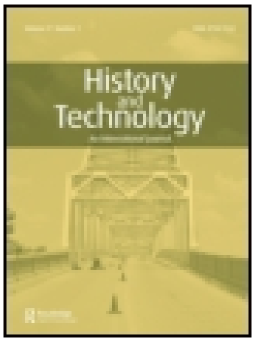

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FROM INNOVATION TO USE: TEN ECLECTIC THESES ON THE HISTORIOGRAPHY OF TECHNOLOGY

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Abstract: The paper argues that most (Anglo-Saxon) historiography of technology, including recent sociologically-oriented work, is concerned with innovation rather than technology, and that there has been an unfortunate conflation between the two. Distinguishing innovation from use allows an engagement between the history of technology and history more generally, and is essential to the investigation of questions concerned with gender, race, and class in the history of technology. Moreover a focus on use allows us to make better sense of such terms as "technological determinism". The history of innovation, while interesting and important, cannot address many issues which should be central to the history of technology, and cannot answer many of the questions historians of technology pretend to ask. A history of technology-in-use does so and, at the same time, opens up new areas for investigation, including the history of maintenance, repair and remodelling, as well as further developing accounts of innovation based on use. The paper deals largely with modern technology, and draws on a number of different, and all too often disjointed, traditions of thinking about the role of technology in history.

In this paper I put forward ten theses which, if accepted, would give one a very different perspective on the history of technology from that found in popular (and a great many academic) works.[1] While the development of each thesis is self-contained, all are connected to each other, and the paper makes an overall argument. It is that most (Anglo-Saxon) historiography of technique is concerned with innovation rather than technology, which, because of a failure to differentiate the two, leads to very unfortunate results. Nevertheless, the theses are eclectic in two senses. First, they are largely concerned with modern technology. Second, they are drawn from a number of different, and all too often disjointed, traditions of thinking about the role of technology in history. I regret that all my sources are in English, and am painfully aware that the content of the paper may (as far as I know) be common knowledge to Continental readers, and to specialists in other areas. I especially hope the paper will be of use to those embarking on the study of the history of technology, particularly students.[1] It is with such a goal in mind that I have tried to make explicit some tacit rules of thumb and craft knowledge that I have found useful; to differentiate concepts which are unhelpfully conflated; and, to define important but often confused and confusing concepts clearly.

I. The study of the relations of technology and society must necessarily deal with technology which is in widespread use. However, most writing on the history of technology and on the relations of technology and society is concerned with innovation, with the emergence of new technologies. It fails to distinguish this from the study of technology in widespread use, which is necessarily old, and is often seen as out-of-date, obsolete, and merely persisting.

To say that the study of the relations of technology and society should be the study of technology in use is a mere truism. How could it be otherwise? So banal is the point that it rarely merits attention, and even then only in passing and as a criticism of existing literature. Let me give some examples. Sir George Clark noted in 1937 that silk-throwing machinery had "no place in English economic history before the time of Sir Thomas Lombe; what is relevant to economic history is not the inventing but the adoption and use", indeed, for the economic historian "the diffusion of new technological devices is as important as their origins".[2] Langdon Winner noted years ago that the possible impacts of new technologies was a "jazzy topic" for which one could find funding. But,

> Never raised for serious consideration are techniques and devices whose development and impact came decades ago and are now part of the structure of the human world order. These are understood to be "given" and unquestionable, not subject to social scientific probing or political dispute.

In his view "the *entire structure* of the technological order [should] be the subject of critical inquiry" [original emphasis].[3] Nathan Rosenberg has noted of the discussion of technical *progress*, that

> For several decades, many historians, even economic historians, have focused their attention overwhelmingly upon one aspect of the question of technical progress: "Who did it first?".... Such questions are, indeed, important to the history of *invention*. Much less attention, however, if any at all, has been accorded to the rate at which new technologies have been adopted and embedded in the productive process. Indeed the diffusion process has often been assumed out of existence [original emphasis].[4]

As Rosenberg noted elsewhere, "Inventions acquire their economic importance, obviously, only as a function of their introduction and widespread diffusion".[5] Paul Stoneman and Paul David state categorically that

> What determines improvements in productivity and product quality, thereby enhancing economic welfare and the competitiveness of firms and industries, is not the rate of development of new technologies but the speed and extent of their application in commercial operations.[6]

Walter Vincenti has noted that

> Most historical studies, I think it fair to say, focus on invention, innovation, and the activities which take place in research establishments... In history as in everyday life newness and variety are always more exciting than day-to-day routine... A danger surely exists, however, that preoccupation with novelty on the one hand and undue influence from the study of science on the other could lead to a partial or faulty epistemology of technology.[7]

Most recently, Carroll Pursell has argued that "the history of technology, as currently studied, privileges design over use, production over consumption and periods of 'change' over those which seem static and traditional".[8] Svante Lindqvist, in the most trenchant and general critique of innovation centred-ness yet published, notes the lack of studies of both use and, most interestingly, of disappearance.[9] It is significant too, that while we have terms of art for creation and novelty (invention, innovation, etc) and for increasing use (adoption, diffusion), we have none for use, or decreasing use.

Despite such criticisms, the vast majority of historical studies of technology continue to be studies of invention, innovation, the new, novelty and of change. Such studies are of course necessary and valuable. However, a real difficulty arises from the near universal failure to differentiate such studies from histories of technology. We can see this clearly in reviews of the literature of the history of technology. At a symposium held in 1969 on the state of the historiography of technology, none of the various critical commentaries include a differentiation between technology and innovation.[10] Surveying the work of the mid-1970s Hughes suggested that studies of technological change were an "emerging theme", whereas previously no clear research programmes were apparent. While he differentiated accounts of "technological change" from the older "internalist history of invention", and from studies of "technology and society", technocracy and technology transfer, he made no clear distinction between technology and innovation.[11] Staudenmaier's much-cited critical survey of the contents of the American journal *Technology and Culture* up to 1980, notes three important areas of attention: the problem of innovation; the relations between science and technology; and technology and culture. But he did not note that in the latter two categories, studies of innovation also dominated.[12] Staudenmaier's failure to remark on the very heavy innovation-bias of *Technology and Culture* is particularly interesting because he is critical of the journal for not discussing workers and technology, cultural conflict in transfer, non-western technology, critiques of capitalism, and women and technology. In each of these cases, as I will argue below, an innovation orientation is an important reason for the neglect of these topics.[13] Smith and Reber's review of trends in the late 1980s, also fails to distinguish between innovation and use, despite considering a pioneering study of use by Ruth Schwarz Cowan.[14] Indeed in recent years a number of histories focusing on use have appeared though without fully conceptualising the importance of the distinction between innovation and technologies-in-use.[15]

Just as significant is the fact that general texts purporting to discuss technology focus on, and are organised around, innovation. Invention and innovation define chronological and geographical scope, and indeed are given more attention than use. R.A. Buchanan, who is noted for his industrial archaeology, has written a textbook on the "impact of technology from 1700 to the present". Given his background, and the topic, we would expect some attention to use, as we do indeed get, but the book is explicitly focused on the idea of technological *revolutions*, and hence on "western civilisation" since

1700.[16] Donald Cardwell's history of technology, is more clearly centred on inventions and innovations; even the contents page has repeated use of words like "new" and "first" and "rise". Here too a restricted geographical scope (in this case Britain) is justified on the grounds that the key innovations – the industrial *revolution* – happened in Britain.[17] Self-proclaimed new, more theoretically informed approaches to the history and sociology of technology have compounded the problem by generating further case-studies of innovation, while claiming very explicitly to be concerned with much broader issues.[18] To be sure, some accounts have ventured into the diffusion stage, but only the initial phases: for example Bijker ends his study of the bicycle in 1890; of Bakelite in 1920; and of fluorescent lighting in 1945![19]

II. The histories of innovation and of technology-in-use are remarkably different, in terms of geography, chronology, and sociology.

