Introduction

Much of what is written on the history of technology is for boys of all ages. This book is a history for grown-ups of all genders. We have lived with technology for a long time, and collectively we know a lot about it. From economists to ecologists, from antiquarians to historians, people have had different views about the material world around us and how it has changed. Yet too often the agenda for discussing the past, present and future of technology is set by the promoters of new technologies.

When we are told about technology from on high we are made to think about novelty and the future. For many decades now the term 'technology' has been closely linked with *invention* (the creation of a new idea) and *innovation* (the first use of a new idea). Talk about technology centres on research and development, patents and the early stages of use, for which the term *diffusion* is used. The timelines of technological history, and they abound, are based on dates of invention and innovation. The most significant twentieth-century technologies are often reduced to the following: flight (1903), nuclear power (1945), contraception (1955), and the internet (1965). We are told that change is taking place at an ever-accelerating pace, and that the new is increasingly powerful. The world, the gurus insist, is entering a new historical epoch as a result of technology. In the new economy, in new times, in our post-industrial and post-modern condition, knowledge of the present and past is supposedly ever less relevant. Inventors, even in these post-modern times, are 'ahead of their time', while societies suffer from the grip of the past, resulting in a supposed slowness to adapt to new technology.

There are new things under the sun, and the world is indeed changing radically, but this way of thinking is not among them. Although the emphasis on the future itself suggests originality, this kind of futurology has been with us a long time. In the nineteenth century the idea that inventors were ahead of their time and that science and technology were advancing faster than the ability of human society to cope was a commonplace. By the early twentieth century this notion was made academically respectable with the label 'the cultural lag'. In the 1950s and even later, one could claim without embarrassment that scientists 'had the future in their bones'. By the end of the twentieth century, futurism had long been *passé*. The technological future was as it had been for a long time. Intellectuals claimed there was a new kind of future, one prefigured by 'post-modern' architecture. Yet this new kind of future was to be brought about by an old-style technological or industrial revolution which would change everything.

In the case of technology reheated futurism has held its appeal long after it was declared obsolete. The technological future marched on as before. Consider the case of the first successful flight of NASA's X-43A space aeroplane on 27 March 2004. Although it lasted all of ten seconds, it made the news the world over. 'From Kitty Hawk to the X-43A has been a century's steady advance', wrote one newspaper; from 'seven miles an hour to Mach Seven is a striking indication of how far powered flight has travelled in a hundred years'.[1] Soon we would be enjoying, yet again, almost instant travel to Australia from London.

Just below the surface was another history, which blew great holes in this old-fashioned story. Every few weeks between 1959 and 1968 B-52 aircraft took off from Edwards Air Force Base in California, with one of three X-15s under their wings. Once high up the X-15s fired their rocket engines and were actively flown by twelve 'research pilots', clad in silver pressurised space suits, reaching speeds of Mach 6.7 and touching the edge of space. These hard-drinking engineer-pilots, mostly combat veterans (among them Neil Armstrong, the first man to set foot on the moon), looked down on mere 'spam in the can' astronauts, as Tom Wolfe observed in *The Right Stuff*. While the astronauts became famous, the elite X-15 pilots were left to lament, as one did, that in the early 1990s he was still 'one of the fastest airplane pilots in the world. I am too old for that. Someone younger should have that honor.'[2] Past and present were connected even more directly. The B-52, which took the X-43A and its booster rocket up, was one of the same B-52s used on the X-15 programmes and was now the oldest flying B-52 in the world.[3] It was built in the 1950s. Not only that, but the key technology of the X-43A was the scramjet, a supersonic version of the ramjet. A technique decades old, it was used in a 1950s-designed British anti-aircraft missile, the Bloodhound, which was itself in service into the 1990s. In short, the story might well have been '1950s aeroplane launches unmanned ramjet plane which flies a little faster than 1960s Right Stuff pilots'.

By thinking about the history of technology-in-use a radically different picture of technology, and indeed of invention and innovation, becomes possible.[4] A whole invisible world of technologies appears. It leads to a rethinking of our notion of technological time, mapped as it is on innovation-based timelines. Even more importantly it alters our picture of which have been the most important technologies. It yields a global history, whereas an innovation-centred one, for all its claims to universality, is based on a very few places. It will give us a history which does not fit the usual schemes of modernity, one which refutes some important assumptions of innovation-centric accounts.

The new history will be surprisingly different. For example, steam power, held to be characteristic of the industrial revolution, was not only absolutely but relatively more important in 1900 than in 1800. Even in Britain, the lead country of the industrial revolution, it continued to grow in absolute importance after that. Britain consumed much more coal in the 1950s than in the 1850s. The world consumed more coal in 2000 than in 1950 or 1900. It has more motor cars, aeroplanes, wooden furniture and cotton textiles than ever before. The tonnage of world shipping continues to increase. We still have buses, trains, radio, television and the cinema, and consume ever-increasing quantities of paper, cement and steel. The production of books continues to increase. Even the key novel technology of the late twentieth century, the electronic computer, has been around for many decades. The post-modern world has forty-year-old nuclear power stations as well as fifty-year old bombers. It has more than a dash of technological retro about it too: it has new ocean-going passenger ships, organic food and classical music played on 'authentic' instruments. Aging, and even dead, rock stars of the 1960s still generate large sales, and children are brought up with Disney films seen by their grandparents when they were children.

Use-centred history is not simply a matter of moving technological time forward. As Bruno Latour has aptly noted, modern time, where this behaved as moderns believed, has never existed. Time was always jumbled up, in the pre-modern era, the post-modern era and the modern era. We worked with old and new things, with hammers and electric drills.[5] In use-centred history technologies do not only appear, they also disappear and reappear, and mix and match across the centuries. Since the late 1960s many more bicycles were produced globally each year than cars.[6] The guillotine made a gruesome return in the 1940s. Cable TV declined in the 1950s to reappear in the 1980s. The supposedly obsolete battleship saw more action in the Second World War than in the First. Furthermore, the twentieth century has seen cases of technological regression.

A use-based history will do much more than disturb our tidy timelines of progress. What we take to be the most significant technologies will change. Our accounts of significance have been peculiarly innovation-centric, and tied to particular accounts of modernity where particular new technologies were held to be central. In the new picture, twentieth-century technology is not just a matter of electricity, mass production, aerospace, nuclear power, the internet and the contraceptive pill. It will involve the rickshaw, the condom, the horse, the sewing machine, the spinning wheel, the Haber-Bosch process, the hydrogenation of coal, cemented-carbide tools, bicycles, corrugated iron, cement, asbestos, DDT, the chain saw and the refrigerator. The horse made a greater contribution to Nazi conquest than the V2.

A central feature of use-based history, and a new history of

1. A mule hauling equipment on a track in the building of the Berlin–Baghdad railway near Aleppo between 1900 and 1910. Mules, and railways, were vitally important technologies of the twentieth century in both rich and poor countries.

invention, is that alternatives exist for nearly all technologies: there are multiple military technologies, means of generating electricity, powering a motor car, storing and manipulating information, cutting metal or roofing a building. Too often histories are written as if no alternative could or did exist.

