1. Innovation

1.1 INTRODUCTION

Robots and automation figure at the end of a long line of innovations. In the past, innovation has, by and large, been positive for the world. There have been some problems, some as the result of side effects as with the steam and petrol engines and subsequent carbon dioxide emissions. Other problems, such as with nuclear power, are due to man’s ability to use innovation for both good and evil. However, innovation has facilitated an ever-increasing standard of living, not just in providing more and better quality goods, but new goods and new opportunities. Hence today we can communicate with people on the other side of the world visually as well as with mobile phones. We can then travel to the other side of the world in a few hours, or if we prefer watch a football match in another country from the comfort of our armchairs.

Innovation has been with humans from the very beginnings of their time on Earth. The use of fire to cook and to warm, the spear and the bow and arrow, agriculture, the plough, bronze, iron and the wheel, all had major impacts on human development, just as innovation continues to do so today. It has also been true that innovation has changed societies. The onset of farming fundamentally changed society, and, somewhat later, the printing press facilitated the reformation. But if innovation has been with us since our early beginnings on this planet, its pace is quickening. Today we seem to get major innovations if not every decade then at least every two decades. It is also noticeable how innovations are often linked. It is relatively seldom for a major innovation to appear without it having built substantially on the work of others. For example, the first commercially successful helicopter was designed in 1939 by Sikorsky. However the first piloted helicopter had been developed some 32 years earlier by Paul Cornu. But the concept can be traced all the way back to Da Vinci – a link that can also be made with robots. It
is also apparent how innovation has tended to be focused on specific countries at different times. Hence in the period 1700–1950 many of the world’s major innovations were born in the United Kingdom (UK). Since 1950, the USA, and in particular the West Coast, has been critical.

Some innovations have a fixed life cycle and are then replaced, as the word processor replaced the typewriter. Some are reborn under new, more advanced guises, as with the windmill, which today is a significant generator of electrical power. Initially most innovations were process innovations – new and more efficient ways of doing things. But the average man in 1500 was living pretty much as the average man in 200. The major difference was one of quality and quantity facilitated by innovation, but the basic consumer goods of food, drink and clothing were essentially the same. The way food was cooked was also essentially the same. Sea travel had progressed considerably with navigational aids, but wind was still its energy source. Land travel still essentially involved the horse. Some limited progress had been made on the medical front and man was more efficient at warfare. But, in the late eighteenth century we begin to get more of a change. The railway was a revolution in transport, a fundamental innovation that had enormous spillover effects. Equally, somewhat later, the telegraph revolutionised communication.

Then, around the beginning of the twentieth century, another revolution took place. Innovation was changing people’s lives not by supplying more and better quality of what had been their lot for hundreds of years, but by changing that lot. The vacuum cleaner was invented in 1901, the first of the household goods that would transform women’s role in society. A few years earlier the first motorised vehicles appeared and these would provide freedom of movement, at first to a privileged few such as Mr Toad, but then to the masses. This freedom was eventually translated to the air, courtesy not just of the Wright Brothers but also the low cost airlines. Now, at the beginning of the twenty-first century, we have become used to the idea that our lives will constantly undergo revolution, that just as 30 years ago we wrote letters, searched for telephone boxes and used paper maps to find our way around, so in 30 years’ time things we do now will become revolutionised.
1.2 THE PROCESS OF INNOVATION

In a sense, Schumpeter is to the supply side of economics what Keynes is to the demand side. Both economists were born in the same year, both were giants of their and any age. Initially Keynes’ work had the greater impact, certainly from 1940 onwards, but Schumpeter’s work endures, still inspiring economists and setting the tone for much of today’s research agenda. Schumpeter’s view of innovation was that a discovery could be made at a certain time, but it was unlikely to be developed by entrepreneurs until old technologies had reached the end of their life and firms were having difficulty making profits. At this time entrepreneurs would be receptive to new ideas.