Especially in the last two centuries, the geographical scope of use of technology has been quite different from that of innovation. Innovative activity is much more concentrated than production, by nation, region and firm. Thus proportion of total output of an economy (GDP) accounted for by R&D varies very considerably across countries, regions and firms, from close to zero to around 3% for countries, and 100% for some firms. Indeed it is well established that the richer a country is, broadly speaking, the higher the proportion of output spent on innovation.[20] To take a specific example: after 1945 the USA, easily the richest large economy in the world, was responsible for a greater share of world innovation, than of world output. Shifting from innovation to use thus involves a spatial shift, indeed quite a dramatic one.

Similarly it involves a very large temporal shift. Technique typically takes a long time to diffuse. Steam power, held to be characteristic of the industrial revolution in Britain, was not only absolutely but relatively more important in 1900 than in 1800. At a world level the consumption of coal continued to increase into the 1980s; even in Britain domestic coal consumption peaked in the 1950s. The new science-based industries taken as characteristic of the late nineteenth century were dwarfed by the "old" industries of the industrial revolution, and were themselves a long way from their absolute and relative peak, which came well after the second world war. Even "old" technologies find new leases of life: although the production of motor cars has continued to increase, since the late 1960s many more bicycles are produced each year than cars.[21] Rapid innovation need not correspond to periods of rapid productivity growth; innovations will have the greatest impact on productivity growth at the time of fastest diffusion, which typically takes place long after innovation. The case of electricity is illuminating; the main impact of electricity on productivity in the USA occurred in the interwar years, not the late nineteenth century.[22]

Looking at the world as a whole the spatial and temporal dimensions of technology behave differently, depending whether we are thinking about adoption or the extent of use. Thus, while the gap between first adoption of certain consumer goods was not very great comparing the USA and Europe in the twentieth century, the difference in extent of use could be huge. The density of some important (though not all) household consumer durables in Britain was, for example, some thirty years behind the United States; levels of usage characteristic of the late 1920s in the USA were not achieved until the late 1950s.[23] Motorcars were available in small numbers right across the world at the beginning of this century, but, again, the extent of usage varied enormously. The Argentine city of Salta, in the foothills of the Andes, had more than 200 motor cars by 1915; but even today many roads in the region are unpaved.[24] In certain circumstances very old machines continue in use to this day: in Uruguay one can still see a very few US built motor cars of the 1920s on the roads; Cuba retains many US models from the 1950s; India still makes British designs of cars and motorcycles from the 1950s.

Shifting from innovation to use also involves a massive shift in social class, social status, gender and race of people involved with technology. Modern innovators have been overwhelmingly of mid to high social class, male and white.[25] As Carroll Pursell has rightly noted, studies focussing on innovation are generally and necessarily blind to the experience of technology of US women, blacks, and the poor.[26] In fact the point is stronger and more general than this. A discussion starting from users of technology would obviously recognise that half the world's population is female, and that much more than half is non-white, and indeed poor. We need to remember that the average human being of the twentieth century is closer to the Chinese peasant than the US inventor-entrepreneur.

III. The conflation of innovation and technology is especially apparent in national histories. But the nation-state is not the whole world in miniature.

Much naive writing on technology relates it to the fate of "Man" or "Mankind". The story of technology is radically universalised. Nevertheless, there is also a powerful nationalistic current in writing on innovation and on technology, which has a particular bias toward innovation. Citizens of major countries have a tendency to claim the invention of major technologies for their nation – a classic example is the *Great Soviet Encyclopaedia* – but nationalistic studies of "American technology" are commonplace.[27] Even accounts of world technology have a powerful nationalistic bias. Thus one study, drawing on the notion of long waves of technological activity in the world economy, associated successive innovation-driven waves with the nation-states of Great Britain, Germany, and Japan.[28] Indeed, recent years have seen explicit mention of "national systems of innovation".[29] Behind such arguments is the view that there is at a world level, one best way in technology and associated social relations, but that the best way is intimately linked with particular nation states in particular historical periods. There is in such arguments, and more generally in treatments of technology, the strongly expressed feeling that "other countries do it better", and more specifically that "another country does it best".[30]

In this nationalistic discourse there is an assumption that the site of innovation should be and generally is the major site of use of technology.[31] However, very important counter-examples are not difficult to find. In the case of the motor car, Germany was notable for its backwardness: the USA became easily the dominant producer by 1914. The powered aeroplane was innovated in the USA but aeronautical development was much more rapid in Europe. Seeing the world and the nation-state as qualitatively similar is, in terms of thinking about technology, a serious error. In the case of the world economy, we believe, with the exception of some cranks, that all innovations are of human origin. In the case of particular nation-states, however, most technologies in use have extra-territorial origins. The typical means of acquisition of a new technology is to import it from abroad. Indeed, as a general rule, countries make greater use of technology innovated abroad, than technology innovated at home.[32] There are, however, exceptions to this general rule: they arise when particular nations dominate both innovation and industrial production, and are exceptionally rich. Thus both Britain in the early nineteenth century, and the United States after the second world war probably had unusual levels of home-innovated technology.

One reason for the neglect of inter-economy diffusion of technology is that it is often called "transfer" of technology. This is a term derived from development studies, and highlights the untypical case: the transfer across a large technological boundary, between rich and poor countries. However, transfer or diffusion between rich countries, is much more important, common and fundamental. This is not to say that there are no differences of technology in use across countries. Economic historians have long sought to explain these in terms of natural endowments, availability of labour and so on.[33] Furthermore nation-states have restricted the movement of technology across political boundaries by tariffs, quotas and nationalistic procurement policies. Such means are also used to encourage the import of production technology.[34] Nation-states have also pursued national innovation policies as a way of achieving a technical lead, or at least a technical differentiation, above all in weapons of war, and related technologies like civil aviation.[35] Nevertheless, innovation and use of technology have been internationally rather than nationally oriented. Even in the interwar period, patenting abroad was substantial and multinational enterprises innovated internationally.[36]

The international nature of innovation, and especially of the use of technology, deals a fatal blow to the techno-nationalist assumption that the more a nation-state innovates, the faster its economy will grow. Since national innovation is not the main source of national technology it is not surprising that there is no clear positive correlation between *national* innovation and *national* rates of growth. Indeed, the correlation is, if anything, negative. If innovation had been the main determinant of rates of growth, economies would have diverged massively in terms of income per head, given the very unequal distribution of innovation.[37] In fact, the major economies have converged over the last 150 years. One important explanation is that technology diffused from the leading country to the others.[38] The importance of trans-national diffusion of innovations suggests that collective provision for innovation (which market failure arguments tell us is beneficial) should be trans-national rather than purely national.[39]

IV. The innovation-orientation of most studies of technology makes difficult a serious engagement between general history and the history of technology. Conversely, an engagement with general historical problems has produced histories of technology-in-use.