One particularly important feature of use-based history of technology is that it can be genuinely global. It includes all places that use technology, not just the small number of places where invention and innovation is concentrated. In the innovation-centric account, most places have no history of technology. In use-centred accounts, nearly everywhere does. It gives us a history of technology engaged with all the world's population, which is mostly poor, non-white and half female. A use-perspective points to the significance of novel technological worlds which have emerged in the twentieth century and which have hitherto had no place in histories of technology. Among them are the new technologies of poverty. They are missed because the poor world is thought of as having traditional local technologies, a *lack* of rich-world technologies, and/or has been subject to imperial technological violence. When we think of cities we should think of *bidonvilles* as well as Alphaville; we should think not just about the planned cities of Le Corbusier, but the unplanned shanty towns, built not by great contractors, but by millions of self-builders over many years. These are worlds of what I call 'creole' technologies, technologies transplanted from their place of origin finding uses on a greater scale elsewhere.

A consequence of the new approach is that we shift attention from the new to the old, the big to the small, the spectacular to the mundane, the masculine to the feminine, the rich to the poor. But at its core is a rethinking of the history of all technology, including the big, spectacular, masculine high technologies of the rich white world. For all the critiques, we do not in fact have a coherent productionist, masculine, materialist account of technology and history in the twentieth century. We have big questions, and big issues to address, which are surprisingly open.

A use-centred account also refutes some well-established conclusions of innovation-centric history. For example, it undermines the assumption that national innovation determines national success; the most innovative nations of the twentieth century have not been the fastest growing. Perhaps the most surprising criticism that arises from the use perspective is that innovation-centric history gives us an inadequate account of invention and innovation. Innovation-centric history focuses on the early history of some technologies which became important later. The history of invention and innovation needs to focus on all inventions and innovations at a particular time, independently of their later success or failure. It needs to look too to invention and innovation in all technologies, not just those favoured by being well known and assumed to be the most significant. Traditional innovation-centric histories have space for Bill Gates,

2. The United States became one of the richest agricultural nations in the world partly by creating highly mechanised, but animal-powered, agriculture. Here a farmer drives a team of twenty mules pulling a combine harvester through the wheat fields of Walla Walla County, Washington in 1941. By this time the tractor had been displacing horses and mules in some areas for twenty-five years.

but a history of invention and innovation would also include Ingvar Kamprad, who made his money from mass-producing and selling wooden furniture. He founded IKEA and is, some think, richer than Gates. More importantly, our histories need to have a place for the majority of failed inventions and innovations. Most inventions are never used; many innovations fail.

The innovation-centric view also misleads us as to the nature of scientists and engineers. It presents them, as they present themselves, as creators, designers, researchers. Yet the majority have always been mainly concerned with the operation and maintenance of things and processes; with the uses of things, not their invention or development.

Given the importance of innovation-centric futurism in discussing technology, history can be an especially powerful tool for rethinking technology. History reveals that technological futurism is largely unchanging over time. Present visions of the future display a startling, unselfconscious lack of originality. Take the extraordinary litany of technologies which promised peace to the world. Communications technologies, from railways and steamships, to radio and the aeroplane, and now the internet, seemed to make the world smaller and bring people together, ensuring a perpetual peace. Technologies of destruction, such as the great ironclad battleships, Nobel's explosives, the bomber aircraft and the atomic bomb were so powerful that they too would force the world to make peace. New technologies of many sorts would emancipate the downtrodden. The old class system would wither under the meritocracy demanded by new technology; racial minorities would gain new opportunities – as chauffeurs in the motor age, pilots in the air age, and computer experts in the information age. Women were to be liberated by new domestic technologies, from the vacuum cleaner to the washing machine. The differences between nations would evaporate as technology overcame borders. Political systems too would converge as technology, inevitably, became the same everywhere. The socialist and capitalist worlds would become one.

In order to be at all convincing these arguments had to deny their own history, and they did so to a remarkable extent. The obliteration of even recent history has been continuous and systematic. For example, in the middle of 1945 the bomber ceased to be a peace-creating technology; the atomic bomb took its place. When we think of information technology we forget about postal systems, the telegraph, the telephone, radio and television. When we celebrate on-line shopping, the mail-order catalogue goes missing. Genetic engineering, and its positive and negative impacts, is discussed as if there had never been any other means of changing animals or plants, let alone other means of increasing food supply. A history of how things were done in the past, and of the way past futurology has worked, will undermine most contemporary claims to novelty.

We need to be aware that this futurology of the past has affected our history. From it we get our focus on invention and innovation, and on the technologies which we take to be the most important. From this literature, the work of low- and middle-ranking intellectuals and propagandists, ranging from, say, the books of H. G. Wells to the press releases of NASA's PR officials, we get a whole series of clichéd claims about technology and history. We should take them, not as well-grounded contributions to our understanding, for they rarely are that, but as the basis of questions. What have been the most significant technologies of the twentieth century? Has the world become a global village? Has culture lagged behind technology? Has technology had revolutionary or conservative social and political effects? Has new technology been responsible for the dramatic increase in economic output in the last hundred years? Has technology transformed war? Has the rate of technical change been ever increasing? These are some of the questions this book will try to answer, but they cannot be answered within the innovation-centric frame in which they are usually asked.

These questions become much easier to answer if we stop thinking about 'technology', but instead think of 'things'. Thinking about the use of things, rather than of technology, connects us directly with the world we know rather than the strange world in which 'technology' lives. We speak of 'our' technology, meaning the technology of an age or a whole society. By contrast 'things' fit into no such totality, and do not evoke what is often taken as an independent historical force. We discuss the world of things as grown-ups, but technology as children. For example, we all know that while the use of things is widely distributed through societies, ultimate control of things and their use has been highly concentrated, within societies and between societies. Ownership, and other forms of authority, on the one hand, and use on the other, have been radically separated. Most people in the world live in houses that do not belong to them, work in workplaces belonging to others, with tools that belong to others, and indeed many of the things they apparently own are often tied to credit agreements.

Within societies, states and/or small groups have had disproportionate control; some societies have much more stuff than others. In many places of the world much is owned by foreigners. Things belong to particular people in ways which technology does not.

1

Significance

Is the condom more significant in history than the aeroplane? We all know that technology has made an enormous difference to the history of the twentieth century. But just how important is difficult, perhaps impossible, to assess. When it had the greatest effect is also difficult to assess. Can one distinguish between technological and other changes? What is the appropriate measure of significance? Is it a quantitative measure, perhaps of economic impact, or some qualitative estimate of social or cultural effect? Is cultural significance to be measured by the presence of a technology in the movies, the pages of newspapers, and the works of intellectuals? Or can we detect it even when a technology hardly resonates at all at these levels? The aeroplane is by this measure very culturally significant, the condom insignificant. Once we start thinking seriously about these questions we will open up the history of twentieth-century technology to many fresh insights.