Major or blockbuster innovations are innovations of the first order that either provide a revolutionary new product or a revolutionary new way of making existing products. In their wake, more minor innovations follow. The new technology opens up new possibilities. Because they are new, there are no existing firms in the field and it is often the small-scale entrepreneur who seizes the opportunity, although they often do not stay small. Many entrepreneurs come in at the second stage of innovation, for example with the railways, the hoteliers, and in the wake of artificial intelligence and the Web came Facebook and Google. In general, process innovations often pose a threat to jobs. Product innovations may also pose such a threat, for example the railway replaced the canals and the stagecoach, but they also create new ones and often there is no product being replaced: the innovated product is entirely new. Eventually this new wave of innovations will have reached its full potential and once more the process begins. Thus the entrepreneur is at the heart of innovation. Sometimes they are the inventor who brings their product to the market place. Sometimes they make use of someone else’s research and bring that to market. Schumpeter at different times thought innovation was best served by small firms, as with Steve Jobs working in his Californian garage, or by large firms, such as Apple, who have substantial resources to throw at innovation.

A general purpose technology or GPT is a particular form of blockbuster technology. Specifically, it is an innovative method of producing, important enough to have a substantial and prolonged aggregate impact. It has also been defined as a technology that becomes pervasive, improves over time, and generates complementary innovation (Bresnahan and Trajtenberg, 1995). Sachs (2018)
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argues that GPTs result in deep structural changes, raise GDP, disrupt production processes and restructure labour markets. They impact on the distribution of income and wealth and change human geography and demography. Both steam and electricity would be regarded as GPTs.

Until the 1990s, the linear model of innovation policy was dominant. This viewed technical change as happening in a linear fashion from invention to innovation to diffusion. It led to an emphasis on research and development (R&D) infrastructure provision, financial innovation support for companies, and technology transfer. Variants of the linear model include technology push and market pull models. The stages of the former in the original linear model are shown in Figure 1.1. Basic science is the start of the process, followed by the design and engineering, manufacturing, marketing and sales stages. However, this model tended to ignore prices and other changes in economic conditions that affect the profitability of innovations. Thus, the market pull model starts with the identification of a market need first, followed by technology and product development, production, and marketing. The sequence seems similar, but the implications are different. The first presupposes that the basic impetus for new development comes from the scientist, the second that it comes from market forces. It presupposes that innovation can be ‘made to order’, that once a gap has been identified someone will fill that gap with a suitable technology. Sometimes this is the case; sometimes less so. In reality, both forms of innovation are possible in the real world and the scientist can develop a new technology that the entrepreneur sees as filling a gap – in some cases a previously unrealised gap.

Innovation can also come about through a change in the environment that forces innovation on the private sector, which may happen without any external policy intervention. The case of the sweet potato in Uganda illustrates this (Hall and Clark, 2010). The onset
of disease forced a shift from cassava to the sweet potato not only as a source of food but also as a cash crop. Farmers experimented with, and introduced, new varieties of sweet potato and also developed new products for the market. Much of this they did on their own initiative with little outside help. It required changes not just in economic production, but in diet and culture, and without the necessity of survival forcing change it would not have happened. Policy still has an important potential, if often unrealised, role in: (1) supplementing the limited knowledge and resources of, in this case, farmers; and (2) shifting the boundaries and constraints that limit endogenous innovation. For example in this case, the research institutes should have been immediately focused on this problem and in dialogue with the farmers. They were not. It also illustrates something that is often forgotten in the literature: that innovation is a global phenomenon and has no less a part to play in developing countries than in richer ones.

