From The Social Shaping of Technology, Second Edition. Edited by Donald MacKenzie and Judy Wajcman. Open University Press, Buckingham, 1999.

▶ Introductory essay: the social shaping of technology

Technology is a vitally important aspect of the human condition. Technologies feed, clothe, and provide shelter for us; they transport, entertain, and heal us; they provide the bases of wealth and of leisure; they also pollute and kill. For good or ill, they are woven inextricably into the fabric of our lives, from birth to death, at home, in school, in paid work. Rich or poor, employed or non-employed, woman or man, 'black' or 'white', north or south – all of our lives are intertwined with technologies, from simple tools to large technical systems.

When this intertwining is discussed in newspapers or other mass media, the dominant account of it can be summed up as 'technological determinism'. Technologies change, either because of scientific advance or following a logic of their own; and they then have effects on society. The development of computer technology, for example, is often seen as following trajectories that are close to natural laws, the most famous being Moore's law (Moore 1965), describing how the number of components on a state-of-the-art microchip doubles in a fixed, predictable period of time (originally a year; now 18 months). This key technical underpinning of modernity fuels an information and communication technology revolution that, numerous pundits tell, is changing and will change the way we live.

▶ TECHNOLOGICAL DETERMINISM AS A THEORY OF SOCIETY

Technological determinism contains a partial truth. Technology matters. It matters not just to the material condition of our lives and to our biological and physical environment – that much is obvious – but to the way we live together socially. The historian Lynn White, for example, famously attributed the coming about of feudal society – a 'society dominated by an aristocracy of warriors endowed with land' (White 1978: 38) – to the invention, and diffusion to Western Europe, of the stirrup. Prior to the stirrup, fighting on horseback was limited by the risk of falling off. Swipe too vigorously with a sword, or lunge with a spear, and horseborne warriors could find themselves lying ignominiously in the dust. Because the stirrup offered riders a much more secure position on the horse, it 'effectively welded horse and rider into a single fighting unit capable of a violence without precedent' (White 1978: 2). But the 'mounted shock combat' it made possible was an expensive as well as an effective way of doing battle. It required extensive training, armour and war horses. It could be sustained only by a reorganization of society designed specifically to support an élite of mounted warriors able and equipped to fight in this 'new and highly specialized way' (White 1978: 38).

White's account is better read as parable than as real history.[1] Among the Franks, the stirrup may have 'caused' feudalism. But it had no such effect in, say, Anglo-Saxon England prior to the Norman conquest. To explain why the creation of a feudal system was attempted, and to explain why it was possible, inevitably requires reference to a set of social conditions wider than military technology alone: the decline in European trade, which made land the only reliable source of wealth; the possibility (under some circumstances and not others) of seizing land for redistribution to feudal knights; and so on. As a simple cause-and-effect theory of historical change, technological determinism is at best an oversimplification. Changing technology will always be only one factor among many others: political, economic, cultural, and so on. If technology's physical and biological effects are complex and contested matters (and, for example, the literature on perceptions of risk strongly suggests this),[2] it would clearly be foolish to expect its social effects to be any simpler. A 'hard', simple cause-and-effect technological determinism is not a good candidate as a theory of social change.

However, the failure of a 'hard' technological determinism does not rule out a 'soft' determinism (Smith and Marx 1994), and to say that technology's social effects are complex and contingent is not to say that it has *no* social effects. That is our reason for beginning both this collection and its predecessor with the article by Langdon Winner. His is one of the most thoughtful attempts to undermine the notion that technologies are in themselves neutral – that all that matters is the way societies choose to use them. Technologies, he argues, can be inherently political. This is so, he says, in two senses. First, technologies can be designed, consciously or unconsciously, to open certain social options and close others. Thus, Winner claims (though see also Joerges, forthcoming), New York builder Robert Moses designed road systems to facilitate the travel of certain types of people and to hinder that of others. Second, Winner argues that not only can particular design features of technologies be political, but some technologies in their entirety are political. Even if it is mistaken to see technologies as *requiring* particular patterns of social relations to go along with them, some technologies are, in given social circumstances, *more compatible* with some social relations than with others. Hence, argues Winner, basing energy supply around nuclear technology that requires plutonium may enhance pressure for stronger state surveillance to prevent its theft, and thus erode traditional civil liberties. This particular claim may be wrong – natural uranium shows no sign of running out, as it appeared it might when Winner wrote this article, and the relatively modest recycling of spent fuel has to date led to no restrictions on civil liberties – but the general form of the argument demands attention. In adopting a technology, we may be opting for far more – economically, politically, even culturally, as well as technically – than appears at first sight. Because 'hard' technological determinism is an oversimplified theory of technological change, discovering in advance what that 'more' might be is very difficult, and predictions are, in consequence, often off-beam. But the difficulty of the task is not reason for avoiding it.

▷ TECHNOLOGICAL DETERMINISM AS A THEORY OF TECHNOLOGY

As a theory of society, then, technological determinism is asking a good question, albeit often providing an oversimplified answer. Where we part company with it more decisively is in its aspect as a theory of technology,[3] in its typical assumption that technological change is an independent factor, impacting on society from outside of society, so to speak.

This is a very common way of thinking, but to our minds a mistaken one. Most of the rest of this introductory essay – indeed most of the rest of this book – provides arguments and evidence for its mistakenness, but let us dwell for a moment on why the mistakenness matters. The view that technology just changes, either following science or of its own accord, promotes a passive attitude to technological change. It focuses our minds on how to *adapt* to technological change, not on how to *shape* it. It removes a vital aspect of how we live from the sphere of public discussion, choice, and politics. Precisely because technological determinism is partly right as a theory of society (technology matters not just physically and biologically, but also to our human relations to each other) its deficiency as a theory of technology impoverishes the political life of our societies.

In one of the most influential recent works of social theory, for example, Ulrich Beck (1992) both diagnoses and calls for 'reflexive modernization'. This apparently opaque phrase encodes several linked notions, but the one that is crucial here is the idea that instead of modernization ('progress') being a process that just happens to societies, it should become a process that is actively, and democratically, shaped. Beck's work resonates with the remarkably successful attempt of the German Green Party to bring into the heart of the political process the activities and goals of citizen's initiatives, of investigative journalists, of radical engineers, and of the environmentalist, women's and peace movements. As a vitally important part of 'progress', technological change is a key aspect of what our societies need actively to shape, rather than passively to respond to.

Often efforts to develop a politics of technology are seen as anti-technology, as an attempt to impose upon technology rigid, negative, political controls. The prevalence of that misconception is our reason for including here an extract from the work of Donna Haraway, who has become perhaps the most influential feminist commentator on science and technology. Her dense, playful, poetic, and occasionally oblique prose is sometimes misunderstood as an attack on science and technology, but we see it in a different light. She is sharply critical of those who reject technology in favour of a return to a mythical natural state, and she argues instead for an embracing of the positive potential of science and technology. Of course, there is much in those spheres she would wish to see change, but she eschews an 'ecofeminist' celebration of women's spiritual closeness to an unpolluted nature. Famously, and provocatively, preferring to be a 'cyborg' – a cybernetic organism, such as an animal with a human-made implant – than an ecofeminist 'goddess' (see Haraway 1985), Haraway is, in our reading of her, rephrasing an old theme: the liberatory potential of science and technology. In the passage from her work we have selected, she notes the great power of science and technology to create new meanings and new entities, to make new worlds. While critical of many aspects of the way this happens, such as the wholesale extending of private property (i.e. patenting) to life forms, she warns against any purist rejection of the 'unnatural', hybrid entities produced by biotechnology, admitting at one point (Haraway 1997: 89) her 'frank pleasure' at the introduction into tomatoes of a gene from flounders, which live in cold seas, that enables the tomato to produce a protein that slows freezing. She revels in the very difficulty of predicting what technology's effects will be. The 'lively, unfixed, and unfixing' practices of science and technology produces 'surprises [which] just might be good ones' she comments (Haraway 1997: 280).