Our world abounds with seemingly authoritative stories of which technologies have been most significant, and when. They focus on a small number of cases. For the years up to around 1940 electricity, motor cars and aviation are conventionally deemed to be the most important. The period of the Second World War and later is seen as the age of nuclear power, computers, space rockets and the internet.[1] Sometimes biotechnologies, including new foods, medicines and contraceptives (the Pill), are part of these narratives, as are chemicals.[2] To be sure there are variants. Thus in one account 1895 to 1940 was the

3. Rocketry was, from the very beginning, a very public technology. Its public prominence has led to an exaggerated idea of its significance to history, especially for the 1940s and 1950s. Here photographers record the first launch from what was later known as Cape Canaveral on 24 July 1950. The rocket was a 'Bumper V-2', a modified V-2.

period of *electrification*; 1941 to the late twentieth century was the era of *motorisation*; and this was followed by the age of *computerisation* of the economy.[3]

These accounts bear an uncanny resemblance to claims for significance made long before any historical analysis could be carried out. One analyst, writing in 1948, thought that the world had already gone through three industrial revolutions associated with particular technologies. The first depended on iron, steam and textiles; the second on chemistry, large industries, steel and new communications; and the third, still under way in 1948, was 'the age of electrification, automatic machinery, electric control over manufacturing processes, air transport, radios and so on'. A fourth was on the way: 'with the coming of intra-atomic energy and supersonic stratospheric aviation we face an even more staggering fourth Industrial Revolution,' he claimed.[4] In the 1950s some believed that there had been a 'scientific revolution' which followed the original industrial revolution. This had started in the early- to mid-twentieth century and was associated with aeroplanes, electronics and atomic power. For others a third industrial revolution, of which the 'warning signs' appeared in the 1940s, was based on nuclear energy and electronically controlled automation.[5] In the Soviet Union the idea of a 'Scientific–Technical Revolution', centred on automation, became Communist party doctrine from the mid-1960s.[6] More recently, analysts have tended to highlight what they see as a radical transition from an industrial society to a post-industrial, or information, society brought about through the actions of the digital computer and the internet. In this context, some economists have developed the idea that economic history has been shaped by a very few 'general-purpose technologies'. The central ones are successively steam power, electricity and now information and communication technologies (ICT).

How seriously should we take these claims for these technologies, and for their significance in these particular periods? The answer is that such accounts, for all that they reflect what we think we know, are not as well founded as might be supposed. They are clearly innovation-centric in their chronology, implying that the impact of the technologies comes with innovation and early use. That is not the only problem. What is the basis for the choice of the general-purpose technologies, and how solidly does it rest? Why the steam engine, for example? Why not the heat engine, ranging from the reciprocating steam engine to petrol and diesel engines, to the gas and steam turbines? Similarly, what does electricity mean? It clearly includes lighting and traction, and perhaps industrial uses. But does it include electronics, where there is hardly a substitute? Can we think of telephony, telegraphy, radio, radar and television without electricity? Yet if 'electricity' is to include these, how does one differentiate 'electricity' from ICT? Which leads to the question, what exactly is meant by ICT? Just as importantly we need to ask why other technologies are not on the list. There are many other pervasive technologies to choose from, from the working of metal (the lathe or the milling machine might be good cases), to synthetic organic chemistry or metallurgy.

While there is enough consistency of choice to suggest a common understanding, there is enough variation in dates and arguments to suggest no detailed analysis of significance lies at the root of these choices. The lack of any surprises in the standard lists of technologies chosen suggests that what they are linked by is high cultural visibility and that they have long been claimed to be central to the history of the twentieth century. The technological boosterism of the past has too often been turned into the history of our material world.

Occasionally radio programmes, magazines or newspapers ask their publics or experts for their choice of the most important invention in history. The results are invariably quirky, easily challengeable and often silly. Part of the British radio-listening public responded to an old-fashioned techno-boosterist series of lectures with a vote that made the bicycle easily the most significant technical innovation since 1800. Water-treatment and supply systems topped the list of most beneficial technologies, and the washing machine was the most significant domestic technology.[7] Such polls have the virtue of forcing us to think and to challenge the consensus views about which technologies have been the most significant.

Assessing technologies

How should claims for technological importance be assessed? First, it is essential to distinguish between the innovation itself and use. In most cases the choice of significant technology is not only highly selective, but dating of significance is highly innovation-centric. The process of invention, development and innovation is sometimes enormously expensive. *Sometimes* these costs are recovered and indeed surpluses made, but the benefits (and sometimes increased costs) come only from *later use*. The time of maximum use is typically decades away from invention, or indeed innovation. For example, electricity and car usage are still increasing, more than a century from innovation. This issue was partly recognised in response to an intriguing problem. The rate of growth of the economies of the rich countries was slower in the 1970s, 1980s and indeed 1990s than it had been in the long boom of the 1950s and 1960s, yet everyone was saying that new technology was changing things radically. As an economist put it, information technology was everywhere except in the productivity data. One reaction was to claim that the data were wrong, they could not capture the transformations wrought by information technology; statistical offices – long used to taking account of quality changes – looked closely at their assumptions and techniques, but decided they were recording the effects. Another response was that the impact of ICT, like that of electricity, would be felt much later than an innovation-centric approach suggested. In other words, the timing of the revolution was all wrong, perhaps by many decades. But the dates are just the beginning of the problem, for it is not just a matter of when, but of which technology, and how big the effect is.

Use is not enough

Significance is not the same as pervasiveness or usefulness. Understanding the difference between use and usefulness, between pervasiveness and significance, is essential. Economic historians of technology have done just this. 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. Thus Robert Fogel assessed the importance of nineteenth-century US railways not by assuming that without them people and goods would be impossible to transport, but by comparing railways with other means of transportation, including canals and horse-drawn wagons. He found, in a rough calculation, that railways increased the output of the US economy as it stood in 1890 by less than 5 per cent of GDP. Since the American economy was growing very fast at the time, this was the equivalent of saying that without railways the US economy would have had to wait until 1891 or 1892 to achieve the output it reached with railways in

1890.[8] Twentieth-century motorisation, or electrification, or the role of civil aviation, has not been subject to such detailed assessments, yet we can imagine productive worlds without the motor car or the aeroplane, (though a world without electricity, in some respects only, is a different matter). Rockets and atomic power, so beloved in the 1950s and 1960s as world-transforming technologies, are as likely to have made the world poorer rather than richer once all the costs and benefits have been computed.

Many object to this kind of counterfactual history – one which invokes something which did not happen – as unsatisfactory. And so it is. Yet it is inescapable if we want to assess significance sensibly. For most assessments already have an implicit, hidden counterfactual assumption which is usually critical to the argument.

The hidden counterfactual assumption which lies behind the equation of use and significance is that there was no alternative. Two anecdotal examples illustrate this: an article in the press imagined what the world would have been like without computers; the conclusion was that it would barely work at all, and therefore that computers were extraordinarily significant.[9] This is the equivalent of asking what would happen if all existing (electronic digital) computers suddenly stopped working. The second example is a television programme of the last years of the twentieth century about a Japanese management guru who believed that the internet was bringing about a new era of global citizenship.[10] This was put to the test by interviewing him in San Francisco, but using the internet. The link kept breaking down, and was in any case of low quality. The presenter poked some mild fun at the unfortunate sage, but missed the real joke. The capacity to communicate with someone in San Francisco has existed for a long time. As far back as the late nineteenth century one could have communicated by telegraph; the long-distance telephone was available from the early twentieth. The message about citizens of the world, the borderless market and so on, would have been the same.

