TECHNOLOGY AND ECONOMIC PERFORMANCE

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Opening scenario: The high-definition DVD format war

Toshiba launched its new format HD-DVD player in March 2006. This was followed six months later by Sony's alternative format Blu-ray high definition DVD player. For eighteen months the two rivals fought for supremacy in the format war to find a high-definition replacement for the established DVD player. Toshiba finally conceded defeat in February 2008 after a number of important film producers gave their backing to Sony, allowing Sony's Blu-ray players to set the industry standard.[1] This was in many respects a repetition of the battle between the Betamax and VHS formats for the video player which preceded the arrival of the DVD – except that in the 1980s Sony's Betamax lost out to JVC's VHS format.

In the end, the Blu-ray player won not necessarily because it had better technology or produced a better quality picture, but because of the backing it received from Walt Disney, Twentieth Century Fox, and Warner Brothers, key players in the Hollywood movie industry. Microsoft, whose operating system needs to be compatible with the new technology, especially to facilitate downloading from the internet, had in fact backed Toshiba, as had Warner Brothers until its pivotal decision to abandon Toshiba in January 2008. The support of the major film producers was ultimately crucial as, without a reasonable number of films being produced in the required format, the HD-DVD player would soon have become redundant. Other factors, such as Blu-ray's superior storage capacity and marketing success, including Sony's decision to incorporate Blu-ray into its market-leading PlayStation 3 games console, also helped to secure victory for the Blu-ray format.

This story illustrates the way developments often occur in markets for technological products. The high-definition DVD player is the latest generation in a series of devices for playing films. Although it contains features undreamt of when its earliest predecessors were developed, it is nevertheless an incremental innovation, building on previous technologies. Like any technological development, it is the product of a vast array of general and specialized knowledge, much of which is publically available, some of which is protected. A particular feature of technological products is that one product acts as a platform for another, as the Blu-ray player does for films. This means that compatibility is important. Of course, it would be quite possible to have two alternative formats, each with its own set of films, but there are cost and marketing advantages in having a single format, especially if it attracts the majority of consumers. The dominant format then becomes the industry standard. This raises the issue of intellectual property rights, which should provide sufficient protection to encourage profitable innovation whilst allowing the technology to be shared by a wide range of producers and consumers. These issues, among others, help to create the distinctive characteristics of the technological environment.[2]

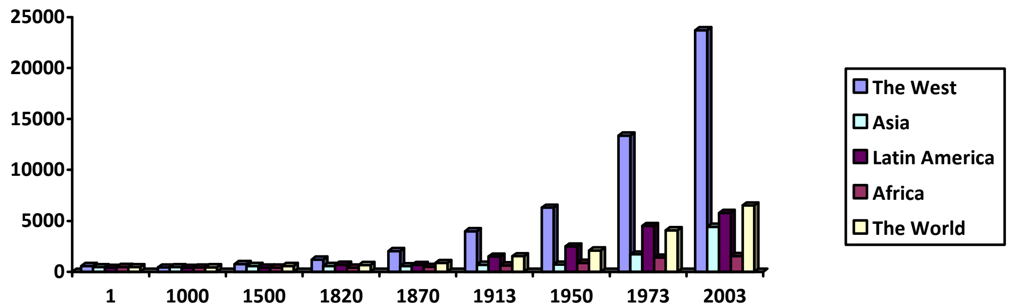
10.1 Perspectives on technological change

10.1.1 Technological 'revolutions'

Technological developments have occurred throughout history. Even in prehistoric times primitive tools made out of stone, wood, and other natural materials represented the technology of a particular period.[3] However, in modern times, the most productive period of technological development dates from the late eighteenth century to the present time. This period has been the most productive, not so much because of the number of inventions (which has been significant), but more especially because of the impact of technological developments on productivity, GDP, and GDP per capita. The early part of this period, from the late eighteenth to the mid-nineteenth century is often described as the 'Industrial Revolution', which began in Britain, then spread to other parts of Europe and North America. The most significant aspect of this period, and indeed the period that followed the Industrial Revolution, is that technological and organizational change led to sustained economic growth and continual improvements in the standard of living in the countries concerned.