▷ DOES SCIENCE SHAPE TECHNOLOGY?

Clearly, any efficacious politics of technology, any systematic attempt to ensure that the surprises are indeed good ones, needs an understanding of technological change. Let us begin to sketch an outline of such an understanding by tackling the most obvious force shaping technology: scientific change. Technology, it is often said, is applied science. Scientists discover facts about reality, and technologists apply these facts to produce useful things. As we have indicated, this view of technological change is a key underpinning of popular forms of technological determinism.

There are several things wrong with the notion of technological change as the application of scientific discovery. First, the notion of 'discovery' – the uncovering of what is already there – is naive. Scientists are, of course, in constant, intimate dialogue with the real, material world, but they are active participants in that dialogue, bringing to it conceptual schema, experimental traditions, intellectual investments, ways of understanding the world, models and metaphors – some drawn from the wider society – and so on (see, for example, Shapin 1982; Barnes *et al.* 1996; Galison 1997).

Furthermore, science and technology have by no means always been closely connected activities. Looking backwards is tricky, because people in previous times did not operate with our notions of 'science' and 'technology' (Mayr 1976), and there is some controversy among historians who have studied the issue (see, for example, Musson and Robinson 1969; Mathias 1972). But it can be concluded that before the latter part of the nineteenth century the contribution of activities we would now think of as science to what we would call technology was often marginal. The watermill, the plough, the spinning wheel, the spinning jenny, even the steam engine – these crucial inventions were in no real sense the application of pre-existing science (see, for example, Cardwell 1971, 1972). *Rhetoric* about the contribution of science to technology there was in plenty, but the rhetoric often bore little relation to the modest reality of that contribution, and needs to be interpreted differently (Shapin 1972: 335–6).

Where science and technology are connected, as they increasingly have been since the second half of the nineteenth century, it is mistaken to see the connection between them as one in which technology is one-sidedly dependent on science. Technology has arguably contributed as much to science as vice versa – think of the great dependence of science on the computer, without which some modern scientific specialties could scarcely have come into existence.[4] Most importantly, where technology does draw on science, the nature of that relation is not one of technologists passively deducing the 'implications' of a scientific advance. Technology, as the word's etymology reminds us,[5] is knowledge as well as artifacts, and the knowledge deployed by engineers is far from just applied science, as engineer-turned-historian Walter Vincenti (1990) demonstrates. Engineers *use* science. They seek from science resources to help them solve the problems they have, to achieve the goals towards which they are working. These problems and goals are at least as important in explaining what they do as the science that is available for them to use.[6]

▶ THE TECHNOLOGICAL SHAPING OF TECHNOLOGY

If science does not in any simple sense shape technology, what of the notion that technological change follows an autonomous logic – the notion that *technology shapes technology* (see Ellul 1964: 85–94; Winner 1977: 57–73)? To understand the force of this argument, it is necessary to see what is wrong with our common, but wholly mystified, notion of the heroic inventor. According to that notion, great inventions occur when, in a flash of genius, a radically new idea presents itself almost ready-formed in the inventor's mind. This way of thinking is reinforced by popular histories of technology, in which to each device is attached a precise date and a particular man (few indeed are the women in the stereotyped lists) to whom the inspired invention 'belongs'.

One important attack on this inspirational notion of invention was mounted by the group of American writers, most importantly William Ogburn, who from the 1920s onwards set themselves the task of constructing a sociology of technology (Westrum 1991). In a 1922 article, Ogburn and his collaborator Dorothy Thomas argued that far from being the result of unpredictable flashes of inspiration, inventions were *inevitable*. Once the 'necessary constituent cultural elements' are present – most importantly including component technologies – there is a sense in which an invention *must* occur: 'Given the boat and the steam engine, is not the steamboat inevitable?' asked Ogburn and Thomas (1922: 90.) They regarded it as crucial evidence for the inevitability of invention that a great many inventions were in fact made independently by more than one person.

Not the least of the difficulties of this position is that apparent inventions of the same thing turn out on closer inspection to be of importantly different things (Constant 1978). A solidly based critique of the inspirational notion of invention can, however, be constructed directly, drawing on the work of writers such as Ogburn's contemporary Usher (1954), his colleague Gilfillan (1935a, 1935b) and, more recently, historians of technology like Thomas P. Hughes (1971, 1983, 1989; see also pp. 50–63 of this book). Hughes's work is of particular relevance because much of it focuses on classic 'great inventor' figures such as Thomas Edison (credited with the invention of, among other things, the gramophone and the electric lightbulb) and Elmer Sperry (famed for his work on the gyrocompass and the marine and aircraft automatic pilot).

Hughes has no interest in disparaging the achievements of those he writes about – indeed he has the greatest respect for them – but his work demonstrates that invention is not a matter of a sudden flash of inspiration from which a new device emerges 'ready-made'. Largely it is a matter of the minute and painstaking modification of existing technology. It *is* a creative and imaginative process, but that imagination lies above all in seeing ways in which existing devices can be improved, and in extending the scope of techniques successful in one area into new areas.

A vitally important type of technical change altogether escapes our conventional notion of 'invention'. Technical change, in the words of Gilfillan (1935a: 5), is often 'a perpetual *accretion* of little details . . . probably having neither beginning, completion nor definable limits', a process Gilfillan saw at work in the gradual evolution of the ship (1935b). The authors of this process are normally anonymous, certainly not 'heroic inventor' figures, and often skilled craft workers, without formal technical or scientific training; it is probably best seen as a process of collective learning rather than individual innovation. 'Learning by doing' in making things (Arrow 1962) and what Rosenberg (1982: 120–40) calls 'learning by using' – feedback from experience of use into both the design and way of operating things – are both of extreme practical importance. Small changes may add up to eventually considerable changes in design, productivity and effectiveness.

New technology, then, typically emerges not from flashes of disembodied inspiration but from existing technology by a process of gradual change to, and new combinations of, that existing technology. Even what we might with some justification want to call revolutions in technology often turn out to have been long in the making. Constant's important study (1980) of the change in aircraft propulsion from the propeller to the jet shows this clearly. Revolutionary as it was in the context of aircraft propulsion, the turbo jet built upon a long tradition of work on water and gas turbines.

Existing technology is thus, we would argue, an important precondition of new technology. It provides the basis of devices and techniques to be modified, and is a rich set of intellectual resources available for imaginative use in new settings.[7] But is it the *only* force shaping new technology? We would say that it is not, and would argue that this can be seen by examining the two most plausible attempts to claim that existing technology is more than just a precondition of new technology, but is an active shaping force in its development. These attempts focus around the ideas of technological 'paradigm' and technological 'system'.