The much lamented lack of interest of "general" historians in the work of historians of technology is not surprising, given that the study of innovation has little purchase on most historical issues.[40] For the reasons given in theses I and II, even the chronologies of the history of invention and general history are radically different. There have of course been strong links between general history and the history of technology, but it is significant that they have clustered around particularly innovation-centred accounts, for example, Schumpeterian economic history.[41] But other traditions in economic and social history have focussed on technology in use, and it is these studies that have yielded the richest interconnections between the history of technology and general history. In the case of the industrial revolution, for example, studies of the diffusion and impact of steam power, influenced by "cliometrics", have centred on use.[42] New histories of the "labour process" influenced by marxism, have yielded many studies of manufacturing technologies; new histories of women, influenced by feminism, have opened up whole new areas of studies of technology in use, notably in the home.[43] Military and imperial history have also yielded accounts of technology.[44]

Moving from innovation to technology-in-use has major implications for the historian. It involves a different kind of historiographical formation, different expertise and new problems of disciplinary demarcation. Particularly important is the relation to the study of technology itself, which is obviously of critical importance to historians of technology. It might be objected that many of the studies discussed above merely look at the use of technologies and not technology itself. But this is not necessarily so at all. It is important to differentiate between the study of the use of technology, and the study of technology-in-use. Studies of innovation are just one way, indeed a narrow way, of studying things. There is, nevertheless, a tendency to equate the study of technology with the study of invention and innovation.[45] The equation is entirely misplaced, and would rule out the study of the technology where there is no documentation on innovation, which is the great bulk of human technology. In any case, a broader conception of the study of things can be very illuminating. Brand's pioneering study of how buildings change (rather than of changes in the design of new buildings) points to a central and neglected issue.[46] It is typical of great and small material structures to be remodelled over time: from cities, to roads, to buildings, and many smaller objects; it does make sense to think of the history of a house, or a bridge, or a ship. The processes of maintenance, repair, remodelling, re-use, and re-cycling have been fundamental to material culture, but are obliterated by the emphasis on initial creation.[47]

V. "Technological determinism" is the thesis that a society is determined by the technologies in use. Nevertheless it is usually defined and attacked as the absurd thesis that technical innovation determines social change.

The issue of technological determinism has been central to much recent work in the history of technology.[48] It is around this issue that the largest questions concerning the relations of technology and history, and methodological innovations in the study of technology have been discussed. "My conjecture" writes Phil Scranton,

> is that technological determinism came closer to being an article of faith in the United States between 1940 and 1960 then ever before or since. Technological innovation powered the national economy, brought the consumer society to full blossom, and reinforced the American image at home and internationally.[49]

Although in part dismissed as an article of faith, technological determinism is seen as a belief that innovation powered change, at a time when innovation was in fact proceeding rapidly. This is the usual definition: technological determinism is "the intuitively compelling idea that technological innovation is a major driving force of contemporary history"[50] or "the belief that social progress is driven by technological innovation, which in turn follows an 'inevitable' course".[51]

We need, however, to distinguish this innovation-determinism from technological determinism. To be at all interesting as an argument, technological determinism must be what early analysts took it to be: the thesis that society is determined by technology in use.[52] Such a thesis is broader in that it includes societies with technology but without technical change. Perdue remarks it is difficult to examine technological determinism in modern societies simply because new technologies appear on the scene before old ones are fully used;

in slower-changing societies the effects of particular technologies are more clearly seen.[53] Similarly, the very lack of innovation might suggest that old societies are more technically constrained, and thus determined, than innovative societies. Innovation-determinism applies only to modern societies with high rates of innovation.[54]

Technological determinism is thus not centrally concerned with change, and it need say nothing specific about the direction, or desirability of either technical or social change. It is not therefore in itself a naive account of *progress*. Innovation determinism is concerned with change, and is usually naively progressivist, though of course it need not be.

In objecting to what they call "technological determinism" historians of technology are usually objecting to naive progressivist accounts of technical and social change, a present-centred historiography, and the view that technical change is determined only by Nature. It is a catch-all label for a number of very different (but not all) conceptual problems in popular accounts of technology. Ironically, the usual definition embodies one of the worst such problems: innovation-centredness. It is significant that recent critics of technological determinism have argued that it is false by showing that innovations are socially-constructed, or are co-created with society.[55] That is, they assume that it is essentially a bad theory of innovation, to be refuted by a better one.

Refuting innovation-determinism is much simpler. First, only a small minority of innovations are widely used; second, the extent of use surely determines the extent of the effect, not the act of innovation. Technological determinism is in principle also easily refuted. It makes the very strong assumption not only that technology is given, but also that the extent of use of a technology be given. To refute it, we need to show that the extent of use of technology is endogeneously determined, and indeed that machines and structures require maintenance and repair, and that they are changed and remodelled.

VI. Technological determinism is primarily a theory of society, not a theory of technology.

What is interesting about technological determinism is not what it has to say about technology, but about society.[56] It seeks to explain the structure and evolution of society, not the nature and evolution of technology. Among theories of society, however, it has a very marginal place indeed. The most famous and important technological determinism is (in one account) Marx's historical materialism. But even this is fatally flawed: Marx's account of technologies of production does not correlate with his account of society.[57] In addition Weber said of Marx's famous argument that "The hand mill gives you society with the feudal lord; the steam-mill, society with the industrial capitalist" that this was "at most correct in its second part, and then only partially. The steam-mill fits without any difficulty into a state socialist economy. The first part of the statement, however, is entirely incorrect: the hand-mill has lived through all conceivable economic structure and political 'superstructures'."[58]

That Karl Marx's technological determinism (if such it is) is unsustainable, does not mean that all possible theories involving some elements of technological determinism are to be ruled out. Indeed, it is worth asking, as Leo Marx has, whether there is any justification for the separate study of the history of technology if technology does not to some extent determine history.[59] There is clearly some relationship between modern societies and the widespread use of modern technologies. It is worth stressing, however, that empirical studies of technologies-in-use of sufficient breadth are too scarce to address the nature of the relationship; studies of innovation simply cannot do so.

VII. The pervasiveness of a technology is not an absolute measure of its significance. Alternatives should always be taken into account.

How might we assess the historical significance of particular technologies, an essential part of any study of technology and society? There is a strong tendency (which should not be confused with technological determinism as such) to attribute to particular technologies a great number of primary and secondary effects. The estimation of these effects is, in most historical accounts, done informally. Indeed, one may note a general tendency to attribute important effects to technologies which have had what might be called high cultural visibility, for example, aviation and nuclear power. Conversely we under-represent technologies which have low cultural resonance or may be invisible, for example, contraceptive technologies.[60] The most obvious and much used systematic measure of significance is, however, the extent to which a technology is in use. But this too needs to be used carefully: economists rightly insist that alternatives and opportunity costs be taken into account. They argue that the significance of a technology for an economy is the difference between the cost or benefit of using a technology and that of the best alternative. Since people will generally prefer a better technology, however small the overall benefit, to be widely used a technology need only be marginally better than the alternative, and thus may have low or negligible economic significance. Only a fool would argue that without paperclips bureaucracies would collapse for, despite the very widespread use of paperclips, we know there are other ways of holding sheets of paper together. Too often, however, we have difficulty in identifying alternatives, not least because they are sometimes invisible.[61] Economic historians of technology have carried out just such exercises, with striking results, but necessarily raising the problem of counterfactual history. Thus, Robert Fogel assessed the importance of nineteenth century US railways not by assuming that without railways people and goods would be impossible to transport, but by comparing railways with other means of transportation. He thus reduced what had been informally assessed to be massive effects, to a few percentage points of GDP by 1890.[62] In the case of the industrial revolution, Von Tunzelman shows that conventional studies of of steampower assume that without steam power there would have been a shortage of energy; instead he measures the significance of steampower as the saving it represented over other energy sources, and finds it to be remarkably small.[63] Studies of choice of technology show that alternatives often exist, and that the fact that one technology supercedes another is not even evidence of superiority at all, since other factors are involved.[64] There are examples of technologies in use which reduce welfare, compared with the best alternative (nuclear power is a powerful example). Furthermore societies can get locked into technologies which are worse than real alternatives.[65]