One of the most dramatic changes in price over the twentieth century was that of electronic communication, resulting in drastic reduction in the real costs of telephone calls (some 99 per cent), and making possible the mass transmission of other data (as in the internet). Similarly, the case of the computer-less world assumes no alternative to computers, but we would use alternatives and do things differently. Of course, computers do things better than alternatives, and for many uses of computers there may well be no alternative, but that is exactly what one needs to catch hold of. The question is not what computers do, but how well they do it, and what they can do that cannot be done otherwise.

Precisely because of the fecundity of invention there usually have been comparable alternatives. There were computing machines before electronic computers. Punched-card machines were used for large-scale data processing, mathematical calculations were done with teams of 'computers' calculating with machines, often electric ones. Slide-rules were important tools in the design workshop – the large industrial versions were far removed from those for school use. Digital electronic computers were preceded by mechanical analogue computers, from tide predictors to differential analysers. Electronic analogue computers played a vital role, along with digital computers, in the design of complex systems for decades after the Second World War. Telecommunications existed before the internet: the telegraph continued to carry large amounts of long-distance traffic into the years after the Second World War. The telephone and the radio were widely used. Television by cable and by high-frequency radio transmission has been around for decades. There was sound reproduction before the CD: wax cylinders, shellac and vinyl records, wire and tape recorders all worked. There is more than one way to skin a cat, to fight a war, to generate energy. Yet, these alternatives are often difficult to imagine, even when they exist. I remember asking engineering students in the mid-1980s what alternatives there were to satellites for long-distance telecommunication but they could find none. This was exactly the moment when the world was once again being girdled with cables – not the copper cables with repeaters of the great era of telegraph, but with fibre-optic cables. Alternatives are everywhere, though they are often invisible. Invention, and human ingenuity in using inventions, means that we should compare with alternatives, but because the world changes in so many ways it is extremely difficult to compare with past or alternative worlds.

The hidden counterfactual assumption that there was no alternative is an extreme one; the more common assumption is that there was no comparable alternative: the newest was radically more effective, efficient, powerful and generally better than what it superseded. But to become widely used, a thing does not have to be massively better than what preceded it; it need only be *marginally* better than alternatives (assuming for the moment that better technologies will replace worse ones). In some cases, often taken to be trivial, we understand this without difficulty. The paper-clip is ubiquitous not because it is an earth-shatteringly important technology. Indeed its very ubiquity, simplicity, its unchanging design over decades, the fact that it does not move at huge speed or consume vast quantities of energy, all seem to point to it being a minor technology. Crucially we know we can do without paper-clips. As a result of invention we have a remarkable repertoire of paper-collating technologies, each adapted to very particular uses. There are many ways of holding paper together: pin it, staple it, punch holes and secure it with 'Treasury tags', use Sellotape, put it in a ring-bind or other sort of folder, or bind it into a book.[11] We use paper-clips so much because they are, for many uses, marginally better than alternatives, and we know this.

Technological choice

The assumption that the new is much superior to older methods is widespread. Thus alternating current (AC) electrical systems were assumed to be superior to direct current (DC) systems in the so-called battle of the electrical systems in the late nineteenth century. So they were, in some respects, but not all. In any case, the big choice lay not in an irrefutable demonstration of the superiority of one over the other, but the belief that AC would be better in the long run, a belief that became a self-fulfilling prophecy. Although, in fact, not entirely:

DC systems remained in operation for many years, and new ones were installed. They were also continuously developed in specialist areas. One of the major advantages adduced for AC was the lower cost of transmission, yet in particular cases, for example underwater transmission, high-voltage DC has been used, including in the first and second English Channel electric links between Britain and France, dating back to 1961.

The assumption that the new is clearly superior to what went before has an important corollary: failure to move from one to the other is to be explained by 'conservatism', not to mention stupidity or straightforward ignorance. 'Resistance to new technology' becomes a problem to be addressed by psychologists, sociologists, even historians.[12] But the idea of 'resistance' makes sense only if there are no alternatives. It is absurd to talk of resistance to technology or innovation in a world where individuals or societies simply could not accept every innovation, or indeed product, on offer. Resistance is required. In choosing one technology, society was necessarily resisting *many* 'old' and 'new' alternative technologies. In that sense, many, perhaps most, technologies fail. However, some new technologies were indeed often additions to existing, alternative technologies. The bomber did not do away with armies and navies; the digital computer did not spell the end of the analogue computer until the 1960s.

Historians who have focused on the issue of technological choice point again and again to the availability of competing technologies. For example, in the USA in the early years of the twentieth century, the petrol-powered car was, briefly, less common than either the steam or electric-powered car; indeed in Chicago the electric car dominated. In later years electric cars found niche markets: they accounted for around 20 per cent of motor taxis in Berlin between 1907 and 1918.[13] Before the Great War German fire departments had a strong tendency to choose electric fire engines to replace horses. In mid-century, with the growth of industrial electric vehicles, came the unique British milk float, delivering milk to nearly every household in the land. Yet, while representing a plausible alternative, the electric vehicle generally lost out to the petrol-powered car. Among the many reasons for this was the problem of use outside the range of electrical networks, and the particular problems encountered with battery maintenance.[14] In the world of cars there have been different kinds of internal combustion engine – diesel, petrol and two-stroke; different kinds of body material, including the use of a great deal of wood as late as the 1940s in the USA, and synthetic materials too. A nice example, developed and kept in production for many years in the particular conditions faced in the German Democratic Republic was the Trabant – a car with a resin/wool body and a two-cylinder two-stroke engine. There have been many types of competing road material in the twentieth century, for example, including tarmacadam and cement.[15]

In aviation too there have been many different types of engine and of aeroplane. There were petrol engines and diesel engines and the Soviet Union devoted huge effort to the *steam* aero-engine in the 1930s.[16] Petrol engines came in many varieties: rotary, radial and inline. Jet engines would develop into turbo-prop, turbo-jet and turbo-fan variants. The transition from wood to metal in aircraft construction in the interwar years provides an interesting case of how choices were made. Moving to metal was often taken as an index of technical progress – metal was obviously better, and the quicker designers switched to metal the more advanced they were made to appear. Conversely, late use of wood was seen as the result of some eccentricity. But the assumption that wood was inferior to metal does not hold. What drove the shift from wood to metal was the *belief* that metal was the material of the future and thus inherently more suitable for aircraft, an ideology later subscribed to by historians of aviation. Nevertheless successful wooden aircraft, notably the British Mosquito of the Second World War, continued to be made.[17] Note too that electric cars are making a comeback, and indeed that aircraft structures are now being made of 'composites', similar in principle to the plywood-glue composites used in aircraft in the interwar years.

One other way in which alternatives remain visible once we look for them is in what might be called reserve technologies, to be used if the technology of choice breaks down. They are much less common now in rich countries than in the past because of the increasing reliability of systems. However, even in rich and stable countries houses with electric light would have had paraffin lamps, and indeed candles, in reserve, and a Primus stove for cooking, in addition to an electric or gas range. Ships had hand-powered reserve steering gear, in case the main gear failed; they carried lifeboats with sails and oars. Cars will carry spare tyres, often more primitive than the usual tyres. Typically, but not necessarily, these reserve technologies are older, simpler technologies. This reversion in time of crisis to an earlier, more robust and perhaps lower stage is an interesting reflection perhaps of an evolutionary pattern of thinking about technology. In many societies older technologies, or rather what are seen as old technologies, have a particular place in ceremonial occasions – from the use of candles at dinner, to the parading of troops in nineteenth-century uniforms and sometimes weapons, and the use of horse-drawn hearses in funerals.