The idea of 'technological paradigm' (see Constant, 1980; Dosi 1982) is an analogical extension of Thomas Kuhn's idea of the scientific paradigm (1970). In Kuhn's work, 'paradigm' has two main meanings, which are interrelated but distinguishable. In the more basic sense, the paradigm is an exemplar, a particular scientific problem-solution that is accepted as successful and which becomes the basis for future work. Thus Newton's explanation of the refraction of light, in terms of forces acting on the particles he believed light to consist in, formed a paradigm for much subsequent work in optics – researchers sought to produce similar explanations for other optical phenomena (Worrall 1982). The paradigm in this first sense of exemplar plays a crucial part in the paradigm in the second, more famous, wider sense of the 'entire constellation of beliefs, values, techniques, and so on shared by the members of a given [scientific] community' (Kuhn 1970: 175).

The discussion of paradigms in technology has been less profound than it might have been because it (like extensions of Kuhn's ideas to the social sciences) has tended to focus on the second meaning of paradigm, despite Kuhn's explicit statement that the first meaning is 'philosophically . . . deeper' (Kuhn 1970: 175; see also Barnes 1982; Gutting 1984; Laudan 1984). But there is no doubt that the concept of paradigm applied to technological change does point us towards important phenomena. Particular technical achievements have played a crucial role as exemplars, as models for further development (see Sahal 1981a, 1981b). In the field of missile technology, for example, the German V-2 missile played this role in early post-war American and Soviet missile development. Because technological knowledge cannot always be reduced to a set of verbal rules, the presence of a concrete exemplar is a vital resource for thought. The Americans possessed actual German-built V-2s, as well as most of the design team; the Soviets painstakingly constructed, with help from some of the designers, replicas of the original missile (Ordway and Sharpe 1979). To a significant extent the V-2 formed the model from which further ballistic missiles were derived by conscious modification.

If we find technologists operating with a paradigm – taking one technical achievement and modelling future work on that achievement – it becomes tempting to treat this as somehow self-explaining and discuss it in terms of mechanical analogies such as following a technical 'trajectory' (Dosi 1982). But to do this would be to miss perhaps the most fundamental point of Kuhn's (1970) concept of paradigm: the paradigm is not a rule that can be followed mechanically, but a *resource* to be used. There will always be more than one way of using a resource, of developing the paradigm. Indeed groups of technologists in different circumstances often develop the same paradigm differently. American and Soviet missile designers, for example developed significantly different missiles, despite their shared use of the V-2 as a departure point (Holloway 1977, 1982; Berman and Baker 1982). Where this does not happen, where there is congruity in the development and extension of a paradigm, this stands equally in need of explanation.

Just how much can be hidden by considering the further development of a paradigm as simply a 'technological trajectory' following an 'internal logic' emerges from another study by Hughes (1969). Here the 'trajectory' being considered is that of successive processes for synthesizing chemicals by 'hydrogenation' – combination with hydrogen at high temperatures and pressures over catalysts. Hughes examines the trajectory of this work in the German chemical firm I. G. Farben and its predecessors. Beginning with the paradigm instance of the Haber-Bosch process for the synthesis of ammonia, the company moved on to the synthesis of wood alcohol and finally of gasoline (from coal). A 'natural' trajectory, indeed, but one that, Hughes shows, at each stage was conditioned by social factors inside and outside the firm, including, most consequentially, the German state's need for wartime independence from external sources of raw materials. In America, the chemical giant Du Pont adopted synthetic processes for the production of ammonia and wood alcohol (Mueller 1964), but did not, in that very different environment, find the step to the synthesis of gasoline 'natural'. In Germany, moving to gasoline synthesis involved greater and greater links between Farben and the Nazi state, links which eventually led 23 executives of Farben to the dock in the Nuremburg war-crime tribunals.

The idea of technological *system* has been used in the history of technology more widely than that of technological paradigm, and thus the characteristics of explanations framed in its terms are more evident. We will follow its usage by Thomas P. Hughes, who makes it in many ways the central theme of his studies of technology. Typically, and increasingly, technologies come not in the form of separate, isolated devices but as part of a whole, as part of a system. An automatic washing machine, say, can work only if integrated into the systems of electricity supply, water supply and drainage. A missile, to take another example, is itself an ordered system of component parts – warhead, guidance, control, propulsion – and also part of a wider system of launch equipment and command and control networks.

The need for a part to integrate into the whole imposes major constraints on how that part should be designed. Edison, as Hughes shows in the extract from his work in Chapter 3, designed the light-bulb not as an isolated device but as part of a system of electricity generation and distribution, and the needs of the system are clearly to be seen in the design of the bulb.

Further, the integration of technologies into systems gives rise to a particular pattern of innovation that Hughes, using a military metaphor, describes as 'reverse salients' (see, for example, Hughes 1971: 273, 1983: 14; for related observations see Rosenberg 1976: 111–12). A reverse salient is a product of uneven development. It is an area where the growth of technology is seen as lagging, like a military front line which has been pushed forward but where in one particular spot the enemy still holds out. Technologists focus inventive effort, like generals focus their forces, on the elimination of such reverse salients; a successful inventor or engineer defines a reverse salient as a set of 'critical problems' that, when solved, will correct the situation. A typical reverse salient appeared in the development of electricity supply systems. As transmission voltages were increased, power was lost between the lines through electric discharge. Because very high voltages were needed to transmit electricity over large distances, loss between the lines was a reverse salient that threatened the development of the electricity supply system as a whole. Consequently, considerable effort was devoted to solving the critical problems involved (Hughes 1976, 1983).

The focusing of innovation on perceived reverse salients is a phenomenon of great generality. Hughes's judgement is that 'innumerable (probably most) inventions and technological developments result from efforts to correct reverse salients' (1983: 80). While this is thus an important way in which technology (as technological systems) shapes technology, does it imply that *only* technology shapes technology? Hughes's answer is 'no', and the reason for that answer is of considerable importance. A technological system like an electric light and power network is never merely technical; its real-world functioning has technical, economic, organizational, political, and even cultural aspects.[8] Of these aspects, the most obviously important one is economic, and it is to that we turn next.

THE ECONOMIC SHAPING OF TECHNOLOGY

The very concept of 'reverse salient' makes sense only if a technological system is seen as oriented to a *goal* (Hughes 1983: 80). Otherwise, any metaphors of 'advancing' or of 'backward' parts become meaningless. Language of this kind is dangerous if it is allowed to slip towards vague talk of the 'cultural need' for a technology (Ogburn and Thomas 1922: 92), but the notion of a goal can be given a direct and down-to-earth meaning. Most importantly, talk of a system goal is normally talk about economics, about reducing costs and increasing revenues. Electricity supply systems, for example, have been private or public enterprises, and those who have run them have inevitably been concerned above all about costs, profits and losses. The reverse salient is an 'inefficient or uneconomical component' (Hughes 1983: 80), and for many practical purposes inefficient means uneconomical.

Technological reasoning and economic reasoning are often inseparable. Our extract from Hughes's work demonstrates this in the case of Edison's invention of the light-bulb. Edison was quite consciously the designer of a system. He intended to generate electricity, transmit it to consumers, and to sell them the apparatus they needed to make use of it. To do so successfully he had to keep his costs as low as possible – not merely because he and his financial backers wished for the largest possible profit, but because to survive at all electricity had to compete with the existing gas systems. Crucially, Edison believed he had to supply electric light at a cost at least as low as that at which gas light was supplied. These economic calculations entered directly into his work on the light-bulb. A crucial *system* cost, a reverse salient, was the copper for the wires that conducted electricity. Less copper could be used if these wires had to carry less current. Simple but crucial science was available to Edison as a resource: Ohm's and Joule's laws, from which he inferred that what was needed to keep the current low and the light supplied high was a light-bulb filament with a high electrical resistance, and therefore with a relatively high voltage as compared to current. Having thus determined, economically as much as technologically, its necessary characteristics, finding the correct filament then became a matter of 'hunt and try'.