Since the turn of the twenty-first century a new understanding of the nature of the innovation process has emerged, which stresses its systemic and interactive character (Todtling and Trippl, 2005). The emphasis on feedbacks, interactions and networks was incompatible with the linear model where the flow is uni-directional (Freeman and Louca, 2001). This approach offers a less deterministic version of the technology push argument, while still emphasising the role of science and technology. It also stresses that the first stage can come from either internally generated knowledge or knowledge acquired from outside the firm. The innovation systems approach argues that innovation should be seen as an evolutionary, non-linear and interactive process, requiring intensive communication and collaboration within firms and between firms and universities, innovation centres, financial institutions, standards setting bodies, industry associations and government agencies. End users too can provide vital feedback. This approach has led to a realisation that there should be a shift away from the traditional firm-oriented perspective towards a more holistic view and one that emphasises inter-organisational arrangements, that is, a move towards a more system-centred approach of innovation policy (Nauwelaers and Wintjes, 2003). This is particularly the case when the innovation is combining science from different fields such as robotics and nanotechnology, or even robotics itself. This does not mean that focusing on R&D and on the technological aspects of innovation is the wrong policy, but that it
The robot revolution needs to be complemented with the other aspects of innovation such as organisational, financial, skill and commercial. The Triple Helix model of innovation brings university, industry and governments together (Etzkowitz and Leydesdorff, 1995). One of the underlying ideas is that in a knowledge-based economy, the potential for innovation and economic development lies in a prominent role for the university. It also allows for the joining of agents from university, industry and government to generate new institutional forms for the production, transfer and application of knowledge. Hence the Triple Helix incorporates a wide diversity of approaches.

1.3 THE STAGES OF INNOVATION

There is relatively little disagreement as to the building blocks of innovation as expressed in Figure 1.1, although some might add more blocks. But the disagreement tends to focus on how they are related and inter-related. Thus, in this section we will examine these building blocks and then turn to the relationships between them. The building block over which there is probably most disagreement, or if not disagreement then variation in perspectives, is that relating to basic science.

1.3.1 Basic Science: Discovery

Invention can arise from: (1) scientific curiosity and ego; (2) need; and (3) a search for profits. The discovery of Vecro provides an example of the first of these. The Swiss engineer, George de Mestral, found seed pods sticking to his socks. Motivated by curiosity, he discovered the pods had small hooks that had caught themselves into the wool of the socks. He reproduced these hooks in woven nylon as a way of fastening clothing together instead of buttons and zips. One thing led to another, and this included joining the chambers of an artificial heart and securing objects in space with zero gravity. ‘Need-driven innovation’ is where there is a specific problem that needs solving and scientific resources are devoted to solving that problem. ‘Curiosity-driven innovation’ often happens by accident. As such it is more difficult to model than need-driven invention. An example of profit-driven invention is when a firm has a research arm, which is given the specific instructions of finding new discoveries with the potential to generate profits.
A combination of need-driven and ‘accidental invention’ is the ‘unintended consequences invention’. A specific invention opens up new possibilities. The original invention was not driven by a need to open up these new possibilities – they happened. The need can reflect a problem that needs solving or a cheaper and more efficient way of doing something. Once the need has been identified, resources are devoted to discovering a solution. It is not simply that the resources are devoted at this objective and a solution found in an almost mechanistic way. Sometimes this is the case, but often a feat of imagination or some blinding insight is a critical part of the process. But this insight would not have happened unless the focus of attention had not been devoted to the problem. Of course, this insight is often a rough diamond and still needs considerable work before it can be presented as a working solution to the original problem.

An example is mobile finance. This possibility was opened up by the mobile phone. This is illustrated with respect to Kenya. Mobile phones have revolutionised telecommunications in Kenya and from a very low base. At the end of the fourth quarter of the 2016–17 financial year, mobile phone coverage was 88.7 per cent of the population. There were 28.0 million active mobile money subscriptions and a total of 480.5 million transactions amounting to 96.4 billion US$ in this fourth quarter. In addition, goods and services purchased over mobile platforms amounted to 6.6 billion US$. Person-to-person transfers were valued at 5.2 billion US$.1 This has transformed the Kenyan economy, facilitated the growth of small businesses, increased the transfer of funds to rural communities and extended financial inclusion to millions. At the heart of this revolution is the M-Pesa system for money transfer and financial services. This permits users to swap cash for ‘e-float’ on their phones, which they can then send to other mobile phone users, who can exchange the e-float back into cash. This developed from research funded by the UK’s Department for International Development (DFID), who observed that Kenyans were transferring mobile airtime as a substitute for money. Together with a UK private mobile service provider they filled this gap. Hence this is an example of one innovation (the mobile phone) leading to another (mobile financial services). It is