Sometimes circumstances forced the use of a reserve technology. For British men around 1960, the preferred method of committing suicide was poisoning using domestic gas, which contained carbon monoxide. From the early 1970s this was no longer possible as methane replaced coal-gas. Partly as a result, use of car-exhaust fumes grew increasingly popular, and in 1990 this briefly became the most common method. The rate then fell sharply, partly because of the spread of catalytic converters, which made exhaust fumes far less lethal. Hanging and strangulation became more commonly used – and by the end of the century were easily the most important methods. This was not by necessity: women preferred solid and liquid poisons.[18]

Assessing aviation and nuclear energy

Private and public bodies have long wanted to assess projects, often in advance of undertaking them. Thus the US Army Corps of Engineers, responsible for water works in America, were instrumental in developing cost-benefit analysis to justify their projects in the early part of the last century.[19] The clinical trial has long been important to doctors and to medical systems, but so have cruder assessments. One interwar doctor claimed that Britain could save 1.67 per cent of its annual national income if instead of treating the common complaint of leg ulcers with bed-rest, a new product, an elasticated plaster (Elastoplast), was used. It is not known whether this saving was realised, but if it was this was surely one of the most important British technologies of the century.[20]

Twentieth-century warfare provides some important cases of the assessment of significance of technologies. In waging war against societies, assessments were made of the significance of particular systems, raw material supplies, industries and so on. What would most effectively incapacitate an enemy, the destruction of its transport, its energy supply, its industry in general or particular industries? What means should be selected to achieve such destruction? Two central cases of such assessments involved the most celebrated and supposedly world-transforming technologies of the century – aviation and nuclear power.

Before the Second World War airmen believed that the new war from the air would be devastating and decisive. The strategic bombing of continental Europe by the RAF and the US Army Air Force, and that of Japan by the USAAF, was the result of such beliefs. A central argument was that modern societies would collapse under the impact of even mild bombing (an argument later transferred to rockets and nuclear weapons). During the war it became clear to some that air power was not necessarily devastating or decisive, leading to acrimonious disputes over the whole bombing effort and/or which targets should be attacked. Sometimes the discussions highlighted the strategic significance of particular industries. Thus there were arguments for attacking ball-bearing production, highly concentrated in a few plants, and manufacturing a product without which motor vehicles could not work; or attacking synthetic oil plants, because without fuel Germany could not fight; or electricity plants and so on. On the eve of the Normandy landings there was a particular debate about how best to help the advancing armies. What should be attacked? German

4. A B-29 bomber drops bombs in the mountains of Korea, early 1951. Although the USA did not use B-29s to drop atomic bombs against what they called the 'communist hordes' in Korea, they devastated the country. Regrettably, more attention is given to the non-use of atomic bombs in this war than the terrible effects of the bombing. Yet, for all the destruction, the USA did not win the Korean War.

industry as a whole, the oil industry or transportation? If the latter, how should it be attacked? Should one attack road and rail bridges or marshalling yards and repair depots? The former were difficult to destroy, but remained so, the latter were easily hit, but were quickly repairable.[21] The commander of the British bomber forces between 1942 and 1945, Sir Arthur 'Butcher' Harris, dismissed precision attacks on particular plants and industries as 'panaceas'; he argued that the only effective targets were whole cities.

There was a broader question: how significant was the bomber? In 1945 Sir Arthur Harris claimed that 'the heavy bomber did more than any other single weapon to win this War', adding that, while the key technologies of a future war would change, the 'quickest way of winning the War will still be to devastate the enemy's industry and thus destroy his war potential'.[22] In his final despatch the British commander used a series of tables and graphs of tonnage of bombs dropped to make his case. He showed that nearly 1 million tons of bombs were dropped by the RAF, some 45 per cent on 'industrial towns'. The index of success was the 'total acreage of devastation' in the target built-up areas of Germany; by the end of the war 48 per cent of them were 'devastated' or 'destroyed' by RAF bombs alone. Harris produced practically no graphical information or data on the effects of bombing on industrial production, or on the effects of attacking synthetic oil or transportation, both of which he had been against. Nor did he consider alternative strategies, except in two cases. He claimed that between April and September 1944, when Bomber Command was, in his view, distracted from 'its proper strategic role', that is diverted to attacking transportation and the German army around D-Day, Germany was able to reorganise war production and increase the supply of armament, particularly of new weapons.[23] Secondly, he claimed that, without bombing, Germany could have used the 2 million workers in anti-aircraft forces and engaged in repairing bomb damage to make arms instead. Relying on the evidence of the captured German armament minister Albert Speer, he claimed Germany could have increased production of anti-tank and field guns by around 30 per cent.[24] In his interrogation Speer claimed that in 1944 30 per cent of output of guns was for anti-aircraft use, as were 20 per cent of heavy shells, 50–55 per cent of the 'electrotechnical industry' and 30 per cent of the optical industry.[25]

However, Harris's claims were to be subject to devastating attack as a result of one of the greatest ever retrospective technology assessment exercises. As the land armies moved in to the bombed areas, they were joined by investigators from the US Strategic Bombing Survey. The survey was led by the head of the Prudential Insurance Company: the monstrous effort involved 350 officers, 300 civilians and 500 enlisted men.[26] The USSBS came out against the RAF and its predominant practice of area bombing, but particular reports supported the attacks on transportation and synthetic oil. They claimed that the bombing of cities had a negligible impact on production, whereas the crippling of transport and synthetic oil production had effects felt right across the German war machine.[27] Everywhere was evidence which contradicted important claims. For example, in 1944 only some 13 per cent of Germany's heavy guns (over 75mm) were anti-aircraft guns. Furthermore, compared with 1943, the proportion of anti-aircraft guns was falling, contrary to the confident assertions of the bomber and the bombed.[28]

The assessment made by the USSBS of the bombing effort against Japan was specially striking. The bombing of the Japanese home islands was much less heavy than that of Germany: 160,000 tons of bombs were dropped rather than the 1,360,000 tons which fell within Germany's borders.[29] Yet, the damage was similar because the bombs were more concentrated in time and more accurately delivered. Some 40 per cent of the built-up area of the sixty-six cities attacked was destroyed. And yet, the effects on the economy were not clear cut because of the repercussions of another form of attack on Japan – blockade. 'Japan's economy was in large measure being destroyed twice over, once by cutting off of imports, and secondly by air attack', reported the USSBS. Even *without* any bombing, war production would have been halved by 1945.[30]