For centuries technological innovation had led to temporary or minor improvements in living standards, but these benefits had generally been cancelled out by conflict or population increases, leaving the majority of people little better off. This is starkly illustrated in Figure 10.1, which is based on Angus Maddison's estimates of GDP per capita from the year 1-2003AD.[4] According to Maddison, world GDP per capita was only about half as much again in 1820 as it had been in the year 1 AD; this represents remarkably little economic progress during most of the first two Millennia AD. The rate of increase was marginally higher in the West (mainly Europe and North America), but Africa was slightly poorer in 1820 than it had been eighteen hundred years previously. By 2003, however, GDP per capita was almost twenty times higher in the West, the cradle of the industrial revolution, than it had been in 1820. Latin America and Asia lagged behind, though their GDP per capita had grown significantly by the end of the twentieth century. African GDP per capita was about three and half times higher in 2003 than it had been in 1820, though some individual African countries experienced little, if any, improvement over this period. These statistics illustrate the dramatic change that occurred after the onset of the industrial revolution, particularly in the West, and also the way in which some parts of the world have been left behind.

Figure 10.1: GDP per capita, major regions and the world, 1-2003AD



Source: Maddison, A. (2007), Contours of the World Economy, 1-2030AD, Oxford University Press, Table 2.1, p. 70. The vertical scale represents 'International Dollars' valued at 1990 prices.

For some economic historians, the industrial 'revolution' was more of a gradual process than the term 'revolution' implies.[5] Certainly, there is often a long time lag between an invention or discovery and the full extent of its applications. Joel Mokyr divides the industrial revolution into separate phases leading up to the present time, an approach which is useful in linking earlier developments with the recent growth of information and communication technology.[6] He describes the first Industrial Revolution as the period from about 1760 to the mid-nineteenth century, characterized by the development of coal mining, textile manufacture, the factory system, and the application of mechanical inventions such as the steam engine. The second Industrial Revolution, covering the period from the mid-nineteenth century to 1914, saw the development of industries such as chemicals and steel, the introduction of the telegraph and telephone, the discovery of electricity, and the development of the internal combustion engine, among others. The third Industrial Revolution covered the period from 1914 to the early 1970s, a period which included the introduction of assembly-line operations and product standardization as well as developments in medicine, air travel, nuclear energy, and many other fields. The period from the early 1970s to the present time is described as the 'Information Revolution' or 'Information and Communication Technology (ICT) Revolution'; this period is characterized not only by the widespread use of the computer, but also by the development of the 'knowledge economy' (see section 10.4 below), including the use of the internet and the way in which ICT has transformed work practices and everyday lives. Practical Insight 10.1 considers the application of ICT to the financial services sector.

Practical insight 10.1: Electronic banking systems

Developments in financial services provide a useful illustration of the way ICT has been transforming our everyday lives. Electronic funds transfer allows salaries and payments of various kinds to be transferred directly from one bank account to another, and credit and debit cards are gradually replacing the need for payments by cash or cheque. Electronic systems enable us to do our banking online and allow call centre staff to access our bank details from the other side of the world. They also link retail outlets to the banking system and are increasingly connecting the banking systems of developed and developing countries. Of course, these systems are not infallible and international connections sometimes involve delays and unexpectedly high costs, but electronic banking is undoubtedly changing the face of banking in many parts of the world.

Question: What are the implications of electronic banking systems for competition in the high-street banking sector?

10.1.2 Technology as an application of knowledge

A core feature of technology is that it represents the application of scientific or practical knowledge. As technological products and processes have become more sophisticated, the term 'knowledge economy' has been used to describe this phenomenon. Of course, technological knowledge is not unique to the economies of the late twentieth and early twenty-first centuries, but there is a perception that the level of human skill and technological sophistication required in the modern world is proportionately greater than in previous periods. The computer provides an illustration of the importance of knowledge relative to physical resources. Consider a personal desk-top computer. The computer is made up of various physical materials and components and has an operating system and various software programs. The cost of the physical materials represents only a small proportion of the computer's total value. Most of its value is contained in the knowledge required to design and build the computer and its components, and to develop its system and application software. This is typical of many technological products.

Whereas a single piece of information contributes to our knowledge, the sense in which we are using the term 'knowledge' here is more than simply a collection of information. Instead, knowledge represents the way in which information and understanding combine to determine patterns and regularities in natural phenomena and their application to the solution of practical problems. Mokyr distinguishes between *propositional knowledge* (beliefs about natural phenomena) and *prescriptive knowledge* (techniques for applying propositional knowledge).[7] This broadly corresponds with the distinction between scientific knowledge and technological knowledge, though propositional knowledge may include practical knowledge gained through experience as well as scientific knowledge. The role of technological knowledge in economic growth and development is explored further in sections 10.3 and 10.4 below.