VIII. Invention and innovation rarely lead to use, but use often leads to invention and innovation.

George Basalla notes that "Alternatives can be found...for almost any major modern invention. The production of novelty is so great that clusters of related innovations, waiting to be selected, exist to fulfil virtually any of our wants, needs or whims";[66] societies have long thrown up many more innovations than have actually been used, or probably could be used. One important corollary is that the majority of technologies were "resisted", and had to be.[67] However, the great majority of studies of invention and innovation are of those which succeed in diffusing.[68] Studies of innovation are further biased towards discontinuous changes, and innovations which turn out big and radical, towards those derived from science,[69] and towards those arising out of novel innovating organisations. The study of innovation is thus systematically biased by the future, in that we study innovations which succeed later; we study the pre-history of innovating organisations of types which came to dominate later, and focus on science-technology relations typical of a later period. Studies of invention are, as many inventors are naively described, "ahead of their time". To take an example: studies of innovation in the late nineteenth century focus on "science-based" innovation in organic chemistry and electricity and on the very early industrial research laboratories. In fact late nineteenth century innovation was concentrated on other areas, and was largely the work of individuals.[70] Inventive activity was obviously not shaped by the future, it was shaped in its own present and past. Innovation was not, and is not, restricted to "new" industries; "old" industries innovate: the twentieth century has seen innovation in coal mining, iron and steel, shipbuilding and textiles. Around 1900 the industrial research laboratory made a small contribution to innovation, and even today R&D is just one, not the only source, of innovation. Furthermore, most changes in products have been incremental. Ignoring design, for example, of motor vehicles and aircraft, gives a quite misleading image of technical change in the twentieth century.[71]

It is useful to ask, how did the existing use of technology, and technology-in-use affect innovation? There are in fact a very wide-range of accounts of innovation, which explicitly or implicitly draw on what is actually in use to discuss innovation. For example, Schmookler's account of patenting suggests that patenting activity responds to changes in use of technology.[72] Other accounts of innovation stress the cumulation of small incremental changes in technologies-in-use.[73] The path-dependence of innovation has been an important theme of recent writing: in this view innovation is strongly affected by what technologies are actually in use, and the particular problems that arise in use.[74] The very fact of adoption, leads to development effort being concentrated on these technologies.[75] "Bottlenecks" or "reverse salients" that arise in use, it is suggested, themselves focus innovative activity, both incremental and radical.[76] In addition, use itself leads to increases in efficiency of use from "learning by doing" and "learning by using".[77] This reminds us that we should not ascribe all changes to machines and processes, and that expertise or "know-how" need not be embodied.

IX. Just as we should not confuse innovation with technology-in-use, we should not confuse changes in knowledge with knowledge-in-use.

One additional reason for the overemphasis on the history of the early industrial R&D in histories of innovation, is that we see the research laboratory as the harnessing of inherently innovative knowledge to industry for the first time. We have tended in fact to identify the links between science and industry with the research laboratory, and scientific and technological knowledge more generally with research. Indeed one historian of science and medicine explicitly argued as follows: "Science is often conceived as a *body of knowledge*. Reflection, however will lead to the conclusion that this cannot be its true nature. History has repeatedly shown that a body of scientific knowledge that ceases to develop soon ceases to be science at all.... *scientific* implies *knowledge making*, and no body of doctrine which is not *growing*, which is not actually *in the making* can long retain the attributes of science [emphasis in original]."[78] There is a profound bias in the literature towards the study of scientists and technologists employed in research, and the distinct silence on employment in other forms of work, such as teaching, routine testing, management, maintenance and so on.[79] Inkster therefore correctly stresses that technical capacities of nations are not to be deduced from their commitment to research.[80] The inherent innovativeness of scientific and technological knowledge is assumed, not least because our histories of scientific and technological knowledge are not, in fact, histories of knowledge at all. They are instead histories of innovation in knowledge, of the movement of the frontier as it were, rather than the whole terrain of knowledge. The modern identification of changing knowledge with knowledge itself does great violence not only to the past of knowledge, but to the present also. Science and technology were and are ways of knowing, not necessarily ways of creating, either of knowledge or things. Even in the period since the late nineteenth century, when innovation became a very important, even routine, part of science and technology, creating has remained a small element in knowing.[81]

These points are important not only for the study of technology-in-use, but also for innovation itself. The use of technologies has been associated with formal knowledge from long before the creation of research laboratories; think of the cases of engineers and doctors. That association has obviously continued: routine analysis, maintenance, repair and so on are not just the work of the untutored. More than this, the transfer of knowledge from a domain in which it is long-established and routine, to a domain in which it is new, plays an important part in what from the perspective of the new domain we would call innovation, but might otherwise label as transfer. We can go further still: innovation is highly dependent not only on the existing knowledge, but on the active, indeed routine, use of existing knowledges in the process of innovation, for example the standard procedures for testing the efficacy, safety etc, of new products and processes, which might themselves be created by long established routines. We are pointing here to the importance of the "invention of invention", the "industrialisation of invention" and the "routinisation of innovation", to the paradox highlighted by Schumpeter, of innovation without innovators.

X. Innovation-centred and knowledge-centred accounts of technology are central to twentieth century culture.

The commitment to an innovation-centred view of technology, of technology, of science, and of knowledge is deeply institutionalised. Where governments have science and technology policies, they mean policies for research, and for innovation, and not for all science and technology. Great efforts have gone into the collection of data related to innovation, such as statistics concerning research and development; by contrast the data on the use of technology, and even on its diffusion is meagre. Only for certain things, like numbers of telephones (or the case of countries like Britain where licences are required, the number of television receivers), do official data exist. Otherwise diffusion and use is the province of market research. Technique-in-use ceases to become technology, and becomes cars, aeroplanes, water, electricity etc; the banal accoutrements of everyday life.