The precise characteristics of the Edison case are perhaps untypical. Even in his time Edison was unusual in his conscious, individual grasp of the nature of technological systems (therein, perhaps, lay his success), and since his time the inventor-entrepreneur has in many areas been overshadowed by the giant corporation with research and development facilities. Menlo Park, Edison's research and development institution, was only an aspect of the beginning of the great transformation brought about by the large scale, systematic harnessing of science and technology to corporate objectives (Noble 1977). But the essential point remains: typically, technological decisions are also economic decisions.

Paradoxically, then, the *compelling* nature of much technological change is best explained by seeing technology not as outside of society, as some versions of technological determinism would have it, but as inextricably part of society. If technological systems are economic enterprises, and if they are involved directly or indirectly in market competition, then technical change is forced on them. If they are to survive at all, much less to prosper, they cannot forever stand still. Technical change is made inevitable, and its nature and direction profoundly conditioned, by this. And when national economies are linked by a competitive world market, as they have been at least since the mid-nineteenth century, technical change outside a particular country can exert massive pressure for technical change inside it.

The dominant way of thinking about the connection between economics and technology is the 'neoclassical' approach, which is based upon the assumption that firms will choose the technique of production that offers the maximum possible rate of profit. Despite its apparent plausibility, this assumption has been the subject of much criticism within economics. The issues involved are complex (there is a useful review of them in Elster 1983) but they hinge upon whether human decision-making does, or indeed could, conform to the strict requirements of the neoclassical model. For example, how can a firm possibly know when it has found the technique of production that produces maximum profits? Is it not more reasonable to assume that a firm will consider only a very limited range from the set of possible options, and will be happy with a 'satisfactory' (and not necessarily maximum) profit rate? In the new approaches that have developed within economics, inspiration has been found in the work of Joseph Schumpeter (1934, 1939, 1943, 1951), with its emphasis on the aspects of innovation that go beyond, and cannot be explained by, rational calculation.[9]

ECONOMIC SHAPING IS SOCIAL SHAPING

The 'alternative', non-neoclassical economics of technology thus offers a direct bridge to more sociological explanations (MacKenzie 1996a, Ch. 3). Costs and profits matter enormously, but in situations of technical innovation key factors are *future* costs and *future* profits. Since there is an element of uncertainty in these, they cannot be taken as simple, given facts. Estimating costs and profits is part of what Law (1987) calls heterogeneous engineeering: engineering 'social' as well as 'technical' phenomena; constructing an environment in which favoured projects can be seen as viable.[10] Market processes punish those who get this wrong and reward those who get this right, but which outcome will prevail cannot be known with certainty in advance (see, for example, Schon 1982). Nor can it be assumed that market processes will eventually lead to optimal behaviour, as successful strategies are rewarded by the differential growth of firms that pursue them. That standard neoclassical argument may have validity for static environments in which selection has a long time to exercise its effects, but not for situations of technological change. A strategy that succeeds at one point in time may fail shortly thereafter, and the market's 'invisible hand' may simply have insufficient time for the neoclassical economist's optimization to take place.

Furthermore, even if sure calculation of costs and profits – and even optimization – were possible, the economic shaping of technology would still be its social shaping. Economic calculation and economic 'laws' are, after all, specific to particular forms of society, not universal, as Karl Marx famously argued (see, for example, Marx [1867] 1976: 173–6). Even if in all societies people have to try to reckon the costs and benefits of particular design decisions and technical choices, the form taken by that reckoning is importantly variable.

Consider, for example, technical innovation in the former Soviet Union. People there certainly made calculations as to what served their economic interests, and plant managers had greater autonomy to make decisions than is often assumed. But the framework of that calculation was different. Prices were set by central planners of the State Price Committee, rather than being subject to the vagaries of the market as in the West. A price, we might say, was thus a different social relation in the Soviet Union. In its classical form, the system of rewards to Soviet managers hinged upon *quantity* of production in the short run – fulfilling the 'norms' of the plan in the current quarter. The focus on quantity implied that while small technological innovations might be welcomed, larger changes (for example, changes that meant elaborate retooling) were a threat; developing a new product meant courting risks with little promise of commensurate reward if successful. The reforms that Soviet leaders introduced to alleviate this situation often made it worse. Thus economic reforms in 1965 tied the rewards to managers more closely to the profitability of their enterprises. But because the price system was not fundamentally changed, the greatest profits could be earned by concentrating on existing products whose costs of production had fallen well below their (bureaucratically set) prices. Innovation, instead of speeding up, actually slowed (Parrott 1983: 225–6), and the consequences contributed to the eventual dramatic collapse of the Soviet system.

Furthermore, even if we restrict our attention to societies in which prices reflect market competition, we find that economic calculation remains a mechanism of social shaping. Economic calculation presupposes a structure of costs that is used as its basis. But a cost is not an isolated, arbitrary number of pounds or dollars. It can be affected by, and itself affect, the entire way a society is organized. This point emerges most sharply when we consider the *cost of labour*, a vital issue in technical change, because much innovation is sponsored and justified on the grounds that it saves labour costs. To take a classic example, because of the different circumstances of nineteenth-century British and American societies (such as the presence in the USA of a 'frontier' of agricultural land whose ownership by indigenous peoples was largely disregarded), labour cost more in America than in Britain. Hence, argued Habakkuk (1962), there was a much greater stimulus in America than in Britain to search for labour-saving inventions, and thus a different pattern of technological change in the two societies. Habakkuk's claim has in fact proven to be controversial (see Saul 1970 and Uselding 1977 for introductions to the controversy), but the general point remains: the way a society is organized, and its overall circumstances, affect its typical pattern of costs, and thus the nature of technological change within it.

That men are typically paid more than women, for example, is clearly not an arbitrary matter, but one that reflects deep-seated social assumptions and an entrenched division of labour, including unequal domestic and child-rearing responsibilities. The different costs of men's and of women's labour translate into different economic thresholds for machines that have to justify their costs by elimination of men's, or of women's, tasks – a mechanism of the gendered shaping of technology that deserves systematic study (see Cowan 1979).

TECHNOLOGY AND THE STATE

Social relations, then, affect technological change through the way that they shape the framework of market calculations. But the market is far from the only social institution that shapes technological change.

From antiquity onwards, states have sponsored and shaped technological projects, often on a vast scale. Lewis Mumford (1964: 3) provided a classic account of this, and it is worth quoting from a short summary of his ideas:

> authoritarian technics . . . begins around the fourth millennium B.C. in a new configuration of technical invention, scientific observation, and centralized political control . . . The new authoritarian technology was not limited by village custom or human sentiment: its herculean feats of mechanical organization rested on ruthless physical coercion, forced labour and slavery which brought into existence [human-powered] machines that were capable of exerting thousands of horsepower.

Seventeenth- and eighteenth-century European states were interested in technical progress as a source of greater national power, population and treasure (Pacey 1976: 174–203). This 'mercantilist' framework carried different implications for the shaping of technology than did straightforwardly capitalist judgements. As Hafter (1979: 55–6) writes, 'while in England there was strong commitment to labor-saving devices, in France the mercantilist notion that work must be found for the largest number of hands prevailed'. As late as 1784, the brocade loom was praised in France because it 'employed twice as many workers' as the plain-cloth loom, it being argued that it was 'the benefit of labor which remains in the towns when the products have left that is the real product of the manufactures' (Hafter 1979: 56).