also an example of how market opportunity, government involvement and private sector firms are often interconnected in innovation. The identification of need at the corporate level can be a widely recognised need on which other firms are also working, as with new drugs to meet specific diseases, or it can be something unique to the firm itself. In the latter case the identification of need is a critical part of the innovation process and is the first stage where imagination plays a critical role. Examples include the invention of cat’s eyes by Percy Shaw in 1933 to help with the problem of unlit roads following the advent of the car. In this case the realisation of need and the outline of a potential solution came at the same time. Shaw had been using the polished strips of steel tramlines to navigate, something he realised when the tram lines were pulled up. Hence potential solution and need appeared at one and the same time. The exact process by which intuition takes place and insights are formed is more in the realm of psychology than economics. One example is that of bisociation (Koestler, 1964) a process by which two apparently unconnected ideas are linked.

1.3.2 Development

The ‘valley of death’ is the stage between a new invention or discovery being translated into a product or service. The company needs to find sufficient money to develop the prototype until it can generate sufficient cash, through sales to customers, which would allow it to be self-sufficient and grow. Many do not cross the valley, hence its name. One reason for this failure is linked with an inability to attract sufficient finance to develop the project. Another feature of the valley is that often when crossed, we find ourselves in another country from where the research was done, with the finance coming from foreign firms. Raising finance can be difficult due to enhanced uncertainties. Innovations are, almost by definition, riskier than other investments, although offering the prospect of greater returns. This is emphasised by the World Bank (2010), who observe that most innovations fail. In order to bring the research to market, translational or developmental research is frequently needed. Even with successful innovation, feedback from manufacturers or from retailers and consumers may modify the innovation. This can often lead to unexpected ideas and products, but it can also lead to increased expense in developing the technology. In general, governments cannot directly help in the
raising of finance for the development, as opposed to the research stage. But they can act to bring together sources of finance and firms seeking to develop new products.

1.3.3 The Process of Technological and Innovation Diffusion

Rogers’ (1995) theory of technology adoption has been highly influential. This focuses on the user of the innovation, for example the consumer. There are five stages to innovation adoption. Firstly is where the individual becomes aware of an innovation. Secondly, the individual obtains enough information on the innovation to make a judgement on its usefulness. In the third stage the individual chooses whether to adopt. Stage four sees the individual buying the innovative product and, finally, in stage five, the individual re-evaluates whether to continue with the innovation. Rogers also identifies five innovation characteristics that influence adoption. The first relates to the advantage of the innovation over alternatives. Secondly, compatibility may be negatively correlated with this, and relates to the similarity of the innovation to previous ways of doing things. Thirdly, the greater the similarity, the less complex it will be to understand the innovation. Fourthly, trialability is when the individual can experiment with the innovation prior to adoption. Finally, observability is linked to how many others are using the innovation – which, with some innovations such as the mobile phone, relates to relative advantage.

Innovation adoption is often characterised by an S-shaped adoption curve, with there being a relatively small number of initial adopters, following which, if the adoption is successful, adoption accelerates. Early adopters tend to have high socioeconomic status, to be literate and relatively intelligent with good methods of communication (Straub, 2009). Innovation and knowledge tends to be first diffused in large towns and cities (Henderson, 2007). It then becomes diffused to other areas (OECD, 2010). Thus, in general, stimulating innovation in a new country is in most cases a two-stage process. Firstly, it needs to be targeted at the large cities, where it will be most successful with ready acceptance (ibid.). Secondly, it then needs to be diffused to the rest of the country. If not, innovation will simply widen inequalities within the country, as can be observed, for example, in India and China. Consistent with this, the World Bank (2008) repeatedly emphasises that technology diffusion differs within countries as well as between them. This discussion largely relates
to product innovation. Process innovation relates more to firms, although similar considerations apply.