10.1.3 Spatial implications of technology

One of the characteristics of the ICT revolution that seems to distinguish it from earlier industrial revolutions is the way in which it brings people, businesses, and other organizations around the world closer together. To some extent this also happened in earlier periods because of improvements in transport and communication, but the instantaneous flow of information provided by the internet and wireless communication seems to represent a revolution of an altogether different kind. Frances Cairncross has described this phenomenon as the 'Death of Distance', arguing that while the nineteenth and twentieth centuries witnessed the falling cost of transporting goods and people respectively, the twenty-first century will be characterized by the falling cost of transporting ideas and information.[8] Electronic commerce (e-commerce) bridges the physical distance between buyer and seller, including both retail and business-to-business transactions, enabling them to find each other more easily, make more informed choices, and reduce the cost of their transactions.

Practical insight 10.2: e-Government

The breaking down of distance barriers is not restricted to the private sector. A number of initiatives are being taken to link citizens with central and local government through e-government schemes. Citizens can increasingly apply for benefits, complete income tax returns, or exchange information with government departments online. e-Government is also being considered as a way of encouraging voters to engage with the electoral process, either through online voting, automated telephone voting, or electronic voting at polling stations. The potential benefits in terms of speed, efficiency, and cost saving are clear and late-night election counts could become a thing of the past.

Question: To what extent do you think e-government will help to break down barriers between government and people and lead to greater public engagement by ordinary citizens?

For Thomas Friedman, technology is a flattening process that removes the spatial and economic barriers that separate different parts of the world, especially between the Western developed countries and technologically emerging countries like India.[9] In this sense, technology is starting to break down barriers between rich and poor countries, allowing a multitude of business services to be offshored across an increasingly ‘flat world’. Not only is information transferred rapidly across vast distances, but so also are technological knowledge and economic wealth. This picture of a world where distance no longer matters is of course exaggerated; otherwise, there would have been no need for the huge increase in foreign direct investment that has occurred in recent years. What is clear, however, is that businesses are now able to undertake operations and communicate between different parts of the world with relative ease. This facility is available to smaller organizations as well as larger ones and also to private citizens. Perhaps belatedly, citizens are now also being connected to local and central government much closer to home (see Practical Insight 10.2).

10.1.4 Technology and employment effects

In this section we consider the effect of technology on the labour market and the skills profile of industries and countries. It has long been feared that the substitution of technology for labour leads to unemployment. This concern dates back to the Luddites who tried to destroy the new power looms that were replacing handloom weavers in textile factories in early nineteenth century England – a concern which has been expressed more peacefully in relation to the ICT revolution today. If one takes a narrow perspective on the immediate effects of the introduction of labour-saving technology at a particular workplace, it is clear that there are likely to be job losses for the displaced workers. However, when considering the effect of technology on an economy as a whole, there seems to be little if any long-term effect on employment. This can be seen in Figures 10.2a and 10.2b in relation to employment and unemployment in the US economy over the period from 1948 to 2008. The US economy has maintained its ability to create employment, despite having probably experienced more technological change than any other economy over this period. The unemployment rate is more ambiguous, though its rise in the 1970s and early 1980s probably has more to do with the inflation and recession that accompanied rising oil prices at that time than with the impact of new technology.