How may we explain the emphasis on novelty in studies of the history of technology? Recently, Carroll Pursell has argued that it is due to the fact that it is written by white middle class (and one can add, North American) males.[82] However, for white middle class males the dominant experience is also use, not innovation. George Basalla attributes it to 1) the loss or concealment of antecedents; 2) the emergence of the inventor as hero, especially as national hero, leading to downgrading of antecedents to invention, especially foreign ones (furthermore patent systems provided a strong incentive to maximise individual radical contributions); and, 3) the overattribution of revolutionary social and economic change to technology.[83] Basalla usefully points to the historical specificity of the emphasis on innovation. More specifically still, MacLeod sees the heroic inventor being installed in the British consciousness in the third quarter of the nineteenth century, alongside a major controversy about patents.[84] David Nye's study of US attitudes to technology notes a shift from awe at machines that actually existed to awe only at the latest and then future technology. By the late 1930s the exhibitions of technology which engaged the public imagination were unrealised projects of the research laboratories of major corporations.[85] The history of technical toys shows a similar process: in the interwar years toys were a reflection of current practice; by the 1950s toys showed a strong bias towards technologies not yet in use.[86]

Paul David has pointed to the political significance of this futurism:

> There is an understandable inclination to concentrate on the future, holding onto the prospect of dramatic improvements in the material circumstances of the mass of humanity without having to contemplate overt conflicts that would be provoked by the purposive redistribution of existing wealth. In the long-run it may be a functional response on the part of the modern industrial democracies to try and direct the energies of society away from redistributive struggles and toward the cooperative conquest of the "endless frontier" of science . . .[87]

He goes on to note that the resulting "technological presbyopia" leads to lack of analysis of the complexities of techno-social change, and to puzzlement as to why new technology has not transformed the present. Brian Winston has noted that "From the 1970s I was increasingly aware of a gap between the rhetoric of runaway technological change and the reality of my professional life as a media worker and teacher. Working with film and teaching film-making when videotape was supposed to have wiped out that technology spurred a central thought that change was occurring much more slowly than was (and is) commonly believed".[88] David Noble has noted the centrality of claims for radical changes about to come about, in discussion of technology. He has wanted to show that, despite the promise of revolutionary changes, the old order reproduces itself. "Every major scientific advance, while appearing to presage an entirely new society", he says, "attests rather to the vigor and resilience of the old order which produced it." It was a "strange state of affairs: a remarkably dynamic society that goes nowhere".[89] An important task for the historian was to account for this "change without change".[90]

A revolutionary, future-oriented rhetoric has become the dominant mode of discussing technology. It has a very curious feature which is not sufficiently remarked upon: the revolutionary rhetoric is very largely unchanging over time: it does not revolutionise itself.[91] The same bright new future is promised all the time, but will come about on the basis of a different technology. A good example is the extraordinary litany of technologies which promised peace to the world. On the one hand there are communications technologies, from railways, steamships, to radio and the aeroplane, and now the internet. These promised to make the world smaller, and bring people together, ensuring a perpetual peace. Similarly, technologies of destruction are supposed to bring peace: the great ironclad battleships, Nobel's explosives, the bomber aircraft, and the atomic bomb were so powerful that they would force the world to make peace. In order to be at all convincing these arguments must deny their own history, and they did so to a remarkable extent. In the middle of 1945 the bomber ceased to be a peace-creating technology; the atomic bomb took its place, and in doing so made an original-sounding argument. This obliteration of even very recent history and the present is continuous and systematic. It makes us ignorant even of the very recent past, and in doing so presents an entirely false claim for the novelty of new technology. New technology appears thus to challenge humanity in ever new ways, such that we suffer from a continuous "cultural lag". When we think of information technology we forget about postal systems, the telegraph, radio, and television. Genetic engineering is made to seem radically distinct in its effects from animal and plant breeding or eugenics.

CONCLUSION

Technological futurism has certainly affected our historiography; we reproduce the innovation orientation, both in the choice of innovation as subject matter, and in confusing the innovation with the technology-in-use. Furthermore, the historiography itself makes claims to methodological and other forms of novelty by rubbing out previous accounts from our collective memories; we re-invent the wheel.[92] It is also significant that in thinking about theories of technology we engage with methodological and theoretical issues concerning science, innovation, and contemporary understandings of technology, rather than historical or historiographical problems.[93]

It has been the argument of this paper that we should not conflate the history of invention and innovation with the history of technology. This is not, I insist, an original point. It has been made many times, as I have shown. But it has been ignored again and again, with very unfortunate results for our understanding of the relations of technology and society. The history of technology is too important to be left to the historians of invention, or their modern equivalents. This paper has been unoriginal in another way: for a long time writers on technology have criticised previous writers for methodological confusion, and other vices. But there is a difference: I have tried to show that we already have the intellectual resources at least to clarify many of these problems. The most important is history. We should be in a position to cumulate knowledge, derived from many different traditions, to be aware of alternative forms of understanding, to beware of claims of a one best way, and to remember that we have lived with technology for a very long time.

Notes

1. An earlier version of this paper has appeared as "De l'innovation aux usages. Dix thèses éclectiques sur l'histoire des techniques" in *Annales HSS*, juillet-octobre 1998, Nos 4–5, pp. 815–837, and in Roger Guesnerie and Francois Hartog (eds), *Des Sciences et des Techniques: un debat. Cahier des Annales 45* (Paris: Armand Colin, 1998), pp. 259–88. Commentaries on this paper may be found in both volumes (by Yves Cohen and Dominique Pestre in *Annales*, pp. 721–744 and by François Sigaut and Frédéric Joulian in *Des Sciences et des Techniques*, pp. 289–311). I am most grateful to the *Annales* for permission to republish this paper, and in particular to Dominique Pestre and Yves Cohen who commissioned the article for the special issue in which it appeared. Dominique Pestre's work on the translation of this paper from its original English version improved it considerably. This present English version includes some material not in the French original. Elements of this paper have been presented at seminars and conferences in Cambridge, Manchester, the Institute for Historical Research, London, the Cite des Sciences et de l'Industrie, La Villette, the Ecole des Hautes Etudes en Sciences Sociales, Paris, the Universidad de la Republica, Montevideo, Uruguay and the Department of the History of Science and Technology in Stockholm. I am also very grateful to masters students of the London Centre for the History of Science, Medicine and Technology for enduring less refined versions of the arguments made here. John Pickstone and I have had many discussions covering many of the themes broached here; my colleagues Graham Hollister-Short, Rob Iliffe, Lara Marks and Andrew Warwick all commented on an earlier version. I have especially valued the detailed critical commentary of Alan Yoshioka. Paul David and Svante Lindqvist have sent me papers I would otherwise have missed. I am also grateful to Eric Schatzberg, Hans-Joachim Braun, Yves Cohen and Dominique Pestre for their comments.