Innovation involves new knowledge, but this does not necessarily come about via R&D within a firm. Instead the firm can acquire this knowledge from other sources. The knowledge may be entirely new, or new to market (that is, new to a country, region or town). When the latter is the case, one of the first stages of innovation involves knowledge diffusion, together with knowledge adaption into a form suitable for ‘market X’, again the country, region or town. The extent of adaption will depend upon the knowledge itself and its application in another market that most closely resembles X. There is a whole continuum of innovations from very large ones to much smaller ones. A key barrier to knowledge diffusion is distance (Jaffe et al., 1993). Geographic distance tends to increase the costs of transferring knowledge and technology, by for example reducing knowledge spillovers. Distance is related but not restricted to spatial distance and Rosenthal and Strange (2004) also emphasise both social or economic distance. Information technology (IT) may also be changing the relationship between knowledge diffusion and spatial distance.

1.4 OPPOSITION TO AUTOMATION AND NEW TECHNOLOGY

The example everyone knows is of course that of the Luddites. But even prior to the Luddites there were concerns that automation would put people out of work. One early example is that of William Lee’s stocking frame knitting machine developed in England in 1589. Queen Elizabeth I refused him a patent, saying: ‘Thou aimest high, Master Lee. Consider thou what the invention could do to my poor subjects. It would assuredly bring to them ruin by depriving them of employment, thus making them beggars’ (cited in Acemoglu and Robinson, 2012, p. 182). Apart from anything else, this illustrates how much easier it is to gain a patent today. Shortly afterwards, William Lee had to leave Britain. Frey and Osborne (2017) argue that the Queen’s concerns were linked to the hosiers’ guild’s fear that Lee’s invention would make obsolete their artisan members’ skills. The guilds systematically opposed technological progress and new inventions where this would be against their members’ interests (Kellenbenz, 1974). However, by the mid-seventeenth century, in con-
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Contrast to Continental Europe, the craft guild in Britain had declined in importance and influence (Frey and Osborne, 2017). This helped pave the way for a change in attitudes reflected by legislation passed in 1769 making the destruction of machinery punishable by death (Mokyr, 1990). The decline of the gilds helped pave the way for the industrial revolution. Their opposition to much innovation was from their own perspective partially justified. Most of the technologies of industrial evolution substituted unskilled or semi-skilled workers for skilled artisans, a process that accelerated with the development of steam power (Goldin and Sokoloff, 1982). Hence, in the nineteenth century, new technologies tended to substitute for skilled labour through task simplification (Goldin and Katz, 1998). Thus as with the current technological revolution, innovation shifted the balance between skilled and unskilled workers as well as between labour and capital.

During the nineteenth century, establishments grew in size, as improvements in steam and water power technologies facilitated the adoption of powered machinery that resulted in large productivity gains from combining higher capital intensity with greater division of labour (Atack et al., 2008). However, in the twentieth century, the balance shifted back in favour of the skilled worker with the switch to electric power and away from steam and water power. This shift, together with the development of continuous process and batch production methods, reduced the demand for unskilled manual workers and increased the demand for skilled workers (Goldin and Katz, 1998). The increase in production and market size also increased the number of managerial tasks, which in turn required more white-collar, non-production workers (ibid.). Hence technological change has continually changed the relative advantage of skilled versus unskilled labour over long waves lasting many decades.

1.5 INNOVATION CASE STUDIES

In this section we consider several specific innovations that help us to understand the process of innovation.