Figure 10.2a: US employment level, 1948-2008

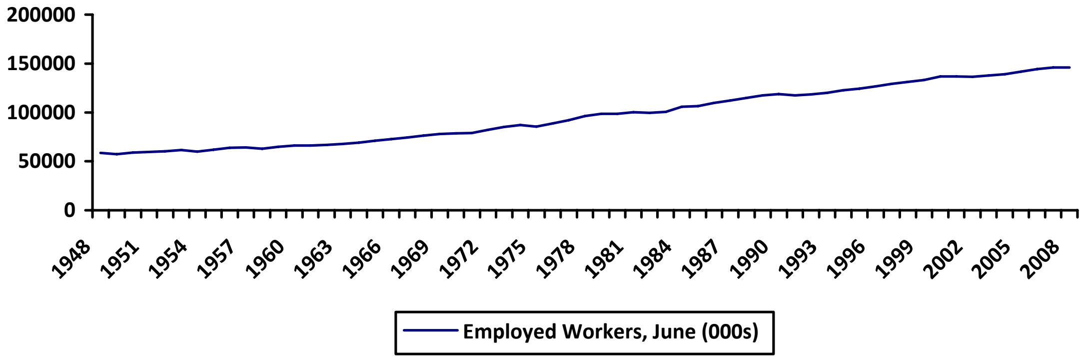
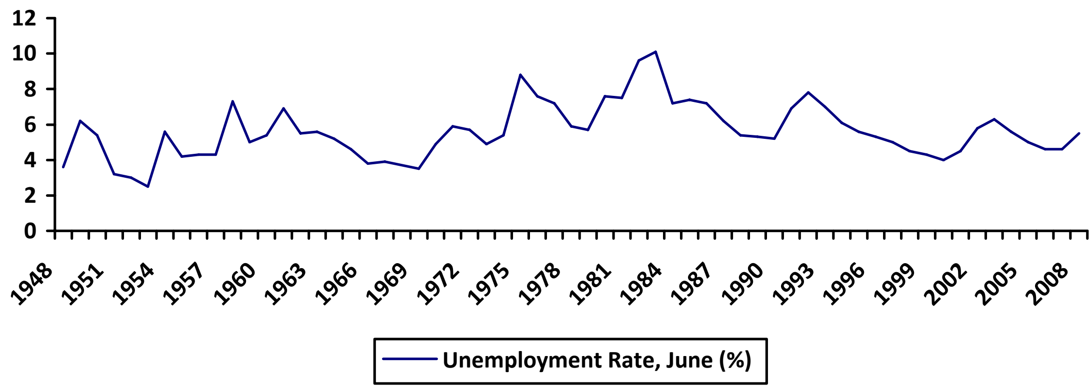


Figure 10.2b: US unemployment rate, 1948-2008



Source: US Bureau of Labor Statistics

The lack of a negative impact of technology on overall employment, especially in the longer term, is probably due to the way in which markets and economies adjust to new technology. As well as reducing the need for direct labour in the production process, technology increases output and reduces the cost of production. Lower prices enable consumers to buy more, including new goods and services created by the new technology. The new products then generate employment opportunities to compensate for the loss of jobs in conventional production. In this way, the ICT revolution has helped to reduce employment in former labour-abundant industries such as car manufacturing or banking, and has created employment in the computer, electronics, telecommunications, and related sectors. In particular, modern economies are experiencing increased employment in the service sector as consumers demand more sophisticated leisure services and businesses add value to their products by offering support services to their customers. Technology also allows greater flexibility in the use of labour, enabling an increasing number of people to work from home or at other off-site locations. There is even some evidence to suggest that people who work mainly with technology work longer hours and are paid more than more conventional workers, though this may be because their roles generally require a higher level of professional commitment and attract people with higher skills.[10]

10.1.5 Technology and the working environment

One of the most significant effects of technology has been on the working environment. Most organizations have now vastly increased their ability to store, process, and share information. This facilitates communication with colleagues, customers, and suppliers at remote locations. For office workers, the computer has replaced the typed documents and hand-written account books; for production workers it has replaced the draughtsman's drawing and the painstaking machining of precision products. Marketers use PowerPoint presentations instead of overhead projection and teachers have replaced their blackboards with electronic whiteboards. The use of computer-aided design (CAD) and computer-aided manufacturing (CAM) has transformed the manufacturing sector, allowing complex processes to be undertaken rapidly and accurately. Technology has also revolutionized many other areas of work, ranging from the use of DNA profiling in police investigations to Kuala Lumpur's driverless urban transit system.

Many tasks that were previously undertaken by teams of people or large organizations can now be carried out by an individual or small business in a fraction of the time. In this way, technology empowers small and medium-sized enterprises to take on work that was once the domain of large corporations. Even international markets are now within reach via the internet as long as customer requirements can be met either electronically or using the services of one of the many international logistics companies. In a similar way, technology is reducing the scale of conventional production operations, allowing steel producers to use more efficient mini-mills and motor manufacturers to produce differentiated finished products from shared production platforms. These developments enable efficiencies to be achieved with smaller scale at the same time as providing the customer with an individually customized product. In a variety ways, therefore, technology is changing the relationship between inputs, output, and the consumer.