2. Sir George Clark, *Science and Social Welfare in the Age of Newton* (Oxford: Clarendon Press, 1949), pp. 38, 39. [Origin. Publ. 1937]. Thanks to Rob Iliffe for lending me this book.
3. Langdon Winner, *Autonomous Technology* (Cambridge, MA: MIT Press, 1977), pp. 225–6.
4. N. Rosenberg, "The historiography of technical progress", in *Inside the black box* (Cambridge: Cambridge University Press, 1982), p. 19.
5. Rosenberg, *Inside the black* box, p. 55.
6. P.L. Stoneman and P.A. David, "Adoption subsidies vs information provision as instruments of technology policy", *The Economic Journal* 96 (1986) Supplement, pp. 142–150, on p. 142.
7. W. Vincenti, "Engineering Knowledge, type of design, and level of hierarchy: further thoughts about *What Engineers Know...*" in P. Kroes and M. Bakker (eds), *Technical development and Science in the Industrial Age* (Dordrecht: Kluwer, 1992), pp. 17, 18.
8. C. Pursell, "Seeing the invisible: new perceptions in the history of technology", in *ICON* 1 (1995), pp. 9–15.
9. Svante Lindqvist, "Changes in the Technological Landscape: the temporal dimension in the growth and decline of large technological systems", in Ove Granstrand (ed.), *Economics of Technology*, (Amsterdam: North Holland, 1994), pp. 271–288. I regret that this paper was not known to me until Prof Lindqvist had kindly sent me a copy. It should be compulsory reading.
10. G. Daniels, "The big questions in the history of American technology", *Technology and Culture* 11 (1970), pp. 1–21; J.G. Burke, "Comment: the complex nature of explanations in the historiography of technology", *Technology and Culture* 11 (1970), pp. 22–26; E. Layton, "Comment: the interaction of technology and society", *Technology and Culture* 11 (1970), pp. 27–31; G. Daniels, "The Reply: Differences and Agreements", *Technology and Culture* 11 (1970), pp. 32–5. See also the discussion in 1974: R. Multhauf, "Some observations of the State of the History of Technology" *Technology and Culture* 15 (1974), pp. 1–12; E. Ferguson, "Towards a discipline of the history of technology" *Technology and Culture* 15 (1974), pp. 13–30; E. Layton, "Technology as Knowledge", *Technology and Culture* 15 (1974), pp. 31–41; and D. De Solla Price, "On the historiographic revolution in the history of technology: commentary on the papers by Multhauf, Ferguson and Layton", *Technology and Culture* 15 (1974), pp. 42–8.
11. T.P. Hughes, "Emerging themes in the History of Technology", *Technology and Culture* 20 (1979), pp. 697–711, on p. 699. Hughes is an important case because his *Networks of Power Networks of Power: Electrification in Western Society, 1880–1930* (Baltimore, Johns Hopkins University Press, 1983) did indeed proceed in the sequence: "invention and development", "technology transfer", "system growth", and "momentum". Indeed, his study, much more oriented to use than most historical accounts, is nevertheless overwhelmingly concerned with the "evolution" of electrical systems, and notably stops in 1930. Also note that Hughes" *American Genesis* (New York: Viking, 1989) is a history of invention and development, not of American technology.
12. J.M. Staudenmaier, *Technology's Storytellers: Reweaving the Human Fabric*, (Cambridge MA: MIT Press, 1985). See also his "What SHOT hath wrought and what SHOT hath not: Reflections on twenty-five years of the history of technology", *Technology and Culture* 25 (1984), pp. 707–30, and commentaries by John Rae and Melvin Kranzberg in the same issue (pp. 731–49).
13. Staudenmaier pointed to another area of neglect: failed innovation. This points to the fact that most studies were of the innovation of technologies which went on to be successful. Studies clearly focussed on innovation itself would presumable mostly be of unsuccessful innovations. Again the problem is one of conflation of technology with innovation.

14. M.R. Smith and S. Reber "Contextual Contrasts: recent trends in the history of technology", in Stephen Cutcliffe and Robert Post (eds), *In Context: history and the history of technology* (Bethlehem: Lehigh University Press, 1989), pp. 133–49, reviewing David Hounshell, *From the American System to Mass Production, 1800–1932: the Development of Manufacturing Technology in the United States* (Baltimore: Johns Hopkins University Press, 1984); T.P. Hughes, *Networks of Power: Electrification in Western Society, 1880–1930* (Baltimore: Johns Hopkins University Press, 1983); David F. Noble, *Forces of Production: a Social History of Automation* (New York: Oxford University Press, 1985); and R. Schwartz Cowan, *More Work for Mother: the ironies of Household Technology from the Open Hearth to the Microwave* (New York: Basic Books, 1983; London: Free Association, 1989), the last being the study of use.
15. See in particular C. Fischer, *America Calling: A Social History of the Telephone to 1940* (Berkeley: University of California Press, 1992), and its introduction; K. Jellison, *Entitled to Power: Farm Women and American Technology* (Chapel Hill: Duke University Press, 1993). Thanks to Eric Schatzberg. See also the recent textbook by Ruth Schwartz Cowan, *A Social History of American Technology* (New York: Oxford University Press, 1997) and Cynthia Cockburn and Susan Ormrod, *Gender and Technology in the Making* (London, 1993), a marvellous study of the design, manufacture and use of the microwave oven. Indeed it is worth remarking that a recent survey on the historiography of gender and technology fails to fully explore the centrality of the innovation/use distinction to the question of gender (Nina Lerman, Arwen Mohum and Ruth Oldenzeil), "The Shoulders we stand on and the view from here: historiography and directions for research", *Technology and Culture* 38 (1997), pp. 9–30.
16. R.A. Buchanan, *The Power of the Machine: the Impact of Technology from 1700 to the Present* (London: Viking, 1992).
17. D.S.L. Cardwell, *The Fontana History of Technology* (London: Fontana, 1994), p. xiv.
18. For examples see W. Bijker, T.P. Hughes and T. Pinch (eds), *The Social Construction of Technological Systems*, (Cambridge, MA: MIT Press, 1987); D. MacKenzie, *Inventing Accuracy*, (Cambridge, MA: MIT Press, 1990) and *Knowing Machines: Essays on Technical Change*, (Cambridge, MA: MIT Press, 1996); W. Bijker, *Of Bicycles, Bakelites and Bulbs: Toward a Theory of Sociotechnical change* (Cambridge, MA: MIT Press, 1995); B. Latour, *Aramis, ou l'amour des techniques* (Paris: Editions La Decouverte, 1993). For criticism of the innovation centredness of such studies see L. Winner, "Upon opening the black box and finding it empty: social constructivism and the philosophy of technology", *Science, Technology and Human Values* 18 (1993), pp. 362–78 on pp. 368–9. For additional critiques see David Edgerton, "Tilting at Paper Tigers", *British Journal for the History of Science* 26 (1993), pp. 67–75 and Yves Gingras, "Following scientists through society? Yes, but at arm's length!", in J.Z. Buchwald, *Scientific Practice: Theories and Stories of Doing Physics*, (Chicago: Chicago University Press, 1995), pp. 123–48.
19. W. Bijker, *Of Bicycles, Bakelites and Bulbs: Toward a Theory of Sociotechnical change* (Cambridge, MA: MIT Press, 1995). But see R. Kline and T. Pinch, "Taking the Black Box off its wheels: the social construction of the American rural car" in K.H. Sorensen (ed), *The Car and its Environments: The Past, Present and Future of the Motorcar in Europe* (Luxembourg: European Commission, 1994) for an extension to use. See C. Chant (ed.), *Science, technology and everyday life, 1870–1950* (London: Routledge, 1989) for a collection of studies, some of which deal centrally with use.
20. For references see David Edgerton, *Science, Technology and the British Industrial "Decline", 1870–1970* (Cambridge: Cambridge University Press/Economic History Society, 1996).
21. Lester Brown et al, *Vital Signs* (London: Earthscan 1993), pp. 86–89.
22. P.A. David, "Computer and Dynamo: The Modern Productivity Paradox in a not-too-distant mirror", in OECD, *Technology and Productivity: the Challenge for Economic Policy* (Paris: OECD, 1991).