The single most important way that the state has shaped technology has been through its sponsoring of military technology. War and its preparation have probably been on a par with economic considerations as factors in the history of technology. Like international economic competition, war and the threat of war act coercively to force technological change, with defeat the anticipated punishment for those who are left behind.[11] Military technology is the subject of Part Four of this reader, and we need make only one point here, regarding the extent to which military concerns have shaped 'civilian' technology. Military interest in new technology has often been crucial in overcoming what might otherwise have been insuperable economic barriers to its development and adoption, and military concerns have often shaped the development pattern and design details of new technologies.

Three cases in point are nuclear power, air transport and electronics. The initial work on the technology of nuclear energy was directly military in inspiration, and subsequently the economic drawbacks of nuclear power have often been overridden by state interest in securing fissile material for atomic weapons and in gaining 'autonomous' national energy supplies. These state interests closely shaped reactor design, at least in the early years of nuclear energy (Gowing 1982; Rüdig 1983; Simpson 1983; Hecht 1998). Similarly, the civilian jet airliners of the post-war period were made possible by a generation of work on military jets, and Constant (1980: 166–7) argues that the design of 1930s' British and German civil airliners reflected the ways in which those countries' airlines were 'chosen instruments' of foreign and imperial policy. Much of the development of electronics in this century has been sponsored by the military, especially in the USA. Military need and military support played a crucial role in the development of the digital computer (Goldstine 1972; Dinneen and Frick 1977; Flamm 1988; Edwards 1996). Braun and MacDonald's history (1978) shows the crucial role of military support in the development of semiconductor electronics (and thus in the origins of the microchip). That support was particularly important in the early phase of development when on most commercial criteria solid-state devices were inferior to existing valve technology.

▷ CASE STUDIES OF THE SHAPING OF TECHNOLOGY

Even in these cases of the shaping of technology by military interests, 'shaping' should not be understood as always being direct and conscious – as the simple imprinting of human will on the material world. What emerged, even in the cases just discussed, was by no means always what sponsors had intended: for example, though the military wanted miniaturization, their originally preferred approach was not the eventually successful integrated circuit. Technologies (especially radically new technologies) typically emerge, or fail to emerge, from processes in which no one set of human actors plays a dominant role, and in which the role of a recalcitrant material world cannot be ignored. The confused, unsuccessful negotiation beautifully described by Latour (1996) is far more typical, even for state-sponsored technologies.

The social shaping of technology is, in almost all the cases we know of, a process in which there is no single dominant shaping force. We have chosen as exemplary of this Paul Ceruzzi's study of the emergence of personal computing (a phrase that includes not just the hardware necessary for personal computing, but also, for example, the software needed to make the hardware useful). He eschews technological determinism, denying that the personal computer or personal computing were simply the outgrowth of changing microchip technology (while accepting that developments in that sphere were crucial). Members of the radical counterculture of the

1960s and 1970s, Ceruzzi points out, wanted to liberate computing from its military and corporate masters: they were pursuing one version of the active politics of technology that we are recommending. Author Ted Nelson, for example, combined technical and social radicalism, for instance in his influential proposal for 'hypertext' (designed to help untrained people find their way through computer-held information organized in more complicated ways than in paper documents, and in one sense a precursor of the enormously successful World Wide Web: see Campbell-Kelly and Aspray 1996).

This kind of countercultural impulse interacted with a largely male hobbyist culture, members of which simply wanted to have computers of their own to play with (part of the development of personal computing was starting to treat computers less seriously). The interaction was, for instance, at the heart of the Californian Homebrew Computer Club, which played an important role in the emergence of personal computing. Steve Wozniak and Steve Jobs, founders of Apple Computer, famously started out making 'blue boxes' that mimicked telephone dial tones, allowing users to make free telephone calls, a laudable goal from a countercultural viewpoint. However, Ceruzzi also shows other strands that came together in personal computing, notably the role of previous developments in time-sharing mainframe computers, such as the BASIC programming language developed for students at Dartmouth College (including humanities students, who were presumed to be less sophisticated technically).

Personal computing was indeed socially shaped, but no one actor determined the shape it was to take, and the outcome was no simple reflection of an existing distribution of power. The mighty IBM Corporation, which dominated the mainframe computer business, notoriously came to personal computing relatively late, and the field's development was eventually seriously to weaken IBM's dominance. Orthodox corporate power has subsequently been re-established in the form of the near monopoly of software supplier Microsoft (the early role of Microsoft's founder, Bill Gates, is discussed by Ceruzzi) and the microprocessor supplier Intel. Nevertheless, the more pessimistic analyses of the development of word processing (Barker and Downing 1980) now seem wide of the mark, in part because some of the aspirations of the counterculture were fulfilled. The computer has indeed come 'to the people' – not all the people, to be sure, but enough to make a difference.

Ceruzzi's study is of the development of an entire field of technology. The other case study we have selected for this introductory section is much narrower in its focus. We have chosen it because it shows social shaping, not just of the overall contours of a technology, but of specific, apparently 'purely technical', features of technological designs, of engineering research, and even of mathematical models of artifacts. Eda Kranakis compares in detail two suspension bridge designs: one by the American, James Finley, inventor of the modern suspension bridge with a flat roadway; the other by Claude-Louis-Marie-Henri Navier, a leading French engineer-scientist. Both Finley and Navier were heterogeneous engineers, but heterogeneous engineers working in very different environments with different goals.

Finley, working in the USA in the early nineteenth century, aimed at a relatively cheap bridge design that could fairly easily be tailored to a specific location by craftworkers with limited mathematical skills. He wanted to make money not primarily by building bridges himself but by getting others to pay to use his patented suspension bridge design. His design crystallized these goals. For example, Finley chose a sag/span ratio (see the figure on p. 89) between 1:6 and 1:7, not because this was in any abstract sense optimal, but because this ratio greatly simplified the calculations that users of his patent had to make.

Navier, in contrast, positively sought sophistication in mathematical modelling. He was a salaried state employee, working in an engineering culture where mathematical competence was deliberately fostered and highly prized, and he was seeking promotion as a mathematical scientist as much as an engineer. Navier's bridge was designed, both in its overall conception and in specific features, to demonstrate the applicability to technology of deductive mathematical reasoning. Kranakis suggests that the particular approach to mathematical modelling taken by Navier was influenced by his career goals, and reminds us that even mathematics is not always a universal language. For example, the French mathematical tradition in which Navier worked differed in its approach to the relevant part of mathematics – the calculus – from the approach taken in Britain. On the Continent an algebraic, symbol-manipulating approach predominated, while many mathematicians in Britain clung to a visual, geometric version of the calculus, a preference that reflected the distinctive cultural and educational role of geometry as the paradigm of absolute knowledge, including theological knowledge (Richards 1979).