1.5.1 Case Study 1: The Spinning Jenny

The invention of the spinning jenny is analysed by Allen (2009). It was invented by James Hargreaves in 1764 and was, to an extent,
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a market-driven innovation. Cotton production had difficulties meeting the demand from the textile industry. However, Allen argues that its introduction in England was a consequence of the high wages there, relative to those in both India and Europe. Without technological innovation it would have been difficult for English industry to compete, and viewed in this respect, this and other developments preserved jobs and incomes in England, despite all the concerns amongst, and the opposition of, the ordinary spinners. Thus, to an extent it was the cotton industry and workers outside the UK who were disadvantaged by this technology more than British workers. This is seldom a concern of research: when it looks on the employment consequences, the focus is generally within the same country. This is a mistake.

Prior to the spinning jenny, spinners used the spinning wheel. The cotton had previously been cleaned and carded, which is similar to being combed, to produce a loose strand of cotton called a roving. The spindle was in front of the spinner and the wheel on the spinner's right. One end of the roving was attached to the spindle and the spinner held the rest in their left hand. Drawing their left hand away from the spindle lengthened and thinned the roving, which was then twisted. This twisting made the yarn strong. Hargreaves’ key objective was to allow the spinner to operate multiple spindles rather than one. He had tried operating several wheels by holding all of the threads from each in one hand, but that proved impossible with horizontal spindles. The key insight was to use vertical spindles with a single wheel. The earliest jennies had 12 such spindles, but soon 24 became the standard. The increase in productivity was enormous, but it came at a cost, with a single 24-spindle model costing 70 times as much as the spinning wheel. But they were still small enough to be operated in a spinner’s cottage.

This resulted in a reduction in the price of yarn, which angered the spinning workers in Lancashire where Hargreaves lived. They broke into his house and smashed his machines. He then moved to Nottingham where he again began the production of jennies. He patented his invention in 1770, and it continued in common use until superseded by the spinning mule in about 1810. Hargreaves was an illiterate weaver and carpenter who perceived there was a problem and produced a solution. It took him several years to perfect the invention and in this he was financed by a small-scale farmer. His invention mimicked, on a greater scale, the actions of a spinner.
and wheel and, in Allen’s (2009) words, was ‘not rocket science’. Nonetheless its impact was enormous. One final point to note: this was an invention that could have been made many decades earlier.

### 1.5.2 Case Study 2: The Railway

The key technology was the steam engine developed by James Watt. This of course was, in its own right, a key element of the industrial revolution, but when developed by Richard Trevithick who used high-pressure steam to increase the power–weight ratio, it paved the way for a steam engine to power its own movement. An early engine was in use by 1804, running on rails at a Welsh ironworks. The first proper steam locomotive pulling wagons was the Stockton and Darlington line, opened in 1825, which reached a dizzying, for the time, 15 mph. George Stephenson’s engine was, however, unreliable and it was not until the completion of the Liverpool and Manchester line that the railway age truly began. Initially the railways were built with a view to hauling goods and raw materials. From the earliest days, too, carrying the mail was envisaged. What was less expected was the substantial demand from the public to travel. From this time on, the railways prospered, but were hampered by the fact that the gauge, the distance between the rails, was not standardised, thus limiting continuous travel in the same train. This was resolved by a Royal Commission on Railway Gauges in 1845 that had to choose between the broad gauge of Brunel’s Great Western Railway and the narrow gauge used by many others. The Commission came down on the side of the latter, with a width of 1435 mm. This became law in 1846. This standard has since been adopted by much of the rest of the world. Further government intervention, via Gladstone’s 1844 Railway Act, forced the companies to provide at least one daily train costing no more than a penny per mile, thus paving the way for transport for all and not just the richer people.