10.1.6 The global picture

It is clear from section 10.1.1 above that technological developments have not occurred evenly across different regions of world. The US economist, Jeffrey Sachs, has suggested a classification of countries according to whether they are *technological innovators*, *technological adopters*, or *technologically excluded*.[11] Technological innovators are defined as countries with ten or more patents per million inhabitants and technological adopters are those where high-tech exports account for at least 2 per cent of GDP; the remainder are classed as technologically excluded. Whilst these definitions are somewhat arbitrary, they give a broad indication of a country's stage of technological development. The technological innovators account for about 15 per cent of the world's population and include the USA and Canada, most of Western Europe, Japan, Taiwan, South Korea, and Australia. The technological adopters include Mexico, Argentina, Chile, most of Central and Eastern Europe, South Africa, southern and western India, eastern and south-eastern China and much of South-East Asia. This leaves most of Africa, large parts of Asia, most of Central America, and the northern half of South America 'technologically excluded'.

The above picture is of course a changing one as countries progress from one category to another, as Taiwan and South Korea have done in recent years. A number of other indicators could also be used to determine the extent to which technology has permeated the everyday lives of a country's citizens. These might include the level of telephone, mobile phone, or internet usage, for example. Internet usage is now a prime indicator of technological connectivity, something which is becoming increasingly important in international business. Table 10.1 compares internet usage in each of the main regions of the world, though it is important to note that usage also varies considerably between individual countries. Despite the vast increase in internet usage since the mid-1990s, less than a quarter of the world's population were using the internet in 2008. The reasons for the differences between countries and regions will depend on factors such as education, income, the availability of telephone connections and power supplies, and the level of peace and security, among other things. Remoteness of geographical location may also isolate some regions, even within a particular country, though joint-ventures with multinational enterprises in innovator countries may accelerate the technological progress of an otherwise less developed country.

Table 10.1: World internet usage, June 2008

Regions	Internet Penetration (% of population)	% of World Internet Usage
Africa	5.3	3.5
Asia	15.3	39.5
Europe	48.1	26.3
Middle East	21.3	2.9
North America	73.6	17.0
Latin America & Caribbean	24.1	9.5
Oceania/Australia	59.5	1.4
Total	21.9	100.0

Source: www.internetworldstats.com

10.2 Sources of technological change

10.2.1 Uncertainties of technological change

Before considering the factors that lead to technological change, it is important to note that technological change is affected by a large number of uncertainties at every stage of the process. First of all, it is unclear at the outset whether an idea or invention will realize its full potential or even produce more modest positive outcomes such as a quality improvement or cost reduction. Even if a product turns out to be technically successful, there is no guarantee it will be a commercial success. This was the case with the Anglo-French Concorde supersonic aircraft. The planning and design process for the Concorde began, with the support of the British and French governments, in the early 1960s. The aircraft went into service in 1976 and was finally withdrawn in 2004 after a period of uncertainty following a major accident near Paris and a number of technical problems.[12] Concorde was well ahead of its time technologically, but its commercial success was limited by the fact that most of its potential customer airlines withdrew their orders after a number of international airports refused it permission to land because of what they perceived to be excessive noise.

In some cases the eventual success of a discovery may be dependent on further discoveries in the future. Thus, for example, the drug aspirin was developed by scientists during the latter half of the nineteenth century, and was marketed successfully during the twentieth century until the launch of paracetamol and ibuprofen in the 1950s and 1960s. Its popularity was then revived in the 1980s after its effectiveness as an anti-clotting agent in preventing heart attacks and strokes had been established – something which was not foreseen by its original discoverers. Similarly, there may be unforeseen applications of a particular invention, such as the use of computer technology to create digital photography, or complementary inventions may create unforeseen synergies, as for example with the combined use of laser and computer technology to guide or track missiles and other weapons. Alternatively, a technology with significant potential may be held back by unforeseen problems or lack of public or consumer acceptance. This has been the case with the genetic modification of plants and animals, especially in Europe (see Practical Insight 10.3). Even when a new technology becomes commercially established, it is difficult to know how soon it will be replaced by a superior technology.[13]