23. S. Bowden and A. Offer, "Household appliances and the use of time: the United States and Britain since the 1920s", *Economic History Review* 47 (1994), pp. 725–48.
24. Data from Salta Museum.
25. One study suggests that the proportion of patents granted to women in the United States was, in ten selected years between 1905 and 1921, only 1.4% (C. Pursell, "Women inventors in America", *Technology and Culture*, 22 (1981): 545–49) African-Americans were deemed uninnovative, to the extent that one analyst of per capita patenting noted that it is "inadvisable to count in the colored populations of the United States and the British Dominions, since these people do not figure in invention" (S.C. Gilfillan, "Inventiveness by Nation: a note on statistical treatment", *The Geographical Review* 20 (1930), p. 301). M. Jefferson, "The Geographic Distribution of Inventiveness", *The Geographical Review* 19 (1929), pp. 649–64 argued also argued that the USA had low per capita inventiveness because "the United States have a dilution in the negroes in our population" (p. 659).
26. See "Seeing the invisible: new perceptions in the history of technology", in *ICON* 1 (1995), pp. 9–15.
27. David Hounshell, "Rethinking the History of 'American Technology'", in Cutliffe and Post, *In Context*, pp. 216–29 criticises the nationalism in studies of US technology. Edgerton, "British Industrial R&D 1900–1970", *Journal of European Economic History* 23 (1994), develops the point with respect to the British case.
28. C. Freeman, *Technology Policy and Economic Performance* (London: Pinter, 1987).
29. See Freeman, *Technology Policy* and the recent comparative study edited by R.R. Nelson, *National Innovation Systems: a Comparative Analysis* (New York, Oxford University Press, 1993).
30. In the British case that other country usually resembles Germany or Japan, rarely the United States. See Edgerton, *Science, Technology and the British Industrial "decline."*
31. This is usually expressed in the form of a regret that the innovating nation is not the dominant user of a particular technology: many nations share the belief that they are good at inventing, but bad at developing and using technology.
32. I derive the point from the informal observation of the objects in my room: most are not of British invention. More formally, Britain has accounted for around 10% of this century's significant innovations; I have no evidence that Britain has neglected to use any significant proportion of the remaining 90%.
33. For example, P.A. David, *Technical Choice, Innovation and Economic Growth* (Cambridge: Cambridge University Press, 1975).
34. For examples see: L.F. Haber, "Government intervention at the frontiers of science: British dyestuffs and synthetic organic chemistry 1914–1939", *Minerva* XI (1973), pp. 79–94; A. Kramer, "Fueling the Third Reich", *Technology and Culture* 19 (1978), pp. 394–422; A Stranges, "From Birmingham to Billingham: high-pressure coal hydrogenation in Great Britain", *Technology and Culture* 26 (1985), pp. 726–57; A.S. Milward and G. Brennan, *Britain's Place in the World: a Historical Enquiry into Import Controls, 1945–1960* (London: Routledge, 1996).
35. David Edgerton, "Science in the United Kingdom a case study in the Nationalisation of Science", in J. Krige and D. Pestre (eds.), *Science in the Twentieth Century* (Harwood Academic Publishers, 1996).
36. Jefferson, "Geographic Distribution".
37. There is, however, one extremely important case of divergence: the United States. In the late nineteenth century its per capita income was comparable to that of leading European nations; by the interwar years, and especially in the 1940s and 1950s it was much greater. Innovation may well have played an important role in causing this divergence.
38. For references and a discussion with respect to Great Britain see Edgerton, *Science, Technology and the British Industrial "decline"*.

39. I do not wish to suggest there is no argument for the state funding of research. There are many, but the free rider argument does not clinch the argument. See Terence Kealey, *The Economic Laws of Scientific Research* (London: Macmillan, 1995), a brilliant polemic critique.
40. Hunter Dupree, according to Caroll Pursell, felt that "when the history of American science and technology is properly understood, that knowledge would force us to rewrite American history as a whole" C. Pursell, *The Machine in America: a social history* (Baltimore: Johns Hopkins University Press, 1995), p. xv. For an attempt to re-write a national story on the basis of a new technical story see my *England and the Aeroplane: an essay on a militant and technological nation* (London: Macmillan, 1991). In composing this work it became very clear to me that the technical history of British aviation was really a history of new types. It proved very difficult to find data on what types were in use at any one time. But once this was done it became very clear, for example, that aircraft designed in the 1950s were still in use in the 1980s.
41. See David Landes, *The Unbound Prometheus* (Cambridge: Cambridge University Press, 1969) for a strongly implicit Schumpeterianism, and J. Mokyr, *The Lever of Riches: Technological Creativity and Economic Progress* (New York: Oxford University Press, 1990) for an explicit version. In my view neo-Schumpeterian accounts are very different from Schumpeterian ones, but I will not consider this issue here.
42. N. Von Tunzelmann, *Steampower and Industrialisation* (Oxford: Oxford University Press, 1977); C. Sabel and J. Zeitlin, "Historical alternatives to mass production: politics, markets and technology in nineteenth century industrialisation", *Past & Present*, No. 108 (1985), pp. 133–76; R. Samuel, "The Workshop of the world: steam power and hand technology in mid-Victorian Britain", *History Workshop* No. 3 (1977): 6–72; M. Berg, *The Age of Manufactures, 1700–1820: Innovation, Industry and Work in Britain*, 2nd edition (London: Routledge, 1994).
43. Thus R. Schwartz Cowan, "The Consumption Junction: a proposal for research strategies in the sociology of technology", in Bijker et al, *Social Construction*, p. 278 has argued for her consumer-oriented study of technology, focussing on the "diffusion" stage, but it is noticeable that she feels it necessary to defend this by noting that diffusion involves change, and also sheds light on invention.
44. W.H. McNeill, *The Pursuit of Power: Technology, Armed Force and Society since AD 1000* (Oxford: Blackwell, 1983); D. Headrick, *Tentacles of Progress* (New York: Oxford University Press, 1988), and *The Invisible Weapon: Telecommunications and International Politics, 1851–1945* (New York: Oxford University Press, 1991). B.C. Hacker, "Military Institutions, Weapons, and Social Change: Toward a new history of Military Technology", *Technology and Culture* 35 (1994), pp. 768–834.
45. See for example, Smith and Reber, "Contextual contrasts", p. 144 and MacKenzie, *Knowing Machines*, p. 5.
46. S. Brand, *How Buildings Learn: What Happens after they're Built* (London: Penguin, 1994). For the importance of maintenance see also N. Rosenberg, "Learning by Using" in N. Rosenberg, *Inside the black box*, (Cambridge: Cambridge University Press, 1982). On, in effect, maintenance, discipline and democracy, see Langdon Winner, *Autonomous Technology* (Cambridge, MA: MIT Press, 1977).
47. Two points are worth adding. First, there is undoubtedly a point in history at which, for many objects, when remodelling, re-using etc, becomes impossible or too expensive (we can remodel our houses, but not our cars). Second, the fact that we can and do change existing things points to the fact such statements as "we shape our buildings; and afterwards our buildings shape us" are far too simple, since we continually shape our buildings (Brand, *How Buildings Learn*, p. 3). The point has great bearing on discussions of technological determinism (see below).
48. See B. Bimber, "Karl Marx and the Three Faces of Technological Determinism", *Social Studies of Science* 20 (1990), pp. 333–51, reprinted in M.R. Smith and L. Marx

(eds) *Does Technology Drive History? the Dilemma of Technological Determinism* (Cambridge, MA: MIT Press, 1994) for a rare cogent analysis of the meaning of "technological determinism". See also Edgerton, "Tilting at Paper Tigers".