Two crucial points about 'the social shaping of technology' can be seen in Kranakis's study. First, she is perfectly well aware that bridges are real physical artifacts, and that their behaviour is in no way reducible to the ensemble of beliefs about them. Bridges built using Finley's patent sometimes collapsed, and Navier's bridge suffered a mishap during construction that opened the project up to eventually fatal criticism. The point is a general one: emphasis on the social shaping of technology is wholly compatible with a thoroughly realist, even a materialist, viewpoint. What is being shaped in the social shaping of artifacts is no mere thought-stuff, but obdurate physical reality. Indeed, the very materiality of machines is crucial to their social role, as Part Two of this reader emphasizes. In producing the first edition of this book, we chose the metaphor of 'shaping', rather than the more popular 'social construction', in part because the latter is too prone to the misconception that there was nothing real and obdurate about what was constructed. (One of the ordinary meanings of 'construction' implies falsehood, as in 'the story he told me was a complete construction'. Although this is emphatically not what is implied when we or others have used the metaphor of 'construction', there is always the risk that this will colour how the metaphor is heard.)

The second point is that 'social shaping' does not necessarily involve reference to wider societal relations such as those of class, gender and ethnicity. These *are* sometimes directly crucial, and we give instances below of this, but often what is more immediately relevant are 'local' considerations, such as engineers' membership of professional communities, the reward structures of those communities, and so on. These are social matters too. The 'social' is not the same as what in old debates about the relationship between science and society used to be called 'external factors'; social processes internal to scientific and technological communities are important too. Often these internal processes are themselves conditioned by wider social and historical matters – for example, the reward structure of nineteenth-century French engineering, with its distinctive emphasis on displays of mathematical competence, emerged out of the clashes of the Revolutionary period (Alder 1997) – but they remain social even when that is not the case.

THE PATH-DEPENDENCE OF TECHNICAL CHANGE

We are aware that case studies of social shaping are unlikely, on their own, to undermine the technologically determinist view of technological change. In the long run, the convinced determinist might say, surely what matters is intrinsic technical efficiency: the intrinsically best technology will ultimately triumph, whatever local contingencies affect particular developments.

There are two answers to be given to this deep-seated determinist assumption. First, of course, is the basic point that the technology that is 'best' from one point of view is not necessarily best from another: what is best for workers may not be best from the point of view of their employers; what men believe to be best may not be best for women, and so on. Throughout this reader, we will see examples of different assessments of what counts as technologically desirable. Second, however, is a subtle and important argument developed in our extract from the work of the economist Brian Arthur, an argument also taken up by the economic historian Paul David.[12]

Arthur's point is a simple one, but broad in its implications. Technologies often manifest increasing returns to adoption. The processes of learning by doing and by using, discussed above, and the frequent focus of inventive effort on removing weak points ('reverse salients') from existing technologies, mean that the very process of adoption tends to improve the performance of those technologies that are adopted. This gives the history, especially the early history, of a technology considerable significance. Early adoptions, achieved for whatever reason, can be built into what may become irreversible superiority over rivals, because success tends to breed success and rejection can turn into neglect and therefore permanent inferiority. The history of technology is a path-dependent history, one in which past events exercise continuing influences. Which of two or more technologies eventually succeed is not determined by their intrinsic characteristics alone, but also by their histories of adoption. The technology that triumphs is not necessarily abstractly best, even if there is consensus about what 'best' means. Path-dependence means that local, short-term contingencies can exercise lasting effects.[13]

The history of personal computing, for example, is full of manifestations of path-dependence. The pervasive qwerty keyboard, so-called because of the letters on the upper left, is in no sense demonstrably optimal. It developed to minimize the frequency with which keys in mechanical typewriters stuck together as a result of adjacent keys being hit in too close succession. That rationale clearly became unnecessary after the development of electronic keyboards and word processing, but proposals for alternate layouts are hopeless: the triumph of qwerty has become in practice irreversible. It would, more generally, be hard to make a case for the intrinsic superiority of the technical system that has come to dominate personal computing: the combination of the IBM personal computer architecture, Microsoft's MS-DOS and Windows operating systems, and the descendants of the Intel 8080 microprocessor. Historical contingency played a clear role in that outcome. For example, in part because of a history of anti-trust litigation against IBM, the corporation was willing to license its architecture and permit others to manufacture clones, while its main rival, Apple, refused to do so; the consequence was an entrenchment of the IBM architecture, and the Intel microprocessors it employs, and the restriction of Apple to niche markets.

The issue of path-dependence needs to be analysed with some care, and some claims for the phenomenon have been criticized by Stan Liebowitz and Stephen Margolis (1990, 1995a, 1995b). If a technology has an actually existing rival that is either demonstrably superior or can quickly and reliably be made so, then lock-in to the inferior variant is, they argue, unlikely to be permanent. There are too many ways in which it can be overcome: for example, manufacturers can offer the 'underdog' technology initially below cost to create a market for it, or governments can subsidize it (this has historically been an important function of military expenditure, for example in helping solid-state electronics overcome its initial disadvantages, as noted above). Arthur is wrong to assert (see p. 111) that the alternatives to qwerty are superior; the evidence for this is at best ambiguous (Liebowitz and Margolis 1990). Whether Apple or IBM personal computers are best is a source of endless dispute, and other putative examples of lock-in to clearly inferior technologies are likewise controversial (see, for example, the discussion of the popular example of VHS and Beta video recorder formats in Liebowitz and Margolis 1995a; for David's reply to the overall critique, see David 1997).

In rightly objecting to neoclassical confidence that the best technology will always triumph, Arthur may have bent the stick too far in the opposite direction in suggesting the likelihood of lock-in to the unequivocally inferior. Arguably, both sides in this debate underestimate the complexity and uncertainty of knowledge of the characteristics of technologies, even the most 'technical' characteristics (MacKenzie 1996b). Apparently easily answered questions about existing technologies, such as what key layout permits fastest typing or how accurate a given missile is (MacKenzie 1990), can turn out to be complex and contested. Yet determining a single characteristic of an actually existing technology is the simplest case: in real historical cases, those involved may have to weigh up the relative importance of differing characteristics (the efficiency of the internal combustion engine versus its potential for pollution, for example) and determine the likely effect of development efforts that have not yet taken place.

Complexity and uncertainty, however, increase rather than diminish the importance of path-dependence. If there is an unequivocally superior alternative to what historical processes of technological change have left us with, then, as noted above, there will often be reasons for modest confidence that it will be adopted. If, on the other hand, the characteristics of alternatives are uncertain and contested, then the low-risk course will be the path-dependent one of starting from what history has given us and seeking to improve it.

THEORIZING THE TECHNOLOGY-SOCIETY RELATIONSHIP

A major development in the social studies of technology since the first edition of this book in 1985 is the flowering of theoretical work on the relationship between technology and society. Two theoretical approaches, nascent in the mid-1980s, have particularly close bearing upon the social shaping of technology.

First is the 'social construction of technology' perspective, developed by Wiebe Bijker and Trevor Pinch (Bijker 1995; Bijker *et al.* 1987), and represented here in a succinct extract from the work of Pinch and his colleague Ronald Kline. Its focus is on the very phenomenon that has been underestimated in the debate over path-dependence: the 'interpretative flexibility' of technology. Interpretative flexibility refers to the way in which different groups of people involved with a technology (different 'relevant social groups', in Bijker and Pinch's terminology) can have very different understandings of that technology, including different understandings of its technical characteristics. Bijker and Pinch's focus is not just on the symbolic meaning of technologies (which in cases like motor cars or aircraft is subject to obvious social variation) but includes also variation in criteria for judging whether a technology 'works'.