The USSBS also made a devastating comparison between the two instances of atomic bombing and conventional bombing, as it came to be known later. They estimated that the Hiroshima bomb did the same damage as '220 B-29s carrying 1,200 tons of incendiary bombs, 400 tons of high-explosive bombs, and 500 tons of anti-personnel fragmentation bombs', while the Nagasaki bomb was the equivalent of '125 B-29s carrying 1,200 tons of bombs'.[31] In another measure they concluded that the atomic bomb 'raises the destructive power of a single bomber by a factor of somewhere between 50 and 250 times'.[32] That gives an effective TNT equivalence of an atomic bomb at something in the range of 500 to 2,500 tons, rather than the usually quoted 10–20,000 tons of TNT. The difference arises because most of the huge explosive power of an atomic bomb was not directed at the target. What the report was suggesting was that an atomic raid did the same sort of damage as a standard large conventional one, a few per cent at most of the destruction meted out to Japan from the air. The designers of the bomb would not have been surprised. In May 1945 a key committee meeting at Los Alamos was told that 'one atomic bomb on an arsenal would not be much different from the effect caused by any Air Corps strike of present dimensions'.[33] This knowledge was critical in target selection, since potential atomic targets had to be 'likely to be unattacked by next August'; the meeting was told of a 'list of five targets which the Air Forces would be willing to *reserve for our use* unless unforeseen circumstances arise [emphasis added]'. Four were selected – Kyoto, Hiroshima, Yokohama and Kokura Arsenal – and 'reservations for these targets' were requested.[34] Atomic bombs showed their destructive capabilities only because alternatives were kept out of play. We should not, however, underestimate the point that they were weapons of mass terror as well as mass destruction.

The atomic bombs were the product of an industrial effort which cost just under $2bn ($20bn in 1996 dollars). One billion dollars to destroy a city which would have been destroyed at minimal additional cost by one conventional raid represented an awful lot of 'bucks per bang'. Another way to look at it is that it cost $3bn to manufacture the 4,000 or so B-29s which were used exclusively in long-range operations against Japan, including as atomic bombers. This figure included their spare parts, but excluded maintenance, fuel, weapon and staffing costs, as well as the cost of building and running airfields.[35] Another index was that the total cost of the atomic bombs was the equivalent of making one-third more tanks or five times more heavy guns.[36] It is not difficult to imagine what thousands more B-29s, one-third more tanks or five times more artillery, or some other military output, would have done to Allied fighting power. Might it not have shortened the war considerably? In other words, by reducing the conventional material available, the atomic programme, it could be argued, lengthened the war and this cost lives. That we do not see this is partly the result of a carefully fabricated myth put about after the war, that the bomb brought the war to a quick end and *saved* no fewer than 1 million US lives.[37] This myth depended on the dubious counterfactual argument that the Japanese would have fought on and on had they not suffered atomic bombing, and that the only other way of defeating them involved an invasion that would cost 1 million lives. In other words, this argument assumed that blockade and conventional bombing were ineffective by comparison with the atomic bomb. Yet Japan was very close to surrender before the bombs were dropped. The crucial factors which led to surrender were the entry of the Soviet Union into the war against them, and the change in the terms of surrender being offered, a change which came *after* the atomic bombs were dropped. The bombs may have made surrender easier, but not more likely. They did not end either the war, or war in general.

The German V-2 project, another huge wartime undertaking, was also economically and militarily irrational, and this too was obvious to some at the time. British scientific intelligence suggested the Germans were building a rocket of around 10 tons, with a warhead of around 1 ton. This estimate, which proved correct, was controversial because it was not cost-effective to build missiles that could fly 200 miles and deliver one ton of explosive once, when you could build aeroplanes which could deliver ten times that, again and again, over greater ranges. And yet, that is exactly what the Germans did.[38] In October 1942 the V-2 was successfully tested. Two years later, the first V-2 was fired in anger, and around twenty were being built a day. The V-2 'was a unique weapon', says its historian, Michael Neufeld, in that 'more people died producing it than died from being hit by it': at least 10,000 slave labourers perished in the course of production and around 5,000 from it.[39] Nearly 6,000 V-2s were made so that, very crudely, it took two human lives to make a V-2 and each killed one person. It is estimated that instead of V-2s Germany could have built 24,000 fighter aircraft.

The total cost of development and production of the V-2 was around $500m, about a quarter of the US atomic bomb project. Yet the destructive power of *all* the V-2s produced amounted to less than could be achieved by a single raid on a city by the RAF or the USAAF. The 'United Nations', as twenty-six and then more, anti-Axis Allies were known from 1942, should have been grateful to Werner von Braun, Albert Speer and Adolf Hitler for supporting a technology this draining to their own war effort. However, the Axis should have been even more grateful to General Groves and the atomic scientists for coming up with the most expensive explosive ever created. There is a terrible symmetry here since the US produced only four atomic bombs during the war, each of the destructive capacity of a conventional raid – in other words, the bang per buck was identical at $500m per destroyed city. Of course, had the war continued longer, the economics would have made a little more sense, as the capital cost had been spent. Nevertheless the costs per bomb or rocket were still huge. Had the war extirpated militarism from the world and had the development of weapons stopped, the rocket and the A-bomb would not have been seen as harbingers of the future, but more likely as the last dreadful examples of the irrationality of war and military technology.

Within the context of the unprecedented peacetime militarism which followed the Second World War, both the rocket and bomb were *later* to make a certain sort of sense. For the combination of the rocket and the *hydrogen* bomb, which was in a quite different class of destructive power from the A-Bomb, was to make sense in bang-per-buck terms, simply because destructive power increased so much. To that extent the atomic bomb and V-2 cases illustrate the short-sightedness of focusing only on the early stages of a technology (though both were put into production on a huge scale in wartime). We have, in other words, an example of the distinction to be made between what is efficient at a given time and what may be more efficient over time, what economists call static and dynamic efficiency.

Yet the post-war US atomic programme, including bombers and missiles, although capable of immense destruction, was not cheap: nearly $6,000bn (in 1996 prices) were spent between 1940 and 1996.

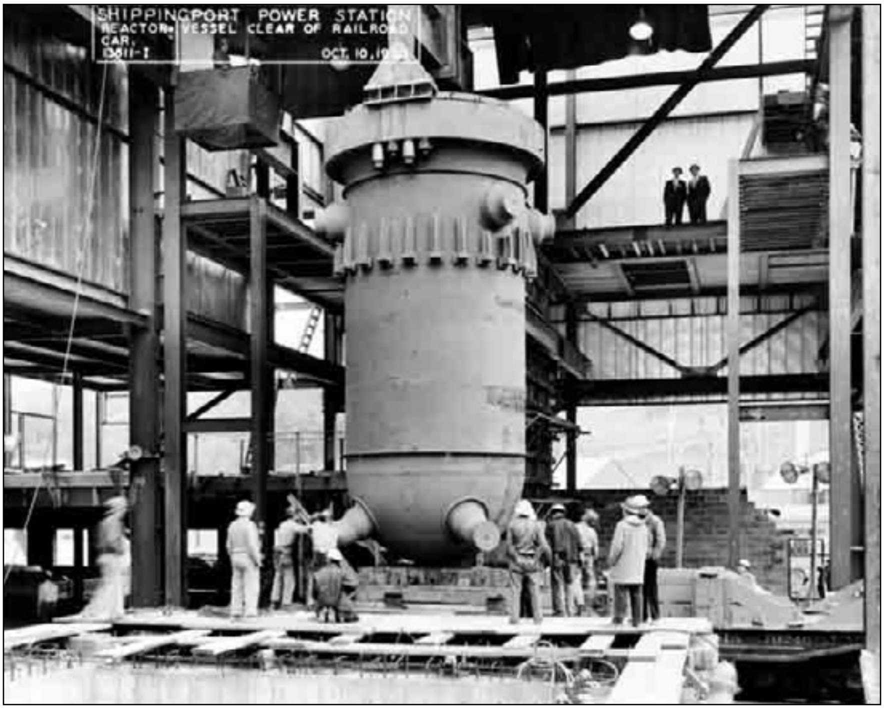
That was about one-third of all defence expenditure and just under the total spent on social security by the United States.[40] So powerful was this arsenal that it could not be used, so at this point we have to throw away our use criterion of significance. Its utility, to the extent it had any, was in preventing certain actions by others. Yet, for the Chinese Communists, famously, atomic weapons were 'paper tigers', although they too built them.