The railways did put people out of business and led to job losses particularly on the canals and in the stagecoach industry, including the many stagecoach inns in more remote areas. In 1830 the industry employed in excess of 30,000 people and there were more than 1000 turnpike companies who maintained the roads (Wolmar, 2009). Both were in decline from 1840 onwards. Towns not served by the railway also went into decline. But by 1860 more than 300,000 people were directly employed on the railways (ibid.) and there were
many employed as a consequence of the railway. Railways facilitated developments as varied as the growth of the whisky industry and professional football. The impact on lifestyles was substantial – not least, the ability to transport food rapidly to large towns improving the average person’s diet. As with any new technology there tended to be various fears about their impact. Thus, there were concerns that cows would stop producing milk because of the noise and that the smoke would turn sheep black. Looking back today, many of the early concerns seem laughable. But few people came up with the even more far-fetched concept that the railways and the steam engine would contribute to carbon emissions that would eventually lead to climate change.

1.5.3 Case Study 3: The Integrated Circuit (IC)

The transistor acts like a switch. It can turn electricity on or off. Its use in early computers substantially reduced their size. But they were unreliable. The solution to this problem came in 1959, when Robert Noyce of the Fairchild Semiconductor Corporation patented a silicon-based IC and Jack Kilby of Texas Instruments patented miniaturised electronic circuits. In many respects the revolutionary nature of the IC lay with making everything out of one material, mainly single crystal silicon wafers, including both transistors and the wiring, although the idea had been around for some time. Prior to this, these elements were used to make transistors, but carbon was used to make the resistors and the connecting wires were made of copper.

There were two other problems facing the IC. Firstly, there was no way to electrically isolate the different components on a single semiconductor crystal. A semiconductor has an electrical conductivity between that of a conductor such as copper and an insulator such as glass. Their conducting properties may be altered by doping, that is, the controlled introduction of impurities into the crystal structure. A p–n junction is a junction between two differently doped regions. The isolation problem was solved in 1958 by Kurt Lehovec, who worked at the Sprague Electric Company using the p–n junction concept. It substantially reduces the electrical flow and hence any degree of insulation can be achieved by having several p–n junctions in series. Sprague was not interested in the idea and Lehovec filed his own patent application and then left the USA for two years. The second
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problem was that the only effective way to create electrical connections between the different components of an IC involved using gold wiring, which was very expensive. This was solved by Robert Noyce, building on Jean Hoerni's planar process, which created a flat surface structure protected with an insulating silicon dioxide layer. This views a circuit in two dimensions (a plane) and allows the use of photographic processing, making a series of exposures, thus creating silicon oxide (insulators) or doped regions (conductors). Noyce connected the transistors on the wafer with aluminium wires placed on top. Both Noyce and Hoerni were among a group of eight who had founded the Fairchild Semiconductor Corporation, where this work was done.

In 1960 a group, under the leadership of Jay Last, started by Noyce at Fairchild, produced the first planar IC. However, it was Texas Instruments who received contracts for planar ICs for space satellites and ballistic missiles. The ICs for the onboard computers of the Apollo spacecraft were, however, designed by Fairchild. As a consequence of this demand and the existence of economies of scale, the price of ICs dropped enormously, and hence, as is often the case, we see defence-related government agencies playing a leading role in the development of an innovation that would eventually have huge private sector demand.

The microchip of today is vastly different from earlier ones and one fingernail-sized chip can contain ICs with millions and even billions of components, hence facilitating the substantial increase in power of both computers and mobile phones. But it is still based on the work of these early pioneers. In passing, we note that Kilby got the Nobel Prize for his work in 2000. Noyce died in 1990 and hence could not be nominated. There is, however, a perception that the contributions of others have been somewhat undervalued (Lojek, 2007, p. 156).

1.6 REFLECTIONS ON INNOVATION

The spur for innovation is some combination of a desire for monetary gain and scientific curiosity. The innovation may stem from the work of the scientist, today often in a university environment, in the past less so, driven by a desire to understand the world, to make discoveries about that world and make it better, and driven too by an ego, with the scientist seeking recognition from their peers and perhaps the history
books. But the innovation may also stem from a perception of a market need that it would be potentially profitable to fill. This perception may come from an established firm, as with Texas Instruments, or from the individual working alone, as with James Hargreaves and the spinning jenny. In the latter case, the individual often seeks to market the device themselves, frequently setting up a new firm in the process. The individual is then both entrepreneur and inventor, which may be difficult as they are combining two distinct skill sets.