The Bijker/Pinch 'social construction of technology' approach draws heavily upon earlier work applying a sociological perspective to scientific knowledge. Those developing the sociology of scientific knowledge, such as Bloor (1976), sought symmetry of explanation. Bloor argued against the then prevalent notion that true scientific knowledge was the result simply of unaided human rationality and causal input from the material world. Instead of invoking social processes only when the credibility of false belief had to be explained, Bloor argued that proper explanation of *all* knowledge, true and false, typically would involve recourse to material input, psychological processes *and* social processes.

There are few more difficult and more contentious topics than what sociology-of-knowledge 'symmetry' should be taken to mean, and certainly not all subsequent authors employed the term in the way Bloor did. For Bijker and Pinch, symmetry means avoiding explaining the success or failure of technologies by whether or not they work. For them, 'machines "work" because they have been accepted by relevant social groups' (Bijker 1995: 270). To our minds, this formulation underplays the extent to which technology always involves interaction between human beings and the material world, but we wholeheartedly agree that historians and sociologists of technology should consider the fact that machines 'work' as something to be explained rather than taken for granted in our explanations. In particular, explanations of success and failure in terms of the *intrinsic* superiority or inferiority of technologies are suspect because of the path-dependence of the history of technology. That one type of machine works better than the alternatives may reflect their histories of adoption and improvement rather than any intrinsic, unalterable features of the technologies involved.

The extract from Kline and Pinch's article ends by citing some of the shortcomings of the approach originally taken by Pinch and Bijker. Of these, two are of particular relevance here. The first is the issue of structural exclusion. In Pinch and Bijker's approach, the social groups relevant from the point of view of a particular technology are typically identified empirically: in historical research, for example, 'we can identify what social groups are relevant with respect to a specific artifact by noting all social groups mentioned in relation to that artifact in historical documents' (Bijker 1995: 46). The trouble, of course, is that the exclusion of some social groups from the processes of technological development may be such that they have no empirically discernible influence on it, and are not, for example, mentioned in documents concerning it: this, for instance, will often be the case with women, ethnic minorities and manual workers.[14] It clearly would be most foolish to assume that gender is irrelevant to the development of a technology just because no women were directly involved and the masculinity of the men involved was never mentioned explicitly in discussion of it; and analogous points hold for class and, especially, ethnicity. The point is a difficult one – we would not claim to have a formula for how to analyse the effects on technological development of structural exclusion – but it needs always to be kept in mind. The influence of 'politics' upon weapons technology is, for example, by no means always the direct one of technologists' compliance with explicit political demands. It can also take the indirect form of the efforts of technologists to keep their technologies as 'black boxes', opaque to scrutiny from the political system. The developers of the US submarine-launched ballistic missile systems, for instance, carefully avoided design options that might lead to political controversy and Congressional involvement, however attractive these options seemed to others (MacKenzie 1990).

The other problem with the original formulation of the Bijker/Pinch approach is one that also manifested itself in the first edition of this book: 'the reciprocal relationship between artifacts and social groups'. The theoretical perspective that has done most to sensitize the field to this issue is what is often called actor-network theory, developed by scholars such as Bruno Latour, Michel Callon, Madeleine Akrich and John Law, and represented here by the extract from the work of Latour and primatologist Shirley Strum. The key point can be conveyed by way of self-criticism. In the first edition of this reader we largely thought of the social shaping of technology in terms of the influence of social relations upon artifacts. The problem with this formulation is its neglect of the valid aspect of technological determinism: the influence of technology upon social relations. To put it in other, more accurate, words, it is mistaken to think of technology and society as separate spheres influencing each other: technology and society are mutually constitutive.

The reason why, from the varied and influential writings of Bruno Latour (see Latour 1987, 1991, 1993, 1996), we have chosen Strum's and his article is that it reveals what the mutual constitution of technology and society means, and why it matters. Their starting point is the developing appreciation in primatology (to which Strum's field observations have contributed centrally) that primate societies – baboon societies in particular – cannot be thought of as having fixed social structures into which individuals simply fit. Primatologists increasingly see baboons as actively, continuously negotiating and renegotiating their relative roles, and see social structure as the outcome of this process rather than as something fixed and given.

Primatologists, in other words, now view baboons very similarly to the way modern sociologists, following the decline of rigid views of social structure, see human actors as creating structure in and through interaction. (The schools of sociology that have emphasized this are known as social interactionism and, especially, ethnomethodology.[15]) Yet there is of course an evident difference between the societies that humans and baboons create: baboon societies are limited in time and space, essentially to the span of face-to-face interaction, while human societies have histories and geographies that go far beyond that span. The difference is made, Strum and Latour argue, by the human use of 'material resources and symbols'. It is the former that is of particular interest here. Material resources – artifacts and technologies, such as walls, prisons, weapons, writing, agriculture – are part of what makes large-scale society feasible. The technological, instead of being a sphere separate from society, is part of what makes society possible – in other words, it is constitutive of society.

To talk of 'social relations' as if they were independent of technology is therefore incorrect, Strum and Latour would argue. Artifacts – things humans have made – are involved in most of the ways human beings relate to each other. Sexual acts (without prophylactics against disease or pregnancy) are one of the few exceptions in which humans interact, baboon-like, with our naked bodies and voices alone, and such exceptions are typically embedded in more material relations. The point is not simply a pedantic issue of choice of words, as a couple of examples of the technological transformation and creation of social relations may make clearer.

Consider first the Marxist accounts of technology discussed in Part Two of this book. In essence, these suggest that production technology 'hardens' earlier relations between workers and capitalists (relations that were closer to pure social relations – in other words, not so strongly mediated by artifacts), so strengthening the subordination of labour to capital. The relation of labour to capital is *not* a social relation, Strum and Latour would point out, but a socio-technical relation; and in that respect it is typical. Second, consider the Internet, whose origins are discussed in Part Four. One does not have to buy into the hype surrounding the Internet to see that it permits the creation of new social groups by facilitating easy communication between geographically widely dispersed people with statistically unusual identities or interests. These newly created, or newly reinforced, groups can in their turn influence technological development.[16]

So we see Strum and Latour's article, despite its apparently esoteric topic, as an ambitious critique of nearly all forms of existing social theory. Because these neglect technology, they implicitly conceive of society as if it were constructed by human beings using their voices and naked bodies alone: most social theory, in other words, is actually baboon theory! This baboon theory cannot, Strum and Latour would point out, answer the fundamental questions of social theory – What is society? How is social order possible? – because satisfactory answers to them, in the case of human society, inevitably involve reference to technology. This aspect of the actor-network position – that its fundamental contribution is to social theory, and not, in the first instance, to the sociology of science and technology, narrowly conceived – is often overlooked in debates about it in the literature of the latter field.

Both society and technology, actor-network theory proposes, are made of the same 'stuff': networks linking human beings and non-human entities ('actors', or, in some versions, 'actants'). In this respect, actor-network theory resembles Hughes's technological systems perspective: a technological system such as an electric light and power network ties inextricably together both material artifacts and human beings – ties together 'technology', on the one hand, and economics, organization, politics and culture on the other.

Actor-network theory, however, differs from Hughes's perspective in its much greater, 'philosophical' ambitions. These again hinge, to a considerable extent, on the treacherous term 'symmetry'. Notoriously (this is the source of much of the controversy surrounding it) actor-network theory calls for symmetry in the analytical treatment of human and non-human actors (see, especially, Callon 1986; for the main critique, see Collins and Yearley 1992). We cannot discuss here the full range of issues this raises (for further discussion see MacKenzie 1996a), but can simply note that one version of the claim is wholly compatible with what we argue here: that the material world is no simple reflection of human will, and that one cannot make sense of the history of technology if the material world is seen as infinitely plastic and tractable. Whether its intractability is interpreted as agency (in the sense of intentionality) is of course another matter, one subject to wide cultural variation; but discussion of this would lead us too far away from the purposes of this volume.