Spin-off

One of the most common responses to claims that a particular technology has not had the powerful positive effect it was claimed to have has been to suggest that there have been significant secondary effects not captured by the direct assessment. Thus one response to the claim that railways were not *that* important to economic development was to point to the stimulating effect they had on other industries such as engineering, iron and steel, and telegraphy. The term 'spin-off' is used to describe this effect. The significance of spin-off has not been properly assessed, for it was a propagandistic argument which few in the know took seriously. One important feature of spin-off arguments is that they tend to be associated, with no convincing evidence, with technologies which are already for other reasons regarded as fundamental. Aviation, rockets and nuclear power were all key cases.

One of the most famous examples, even if regarded with some derision, was that the US space programme spun-off Teflon, a new plastic which found an important use in coating frying pans to make them non-stick. Such arguments were important since there was no economic utility in civil space missions until quite recently. Of course, the civil space programme had other purposes, such as providing entertainment, propaganda and a welcome distraction from more pressing and tedious problems, but these were not aims the promoters would have emphasised. Teflon was hardly enough of a justification for its enormous cost.

Interestingly the origin of Teflon, or PTFE, had nothing to do with the space programme. It had been known and used for decades before



5. Building the Shippingport nuclear reactor, the first commercial reactor in the United States, on the Ohio River, around twenty-five miles from Pittsburgh, Pennsylvania. Based on a reactor designed for an aircraft carrier, it was classic spin-off technology: a military technology applied to civil uses. A long-lived machine, it was built in 1957 and remained in use until 1982. However, the 'atomic age' never materialised.

the 1960s, and was even used for coating frying pans. The DuPont company invented it in 1938; it was given its name and first sold in 1945.[41] Its main wartime use had been in the bomb-production programme. The Teflon non-stick frying pan was invented in France in 1954 by Marc Grégoire, and launched by a new French company called Tefal (TEFlon + ALuminium) in 1956; by 1961 Tefal was selling 1 million a month in the USA alone.[42] NASA maintains a website and publishes a magazine called *Spin-off* yet Teflon is nowhere mentioned, though NASA claims parentage of cordless power-tools, ribbed swimsuits, and important improvements in pacemakers, laser angioplasty, digital signal processing, smoke detectors, bicycle helmets, baby formula and much more besides.

Remarkable as it might seem, some spin-offs have themselves had negative effects on the wealth of nations. In 1956 the British started generating electricity using power from a nuclear reactor the main aim of which was producing plutonium for atomic bombs. This was misleadingly hailed as the first commercial nuclear reactor in the world.[43] Britain already had the most ambitious civil nuclear power plans in the world, and would generate more nuclear power than any other country for the next decade. The first British programme was based on the Magnox reactors. Some are still in operation today, with the last due to close in 2010, giving these machines lives of around forty years. As early as 1965 a decision had to be taken on the next generation of reactors, and the advanced gas-cooled reactor was chosen. Construction started in the 1960s; the first was completed in 1976, the last in 1989. They all still operate, and the last will be decommissioned in 2023. The AGR programme was enormously expensive and led to a net loss to Britain, compared with the costs of using other nuclear, and indeed non-nuclear, technologies. Compared to a hypothetical pressurised water reactor (PWR) programme the total loss was predicted to be around £2bn in 1975 prices.[44] When the electricity industry was privatised, the Magnox reactors could not be sold; the AGRs were effectively given away free.

A second great project of the 1960s derived from military precedents, the Anglo-French supersonic airliner Concorde, was also, according to cost-benefit analysis, a dreadful waste of money. The prototype flew in 1969, and commercial, if that is the right term, flights started in 1976. Would there be any returns? The airlines said that they could not fly Concorde profitably even if it was given to them for nothing, as effectively happened in the cases of British Airways and Air France, who operated them for around thirty years. Worthwhile spin-offs from the Concorde project or the civil nuclear programme are hard to find.

It is significant that these are big, controversial technologies, funded, organised and deployed by states. One result is that many associate the state with horrendously bad technological judgement, while civil society, and markets in particular, it is assumed, will make better decisions. In civil society the question of significance is left to anonymous and multiple calculators. Yet large corporations have great powers of decision and it does not follow that lots of competing decision-makers will give better results. For they make their judgements on the basis of givens which they might not themselves control. The outcome of many such small decisions can add up to an overall negative outcome by comparison with the alternatives. The effect is much harder to calculate, and there is less incentive to do so. Yet it is often claimed, for example, that the motorisation of the world through mass car ownership is not the optimal use of resources. Public transport could, it is argued, yield a better outcome.

Small technologies and big effects

At first blush contraception is associated, at least when we think of technologies of contraception, with the oral contraceptive Pill. The Pill is regarded as important not just because it is a powerful contraceptive, but because it is often held to have initiated a sexual revolution. In the rich countries of the world that sexual revolution was real enough, so the claim that it was brought about by the use of synthetic steroidal hormones is a striking case of how something small and mundane can trigger extraordinary change. What exactly the Pill did is far from clear. When the Pill is linked directly with the sexual revolution, one can easily detect the assumption that either there were no alternatives to the Pill as a contraceptive or that the alternatives were much inferior. The history of these alternatives is, by comparison, hardly known. While the Pill is the subject of a vast literature, the condom and the many other mundane birth-control technologies are rarely made central to the history of contraception.[45] Yet contraception provides a wonderful example of the long existence of many alternative means, the significance of declining and disappearing technologies, and of re-emerging 'old' technologies.

Fertility control, birth control and contraception have all been practised by different means for a long time. In the twentieth century there were several birth-control techniques from abortion to sterilisation, withdrawal, many forms of rubber contraceptives and chemical ones too. Several of them were, for much of the century, illegal in many parts of the world, and nearly everywhere were hidden from public view. Knowing what went on, having any indication of the use of the various methods, is extremely difficult.

One of the most important forms of contraception appears to have been the condom. The condom was associated with the barber shop and the barracks, and the prevention of disease, and was for many decades the product of a semi-underground industry. From the 1930s condoms could be mass produced by dipping glass moulds into latex solution. They could be turned out by the billion, and made cheaply and thinly enough to be disposable. US condom production was 1.4 million daily in 1931 and increased rapidly, so that in post-war America they were widely used. After the Second World War, helped doubtless by the issuing of condoms to troops, contraceptive condom usage went up strongly. For example, annual British sales increased steadily from around 43 million in 1949, to 150 million in the late 1960s.[46] Clearly condoms were not used in the majority of sexual encounters.

