multiplicity of possible representations or accounts of any technology and the difficulties, may impossibility, of providing a definite description of that technology or its outcomes. The result is a profoundly relativist perspective. This position obviously has important consequences for any claims to social relevance by SSK and SST (and social science more generally). For example it calls into question whether any analyst could ever obtain sufficiently robust knowledge to justify policy intervention. Whilst the humility of this view is endearing, it renders problematic the rôle of SST in the world. On the one hand, such a 'radical' relativism presents a very weak view of the utility of SST research; on the other, paradoxically, it also encourages such a profound scepticism about existing structures of power and interest that it may discourage researchers from analysing (and taking responsibility for) the ways in which their knowledge may be used by different social groups (Cockburn, 1993; Winner, 1993) [13]. Reflexivism has proved controversial. Though some of its insights have been interesting and valuable (Kling, 1992), its epistemological preoccupation and claims to be foundational have not been accepted; the formulaic application of this approach has been criticised as potentially limiting (Kling, 1992; Collins and Yearley, 1992; Pinch, 1993).

The French actor-network theorists, Callon and Latour, have come from a very similar background, but have taken their analysis in a rather different direction. They extend their analysis of social networks of actors in innovation to include non-human

[13] Paradoxically, in their reliance on naturalist methodology, some of the relativists in SSK have ended up arguing for a position that would appear to have close parallels to the positivist view of scientific neutrality they already rejected (Cockburn, 1993; Winner, 1993).

actors. They introduce the category of *actants*, interacting with, and conditioning the development of, a network; these include those humans not in a position to shape the network's development, as well as non-human actors, such as microbes, scallops, electrons, integrated circuits and their physical properties. Collins and Yearley (1992) have recently criticised Callon and Latour for this formulation, which they claim reintroduces empiricist concepts of the natural world which sociology of science had only just eradicated.

This brings Callon and Latour closer to the mainstream in SST. Writers, particularly those concerned with policy issues, have developed a critique of the relativist currents within SST, arguing that a useful theory of the relationship between technology and society needs to address more directly the characteristics of the material world, which may not determine, but does constrain, human capability. This is particularly important for an analysis of *technological activities* intended to transform and extend human capabilities by material means. Thus Miles (1988) argues that SST should reconsider its critique of technological determinism so as to retain some concepts about technology's determinate effects: he acknowledges that technology does not 'cause' particular social changes, being used in a variety of ways and social contexts with a range of outcomes, but he argues that particular technologies can change the parameters on which humans interact. After the technology of firearms had been established, one could still use a gun as a club; however, firearms, in nearly irrevocable ways, have changed the terms of lethal combat (Kling, 1992). [14] The price and performance of computer chips may be locally negotiable – but their general properties (as witness, for example, the current dominance of the Japanese economy in some technical fields) do indeed act as an objective constraint (Cawson et al., 1995).

This dispute has been bypassed by most empirical SST researchers, who in practice use a pragmatic conception of technology, within which they address both the socially negotiated nature of its characteristics and its imputed material properties – a position which we could describe as 'modified realism'. There are as yet few theoretical concepts for such an analysis. One important start is Law's analysis (Law, 1988) of the uneven 'malleability/obduracy' of different material components, which seeks to theorise both the material and the social constraints under which engineers build technologies and their associated social systems. We have already argued that the key research questions opened up by SST concern the circumstances and manner in which technologies may be 'hard' or 'malleable' to particular social groups. This takes us beyond the dichotomy between technology and society inherent in traditional realism or relativism/idealism, and sees technology as a *particular form* of social action/structure. Instead models are needed which address the dual character of technologies, not only as 'socialised nature' but also as 'naturalised society'; technologies are at the same time both material and symbolic objects (Rammert, 1995). Addressing these different aspects of technology, rather than reducing one to the other, opens up space to examine how their significance may vary according to the features of the technology and its social setting (Hård, 1994; Vincenti, 1994), and the purposes of the enquiry.

The case for some form of realism derives from the worldly implications of technology in the world, and touches importantly upon the claims and social rôle of SST. Some have argued the need for SST to maintain an intellectual distance from all its objects of study, social or technical, and to treat each with the same sociological scepticism and reflexivity. Other writers have suggested that SST should not limit itself to sociological explanation. Since technology is concerned with 'doing', with changing or maintaining social relations (Hård, 1993), epistemological relativism (with its already-noted conservative implications) has consequences which are 'normatively questionable' (Hamlin, 1992, p. 148), making desirable 'a modest form of realism' (Radder, 1992, p. 167).

[14] Woolgar and Grint (1991) predictably seek to dispute this point. They extend the unobjectionable argument, that 'it is always possible to reconstrue a technical description as (at least in part) comprising social aspects' (p. 378), to a more tenuous insistence that 'the technical capacity of the technology is essentially indeterminate' (p. 367). Another intriguing insight to this question is provided by the attempts to eradicate firearms from 18th-century Japan, on the grounds that they were too subversive to the existing social and military order (Perrin, 1979).