CONSTRUCTING GENDER; CONSTRUCTING 'COLOUR'

One author sharply aware of the mutual constitution of society and technology is Cynthia Cockburn, and we reprint here her 1983 article 'Caught in the wheels', which represents a pivotal point in the growing engagement between feminism and technology (for other work from the same period or just before, see Cowan 1979 and McGaw 1982). Cockburn went beyond concerns for 'equal opportunities' – greater representation of women in the traditionally male professions of science and engineering – to ask two further questions: is technology itself shaped by gender, and is gender shaped by technology?

Cockburn's answer to the first of these questions is that 'industrial, commercial, military technologies are masculine in a very historical and material sense'. In part, this gendering arises because artifacts and forms of knowledge associated with women are often simply not regarded as 'technology'. Ruth Schwartz Cowan, for example, noted in 1979 their exclusion from traditional history of technology:

> The indices to the standard histories of technology . . . do not contain a single reference, for example, to such a significant cultural artifact as the baby bottle. Here is a simple implement . . . which has transformed a fundamental human experience for vast numbers of infants and mothers, and been one of the more controversial exports of Western technology to underdeveloped countries – yet it finds no place in our histories of technology.
>
> (Cowan 1979: 52)

We explore the gendering of technology in several of the pieces in this volume and elsewhere (Wajcman 1991a). Here, what is more immediately relevant – and is arguably Cockburn's distinctive contribution to the debate around gender and technology – is her answer to the second question: is gender shaped by technology? Technology, she argues, is 'one of the formative processes of men'. The appropriation of technology by men, and the exclusion of women from many of the domains deemed technical, are processes that leave their mark in the very design of tasks and of machines, as Cockburn discusses in her article on typesetting in Part Two of this book. They are also part of the processes by which, in our society, gender is constituted. Different childhood socialization, different role models, different forms of schooling, gender segregation of occupations, different domestic responsibilities and sometimes plain historical processes of expulsion (as after the First and Second World Wars: see Summerfield 1977 and Enloe 1983, Chapter 7) have all contributed to what Cockburn describes elsewhere as 'the construction of men as strong, manually able and technologically endowed, and women as physically and technically incompetent' (1983: 203).

If gender and technology are mutually constitutive, so are ethnicity and technology, though this is a topic that has been much less thoroughly explored in recent literature. The mutual constitution is most evident in relation to that commonplace marker of ethnicity: skin colour. We end Part One of this book with an extract from the work of Richard Dyer, which can be seen as suggesting two points. First, technology has been shaped by ethnicity, in that conventional valuations of skin colour have been the benchmark in the development of photographic and film technologies: these typically are fine-tuned so that they provide pleasing renditions of 'white' faces, sometimes to the detriment of the reproduction of other skin colourations. Second, technology has helped constitute ethnicity, in that conventional hierarchies of desirability have been reinforced by the reproduction of 'white' faces as 'pleasing flesh tones' rather than (as often happened with 'untuned' photographic technologies) as unpleasantly 'beefy'.

▶ NOTES

1. The classic critique of White is Hilton and Sawyer (1963).
2. See, for example, Douglas and Wildavsky (1982), Luhmann (1993), Adams (1995), Stern and Fineberg (1996). Woolgar (1991: 31–2) misunderstands our discussion of the physical and biological effects of technology in the introduction to the first edition of this book. We do *not* suggest that, in his words, 'some technologies do in fact have self-evident attributes and capacities'; MacKenzie (1990, 1996a, 1996b) argues the opposite, that knowedge of even the most 'technical' attributes of a technology can be analysed sociologically. Our point is that the attributes and effects of *all* technologies are *both* socially negotiated and real (physical, material, biological). An emphasis on the first does not imply indifference to the second. Were we to fall into the latter, we would indeed be guilty of the amoral and apolitical position attributed to students of 'the social construction of technology' by Winner (1993). Both lay and professional perceptions of technological risk, for example, are shaped by social and psychological processes, but to assert this is not to deny (nor to be indifferent to) the possibility of real, material harm.
3. We owe this useful way of formulating this key distinction to Edgerton (1993).
4. For a material, even a technological, history of modern physics, see Galison (1997).
5. 'Technology' is derived from the Greek *tekhne*, meaning art, craft, or skill, and *logos*, meaning word or knowledge. The modern usage of 'technology' to include artifacts as well as knowledge of those artifacts is thus etymologically incorrect, but so entrenched that we have chosen not to resist it. While our emphasis in this book is on the social shaping of artifacts, we are of course vitally interested in technological knowledge as well. For an outline framework for the sociological analysis of this, see MacKenzie (1996b).
6. See Barnes and Edge (1982, Part 3), Staudenmaier (1980, 1985), and the interesting studies by Aitken of the origins of the radio (1976) and by Cardwell of the development of the science of heat (1971).
7. For two interesting and wide-ranging discussions of this, see Schon (1963) and Edge (1974–5).
8. For the last of these, see Nye (1990).

9 See, for example, Nelson and Winter (1974), Nelson *et al.* (1976), Nelson and Winter (1982), Coombs *et al.* (1987), Dosi *et al.* (1990) and Stoneman (1995). The neoclassical model has also been used by economic historians to explain choice of technology; see Sandberg (1969), the review of the literature of Uselding (1977) and the critique of Sandberg by Lazonick (1981).

10 See, for example, Gansler (1982); for an interesting and detailed discussion of the legitimatory role of cost estimates even in an 'efficient' project, see Sapolsky (1972: 160–91).

11 It is worth rethinking the example of the stirrup and feudalism with this in mind. Even if White is right in the overall features of his account, any causal effect of the stirrup comes not from technology as such but from military competition. For it was surely military competition that, in White's picture, propagated armed shock combat and the feudal system, as those societies that adopted them triumphed over those that did not.

12 See, for example, David (1992) and Arthur (1994).

13 It is interesting to note the analogy that Arthur drew at the end of his article with problems in weather forecasting. Implicitly, he was referring to theories of 'chaos' in advance of the wider vogue that the notion came to enjoy.

14 See, in addition to the sources cited in the extract, Winner (1993).

15 For an accessible introduction to ethnomethodology, particularly in its relations to more traditional sociology, see Heritage (1984).

16 In autumn 1994, an error was discovered in the implementation of floating-point division in Intel's new Pentium™ processor. It was an error that would be triggered only rarely, and 'bugs' in early-release microprocessors are common events: previous generations of Intel chips had had similar errors without provoking much upset. However, the divide bug was seized upon in the Internet newsgroup, **comp.sys.intel**: examples of divisions that would trigger it were circulated; material critical of Intel's originally unalarmed response were circulated widely; bad newspaper and television publicity followed. Intel had eventually to scrap existing stocks of the chip and offer users free replacements, and had to set aside $475 million to cover the costs of doing this. Subsequently, it has been making increasing use of formal, deductive techniques in chip development, techniques which are widely believed to offer the prospect of a reduced risk of bugs. The role of **comp.sys.intel**, it seems to us, was as a 'society' bringing together people with an interest in the detailed behaviour of Intel chips. Without electronic communication it is hard to imagine a sufficient critical mass of people coalescing around such an esoteric matter.