The invention, once successfully marketed, impacts on society, generally increasing wellbeing but sometimes with adverse side effects. Railways were a disruptive technology that destroyed thousands of jobs, putting many people out of business. The same is true for the spinning jenny. But over time many more jobs were created, both in the railway industry and in other industries. They are clear examples of what Schumpeter termed ‘creative destruction’. Railways also fundamentally changed society and the economy. Some of these benefits were seen from the moment the innovation became available and were in part the initial spur for the innovation. But some were not foreseen. The growth of passenger transport took the early railway innovators somewhat by surprise, but they were then quick to exploit the opportunities. This is another feature of innovation: the unintended consequences. In this sense, when you buy a ticket for innovation you buy a ticket into the unknown, and these unintended consequences may take decades to play out. This is one rationale for governments to play a part in the innovative process, as in the helix models, but not to spur innovation, rather to control it and its side effects and also to maximise the benefits to society. An example of the latter would be the insistence on the penny per mile railway ticket. Hence governments play a role not just in correcting for market imperfections, as with specifying the standard rail gauge, but in protecting society and people from the more harmful effects of innovation. Governments also lay out the ground rules for innovation, with the patent laws that specify for how long the firm with the patent can uniquely benefit from that innovation.

1.7 IS INNOVATION GOOD FOR SOCIETY?

Up until now the answer has largely been yes, although a qualified yes. Few would wish to go back even 100 years and have virtually no
domestic appliances and no ability to communicate with others over long distances. But that does not mean that all innovation is good and there is not some innovation that in hindsight we would wish to have stopped, and other innovation we would have done differently. Have developments in nuclear physics, for example, on balance been beneficial to society? More generally, Stiglitz (2018) argues that the free uncontrolled market may result in innovation that leads to greater unemployment and inequality than the socially desirable levels and thus reduce societal wellbeing below what it could be. Indeed, the result may not even be output maximising.

The problem is that innovation is driven by scientific curiosity and greed, the desire to make profits or of governments to enhance their defensive and security capabilities. If it is possible to make something and it will make a profit then it will be made, unless governments, all governments, make it illegal to do so. The main driver of innovation is often not to make society better – that is a side effect. There are exceptions to this of course, as with the example of mobile finance in Kenya. But frequently it is a side effect: an innovation makes profits because people or governments are willing to pay for the innovation, because it makes the former’s lives better or improves the latter’s ability to provide public goods. But this does not automatically mean it makes society as a whole better off. Hence, although until now innovation has largely been beneficial to humankind, this is not something we can bank on continuing into the future. There is no fundamental dynamic to innovation that guarantees it will always improve our lives and our society. Nor has innovation in the past been implemented optimally. There is a balance to be had between the disruptive and beneficial effects of a new technology, and it is not obvious that the invisible hand always achieves the right balance. The invisible hand is good at providing the incentives for innovation. It is less successful at protecting the losers or controlling the speed of innovation. That must also be a role for government.

Because there is no guarantee that innovation always benefits society, and because a desire to do good is only part of the incentive for innovation, there is a rationale for regulating scientific endeavour on several dimensions. Firstly, we imagine a world where some research may be allowed and other research not allowed. In actual fact, this is the world we sometimes at least aspire to, as with the case of human cloning (Langlois, 2017). The difficulty lies in getting all countries to agree to this and then to enforce it – a difficulty that may
be possible to overcome. Secondly, research and innovation that are allowed may still be restricted and subject to regulation, to maximise the benefit and minimise the risk. This is increasingly being seen, in part because governments are becoming more involved with stimulating and directing innovation. Apart from regulation, there is also a case for increasing the emphasis on the teaching of ethics to scientists both whilst students and subsequently (Reiss, 1999).