Condoms were, however, just one of many contraceptive technologies. Alongside them there were all sorts of feminine contraceptive technologies available from a semi-underground market – products such as abortificients, spermicides, douches and more besides, including sterilisation. In the USA in the 1930s sales of such technologies were about the same as those of condoms. The famous birth-control campaigners operating in interwar Britain and the USA, Marie Stopes and Margaret Sanger, promoted a particular kind of feminine rubber technology, the diaphragm and the cap. They were under the control of women, and were respectable in ways in which condoms were not; they also required medical intervention. The aim of these campaigners was to medicalise and feminise contraception. Margaret

Sanger went on to be a key figure in promoting the research that led to the contraceptive Pill, which would be manufactured by the pharmaceutical industry and prescribed by doctors. It was available in the USA from the late 1950s, and licensed for contraceptive purposes in 1960.

The Pill had enormous success. It did not just add to contraception technology but led to the decline of other barely visible contraceptive technologies. In the USA condom sales were falling rapidly in the early 1960s, and by the late 1960s the Pill was a more common form of contraception than the condom. In Britain condom use fell from the early 1970s. The Pill was more effective than previous contraceptives, did not involve the intercession of vulcanised rubber in the mingling of body fluids, and crucially its use was separated in time from sex, all vital qualities which did not affect its contraceptive power, but had a huge impact on its desirability. Also important was the fact that the Pill was the only contraceptive technology that could be, and was, talked about in public.

The Pill made contraception public and respectable in ways unimaginable before it burst on to the scene, and therein lay at least part of its power to help transform sexual relations. The link between Pill availability and sexual behaviour is the subject of debate: there is no clear-cut conclusion to be drawn about its relationship to the sexual revolution; the main novelty was sex between people who did not intend to marry each other, rather than pre-marital sex per se. Its relationship to the use of other techniques in relation to sexual behaviour is unexplored.[47] It is implausible, however, to suggest that the contraceptive Pill was the only available technical means which could have brought about the sexual revolution.

Suggestive is the fact that in the post-sexual revolution era pre-Pill contraceptives did not disappear. After the Pill, there was more research than ever in contraception, leading to the development of competing technologies, including the IUD.[48] The condom is an example of a growing, disappearing and reappearing technology. Sales increased rapidly from the 1980s in the wake of AIDS, a phenomenon which made the condom, for the first time, as mentionable as the Pill. World condom production capacity increased from 4.9 billion in 1981 to 12 billion per annum in the mid-1990s. There was, as one might expect, technological innovation in condoms, with the first anatomically shaped one produced in 1969, the spermicide-lubricated in 1974, and more since. In 2004 the Durex brand celebrated seventy-five years of history with the slogan '75 years of great sex'.

Malaria

The control of malaria, like birth control, has been done in many different ways. As in the case of the Pill, the significance of any particular method needs to be looked at in relation to other methods, not a hypothetical world where malaria was uncontrollable. The re-emergence of diseases thought to have been mastered, like malaria, or cholera or TB, has led to renewed use of old techniques of dealing with them, as well as new ways.[49] Malaria was, and is, one of the most serious diseases on a world scale. It was not, as it now is, confined to tropical regions, but endemic in many temperate areas (for example southern Italy) in the first half of the twentieth century. Malaria was treatable, and it could be controlled with prophylactic doses of treatments, or by eliminating the mosquitoes which carried it. The standard treatment used a natural product, quinine, which the Dutch empire came to control through ownership of plantations in their colony of Java. Synthetic alternatives began to be explored, particularly in Germany. In the 1930s Atebrin (mepacrine) was developed, but because it made the skin go yellow was not much used. However, the loss of the Dutch East Indies to the Japanese in the Second World War forced the Allies to use it, as a prophylactic and treatment. There was a large programme of anti-malarial research during the war which led to three drugs which would be widely used post-war in treatment and as prophylactics: chloroquine (already made and dismissed by the Germans in the 1930s), amodiaquine and proguanil (paludrine). In Syria and in former French colonies in Africa, chloroquine was used in mass prophylaxis in the 1970s in an attempt to eradicate the disease, but the result was increased levels of resistance.[50]

But drugs are just part of the story. Insecticides and the elimination of insect-breeding grounds by controlling water flows and ensuring good drainage had proved to be effective too. Indeed just such multiple measures had already succeeded in eliminating malaria from many parts of the world. But malaria control is particularly associated with DDT. DDT was developed by Ciba-Geigy in Switzerland but taken up on a huge scale by the Americans, not just to deal with malaria, but also with the lice that transmit typhus, notably during the Second World War. Its inventor, Dr Paul Müller, was awarded the Nobel prize for medicine and physiology in 1948. The British developed another powerful new insecticide, Gammexane, though this was less used. In 1944 it was announced that in the Pacific General MacArthur had won 'one of the greatest victories … a victory by Science and discipline over the anopheles mosquito', not surprisingly, since before this malaria had accounted for about ten times as many casualties in soldiers as combat.[51] After the war DDT was widely used to try to eradicate malarial mosquitoes. What DDT offered was not malaria-eradication, but a cheap, quick means of killing mosquitoes, which did not require such detailed and prolonged intervention: it was a low-maintenance option.[52]

But precisely that lack of depth of intervention was probably critical in allowing malaria to survive, and indeed later to expand, as systems of surveillance were weak and further weakened. The late 1950s saw the start of a global programme to eradicate malaria from the areas in which it was still found, excepting sub-Saharan Africa. The programme was based on a 'spraygun war' with DDT, but, though initially successful, it lost momentum in the late 1960s. In India in 1951 there were 75 million cases, and 800,000 people died of the disease. DDT spraying starting in 1953 and the army of spraymen brought malaria cases down to 50,000 in 1961. But new outbreaks were not policed or dealt with, leading to an increase later. By 1965 cases had doubled to 100,000, rising right through the 1960s and early 1970s, to reach perhaps 50 million in the late 1970s. As a result 'WHO began to resurrect older tactics that had been superseded by miracle pesticides … the whole rusty arsenal reappeared.'[53] The production of old drugs had to be stepped up and new variations brought in, with renewed attention given to netting.

In the world as a whole, the motor vehicle is just behind malaria in the list of killers, a sobering measure of the significance of a technology. Three times as many people (nearly 200,000 out of a world total of around 1 million a year) die in Africa from car accidents as in the whole of Europe. In Africa the death rate per car on the road is up to forty times greater than in the rich countries. Even though there are many fewer cars in Africa than Europe, they kill nearly three times as many people, corrected for population, than in the rich countries of Europe. In Kenya, road accidents are the third cause of death after malaria and HIV/AIDS. But this linking of malaria and the motor car tells us that our sense of technological time needs adjusting, and it is to that topic that we now turn. For malaria has been increasing in Africa, not because Africa is reverting in time, but because it has been entering a new future, one not envisaged in the old models.