Taking this point further, SST specialists investigating contemporary technologies could be, and to some degree inevitably are, actors shaping technological development. SST researchers can be seen to possess special expertise relevant to the planning, development and use of new technologies, and could thus stand alongside other actors, such as technical and engineering specialists, whose contribution to technological innovation is well-established. Under this view, SST should explore and foster links with other disciplines – particularly of science and engineering (Rose and Smith, 1986; Hamlin, 1992; Sørensen and Levold, 1992). Here Law (1988) has noted that those concerned with developing new technologies do not play a narrow technical rôle, but are engaged in 'heterogeneous engineering', deploying a variety of knowledges to grapple with the behaviour of (and to create) complex sociotechnical systems. It is then only a small step to see SST as another contributor to this process – with its own heterogeneous knowledge bases (Sørensen and Levold, 1992). In other words, the goal of SST should not be of a 'science of technology' but of a 'technology of technology' (Hamlin, 1992).

Many of the preceding epistemological debates within SST have tended to take place at a high level of abstraction. The more profound differences reflect deeply entrenched debates within the social sciences. This has often added a somewhat religious fervour to the discussion (see, for example, Pickering, 1992). Perhaps these disputes never could (or indeed should) be resolved. However, they have not immobilised empirical research. [15] In some of the most interesting developments, competing theoretical perspectives are applied in analysing comparable technological fields (for example, the body of research on information technology, reviewed above). Though some of the protagonists might well dispute such a view, we would argue that it will be through their ability, in empirical research, to produce adequate and useful accounts that the intellectual value of the different frameworks will be established. Such an empirically rooted programme will highlight the problems of particular approaches, and elaborate possible synergies between different frameworks. Indeed, in handling empirical instances, many epistemological divisions between the different schools may become less acute. In other words, we would argue, intellectual development in SST, as elsewhere, will not come about through abstract considerations, but by a dialogue between theoretically and empirically focused activities.

6. Conclusions

We have attempted to outline how scholars from a variety of backgrounds were brought together by a critique of traditional conceptions of technology (the linear model of innovation; deterministic concepts of the dynamic of technological development, and of its societal outcomes). We have encapsulated this intellectual cross-fertilisation under the banner of 'the social shaping of technology' (SST). We do not wish to imply by this that the field has converged in a unitary or permanent manner: as we said at the outset, we conceive of SST as a 'broad church', without any clear 'orthodoxy'. We emphasise that the circumstances which have brought SST to birth constitute just one moment within the broader development of social analysis of technology – a developmental stage that was, in many ways, contradictory, and perhaps transitional.

We have drawn attention to the tensions between different approaches (in terms of methodology, of disciplinary origins, and above all of their relative emphasis on the negotiability and fluidity of technology) or on the rigidity and concreteness of the social relationships embodied, for example, within technical artefacts. These tensions have persisted. Although, in many ways, SST insights and themes are now becoming incorporated within the field of science and technology studies, the phase of 'convergence' (such as it is or was) may be leading on to a period of differentiation. For example, today, some writers argue that we should acknowledge the determination implicit in the existence of new technologies which *do* transform the range of human poten-

[15] Though they may have impeded such research. As Collins and Yearley (1992) have noted, many writers, particularly from SSK backgrounds, have been preoccupied with the search for epistemological guarantees. This attempt to find the 'constitutive bedrock' ultimately fails, and has been accompanied by a lack of attention to method, and a resort to 'mind experiments' in place of empirical work.

tialities, and thus the terrain on which technology is negotiated and renegotiated (for example, relationships between inputs and outputs, in terms of cost and labour productivity); others are moving in the opposite direction, arguing the need for a more profound deconstructivist approach (and ultimately relativism) in the social analysis of technology.

The field is currently developing in several directions. For example, some government and industrial policy-makers now acknowledge the force of criticisms of traditional approaches, with their relative overemphasis on the supply of technologies, and thus on the contribution to innovation of technical specialists and knowledge, over the 'non-technical' knowledges of users and consumers of technology. The defects of the 'linear model' are now widely acknowledged (Fairclough, 1992; Newby, 1992) In the context of growing concern about the failure of technological development to take into account the requirements of the 'market' of potential users, social science has begun to articulate its contribution to innovation: and some SST researchers have sought to articulate their role as *practitioners* in technological design and policy formation, alongside other disciplines and specialisms in 'heterogeneous engineering'.

Such conceptions of new rôles for SST and new relationships with other disciplines, is part of a broader questioning of traditional disciplinary boundaries. As we have seen, SST has developed importantly through a cross-disciplinary effort, arising from the realisation that the categories they have posed have often been unhelpful – in particular, by narrowing the search for social explanations of complex phenomena. In particular many within the SST church have called into question the artificial gulf between the 'social' and the 'technical' – and thus between the social sciences and natural science and engineering.

Other researchers have shifted their focus, using these insights into technology to explore processes of change, for example, within the organisation, or in regional economic development. Here, it could be argued, the SST perspective, by demonstrating the social malleability of perhaps the most concrete and apparently impersonal products of social processes (technology) and the lack of any clear boundary between the 'technical' and the 'social', has drawn attention to the need to reconsider other aspects of social activity that appeared stable and bounded – such as the traditional distinctions between economic, social and political processes. (For example, work that has sought to integrate 'sociological' and economic accounts of innovation which has led to a reconceptualisation of markets as socially constructed.) It may well be that the 'success' of SST, in the long run, will turn out to be its undoing, insofar as it may ultimately undermine the concept of 'technology' as a separate area of social activity, demanding modes of analysis that are different from those required in other fields.

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