49. P. Scranton, "Determinism and Indeterminacy in the History of Technology" supplement to *Technology and Culture* 36, No. 2 (1995), p. S33., p. S33.
50. Introduction to Smith and Marx, *Does Technology Drive History?*, p. xiv.
51. Smith and Marx, *Does Technology Drive History?*, p. 38. See also pp. 2, 7, 85, 116, 146, 174, 249 for further definitions, implicit and explicit.
52. The innovation-determinism thesis might be thought to follow from the use thesis. In a sense it does: if technology in use changes due to innovation, then society changes. However, it is important to note the complex relation between innovation and use: most innovations do not come into important use.
53. Perdue in Smith and Marx, *Does Technology Drive History?*, p. 171.
54. See R. Heilbroner, "Do Machines make history", *Technology and Culture* 8 (1967), pp. 335–45.
55. For example, MacKenzie, *Inventing Accuracy*.
56. Edgerton, "Tilting at Paper Tigers".
57. That is, the transition from feudalism to capitalism predates the technical revolution of the early nineteenth century. The technical revolution of the early nineteenth century, does not, in Marx's view, bring about a new revolution: the transition from capitalism to socialism was to follow much later. S. Rigby, *Marxism and History* (Manchester: Manchester University Press, 1987). See also Bimber, "Three Faces" for an unusually incisive treatment of technological determinism, which cuts the ground from under most discussions. For a discussion of the work of Lynn White see B. Hall, "Lynn White's Medieval *Technology and Social Change* after thirty years", in R. Fox (ed), *Technological Change: Methods and Themes in the History of Technology* (Amsterdam: Harwood Academic Publishers, 1996), pp. 85–102 and R. Holt, "Medieval technology and the historians: the evidence for the mill", in the same volume, pp. 103–122.
58. Quoted in B. O'Leary, *The Asiatic Mode of Production* (Oxford: Blackwell, 1987), p. 209n.
59. L. Marx, Book review in *Technology and Culture* 32 (1991), pp. 394–6, and letters by Marx and Kranzberg, *Technology and Culture* 33 (1992), pp. 406–7.
60. V. Bullough, "A Brief note on rubber technology and contraception: the diaphragm and the condom", *Technology and Culture* 22 (1981), pp. 104–111.
61. Economists are quick to look for alternatives. The rest of us too easily assume they do not exist. To give two anecdotal examples: an article in the British press imagined what the world would have been like without computers; the conclusion was it would barely work at all. To do this it ignored not only all previously existing alternatives, but also any alternative technical development. (Henry Porter, "Life BC (Before the age of the Computer)", *The Guardian* 14/2/1996). A second example concerns engineering students. Asked by me what alternatives there are to satellites for long distance telecommunications they could find none, despite the fact that the world is being covered in fibre-optic cables.
62. R.W. Fogel, "The new economic history: its findings and methods", *Economic History Review* 19 (1966), pp. 642–56.
63. Von Tunzelmann, *Steampower*.
64. For studies suggesting the importance of non-technical factors see D.F. Noble, *Forces of Production: a Social History of Automation* (New York: Oxford University Press, 1985) and Eric Schatzberg, "Ideology and Technical Choice: the decline of the wooden airplane in the United States, 1920–1945", *Technology and Culture* 35 (1994), pp. 34–69, and *Wings of Wood, Wings of Metal: Culture and Technical Choice in American Airplane Materials, 1914–1945* (Princeton: Princeton University Press, 1998).

65. R. Cowan, "Nuclear Power Reactors: A Study in Technological Lock-in", *Journal of Economic History* 50 (1990), pp. 541–67; P.A. David, "Heroes, Herds and Hysteresis in Technological History: Thomas Edison and 'The Battle of the Systems' Reconsidered", *Industrial and Corporate Change* Vol. 1, No. 1 (1992), pp. 129–80. For a devastating cost benefit analysis of the British nuclear programme, with some important general comments about politics, culture and high technology after the second world war see P.D. Henderson, "Two British Errors: their probable size and some possible lessons", *Oxford Economic Papers* (July 1977), pp. 159–94.
66. G. Bassala, *The Evolution of Technology* (Cambridge: Cambridge University Press, 1988), p. 204.
67. And yet we treat "resistance" as unusual and worthy of special consideration. Similarly, it is often assumed in science policy that the problem is what projects to start, when the problem is one of stopping projects. Any policy decision regarding innovation requires stopping things, but our culture regards this as a bad thing.
68. H.-J. Braun, "Introduction" to *Social Studies of Science* Vol. 22, No. 3 (1992), "Symposium on 'Failed Innovations'".
69. A number of neo-classical accounts of the role of science and technology in economic development can rightly be criticised for concerning themselves overmuch with science, and with radical innovation See N. Rosenberg, *Perspectives on Technology* (Cambridge: Cambridge University Press, 1976), pp. 61–84.
70. See Hughes, *American Genesis* for a defence of the individual inventor.
71. See especially W. Vincenti, *What Engineers Know and How they Know it: Studies from Aeronautical History* (Baltimore: Johns Hopkins University Press, 1990), for a number of important case studies. See also S.H. Lindner and D. Pestre (eds), *Innover dans la regression* (Paris: CRHST/Cite des Sciences et de l'Industrie, 1996).
72. J. Schmookler, *Invention and Economic Growth* (Cambridge MA, Harvard University Press, 1966).
73. Basalla, *Evolution*, pp. 26–43.
74. David, *Technological Choice*, David, "Heroes, Herds, and Hysteresis", Hughes, *Networks of Power* and Cowan, "Nuclear Power Reactors".
75. This applies not only to network technologies, as MacKenzie, *Inventing Accuracy* shows in the case of missile guidance.
76. Hughes, *Networks of Power*, and Rosenberg, *Inside the Black Box*.
77. Rosenberg, *Inside the Black Box*.
78. Charles Singer, *A Short History of Scientific Ideas to 1900* (Oxford: Clarendon Press, 1959), pp. 1, 2. Originally published in 1941, under a slightly different title. The argument, it may be quite identical, appears in the 1941 version, and elsewhere in Singer's work, according to G. Cantor, "Charles Singer and the early years of the British society for the History of Science", *British Journal for the History of Science* 30 (1997), pp. 5–24.
79. David Edgerton (ed.), *Industrial Research and Innovation in Business*, Cheltenham, Edward Elgar, 1996b. *International Library of Critical Readings in Business History 14* collects examples and counter-examples.
80. Ian Inkster, *Science and Technology in History: an approach to Industrial Development* (London: Macmillan, 1991), pp. 89–128.
81. J.V. Pickstone, "Ways of Knowing: towards a historical sociology of science, technology and medicine", *British Journal for the History of Science* 26 (1993), pp. 433–58.
82. Pursell, "Seeing the invisible".
83. Basalla, *Evolution*, pp. 57–62.
84. C. MacLeod, "Concepts of Invention and the Patent Controversy in Victorian Britain", in Fox, *Technological Change*, pp. 137–53.
85. D.E. Nye, *American Technological Sublime* (Cambridge MA: MIT Press, 1994).

86. J. Britton, "Technology in Toyland: a study of miniature technology, 1920–1970", MSc Thesis, London Centre for the History of Science, Technology and Medicine, University of London, 1995.
87. David, "Computer and Dynamo", p. 317.
88. Brian Winston, *Media, Technology and Society, A History: from the Telegraph to the Internet* (London: Routledge, 1998), p. Xiii. The blurb says it all: "The fax was introduced in 1847. The idea of television was patented in 1884. Digitalisation was demonstrated in 1938. Even the concept of the 'web' dates back to 1945."
89. D.F. Noble, *America by Design: Science, Technology and the Rise of Corporate Capitalism* (New York: Oxford University Press, 1977), p. xvii.
90. Noble, *America by Design*, p. xxiii.
91. It is interesting too, that technological dystopias look forward to more advanced technological societies, but ones which are not themselves innovative.
92. Edgerton, "Tilting at Paper Tigers".
93. Eg Bijker, *Bicycles, Bakelite and Bulbs* and MacKenzie, *Inventing Accuracy*.