Practical insight 10.3: GM crops

Genetic modification techniques have been applied to the development of synthetic insulin, human growth hormone, a number of vaccines and drugs, and the prevention of genetic disease, among many others. One of the more controversial applications of biotechnology has been the creation of plants which are resistant to pests and disease. This technology could reduce the need for pesticides and potentially bring increased yields, cost reduction, and security of supply to farmers and the food industry around the world. For the developed countries the potential benefits include increased productivity and profitability; for the least developed countries GM crops could help to create sustainable agriculture and ensure essential food supplies. Inevitably, the genetic modification of crops raises concerns about the potential dangers of GM crops 'contaminating' organic crops, encouraging the spread of increasingly virulent crop diseases, or causing harm to people, wildlife, and the natural environment. There are also suspicions about the motives of companies like Monsanto, which dominate the worldwide supply of GM crops. Whilst GM crops are now well established in the United States, the public is much more sceptical in Europe.[14]

Question: In the light of these issues, how would you assess the future development potential of GM crops?

10.2.2 The process of technological change

A useful way to think about how technological change occurs is to use Joseph Schumpeter's terminology of invention, innovation, and diffusion.[15] Invention is the initial idea or discovery, perhaps including a prototype or trial to determine its feasibility. Innovation involves the commercial development of an invention, often by a large company rather than the original inventor; the term 'innovation' is also commonly (and confusingly) used to describe the entire process. Diffusion describes the spread of the innovation to other firms, products, or industries. Each of these stages is an essential part of the process of technological change and a number of factors may help or hinder the progress of an idea from one stage to the next. These factors include the nature of the invention, the level of potential competition, the availability of finance (risk or venture capital), the degree of legal protection available (intellectual property rights), the willingness of commercial enterprises to give their backing to the idea, and the role of government policy. These factors in turn will depend on the general economic climate and society's attitude towards risk taking. In reality, the process may be less linear than suggested by this three-stage approach, with different aspects of the process overlapping each other, and indeed Schumpeter saw it as an evolutionary process – an essential part of the 'creative destruction' of a capitalist system, where change is driven by entrepreneurial foresight and the outcomes of good or bad commercial decisions.

It should not be assumed that all innovation is radically new. In fact, most innovation involves incremental changes to existing products, services, or processes. Whilst the first electronic cash dispensing machine might be described as a radical, fundamental, or macro innovation, the spread of cash machines to shopping centres, universities, and train stations would be regarded as incremental or micro innovation. Of course, innovation is not restricted to technology; even a new type of financial product or a new marketing strategy might be described as an innovation. The development of technology is often an iterative learning process, where one innovation is followed by others over a period of time as new discoveries are made and new applications found. This is frequently the case with the discovery of new drugs or medical techniques. For example, in 1928 Alexander Fleming discovered the natural antibiotic properties of penicillin, though it was not until the 1940s, after a series of further studies and the need to treat war-time casualties, that penicillin was used to destroy disease-causing bacteria in humans, eventually leading to the development of other antibiotic drugs. A crucial element in this process is the way in which different technologies or discoveries interrelate with each other to develop the full potential of a product or process. This was the case with the discovery of DNA (see Practical Insight 10.4).

Practical insight 10.4: The discovery of DNA

Francis Crick and James Watson are generally credited with having discovered the structure of DNA in 1953. Along with Maurice Wilkins, who carried out further research in this area, they were awarded a Nobel prize for their work in 1962. Watson and Crick's discovery, however, was built on the earlier work of a number of scientists dating back to Gregor Mendel and Friedrich Miescher in the 1860s. Watson and Crick's discovery was in fact made possible by examination of X-ray images of DNA taken by Rosalind Franklin in 1951. Further discoveries were made in the ensuing years, notably the deciphering of the genetic code by Marshall Nirenberg, Har Khorana, and Severo Ochoa in the 1960s and DNA cloning by Herbert Boyer and Stanley Cohen in 1973. These developments provided the foundations for the biotechnology industry and genetic engineering. The discovery of DNA has led to numerous applications in many fields.[16] One such application is DNA profiling (previously known as genetic fingerprinting), a technique which was discovered by Alec Jeffreys in 1984 but was not used in criminal investigations until the 1990s.

Question: Why do you think there is often a time lag between a scientific discovery and its practical applications?

10.2.3 Path dependence and standardization

Processes of technological change are often *path dependent*, as are change processes in the social and natural sciences. Path dependence means that a sequence of events is shaped in a persistent way by a particular event in the past.[17] A classic technological example of path dependence is provided by the standard railway gauge, where the distance between the inside edges of many of the world's railway lines is 1,435 mm (4ft 8½ in). Although the origins of such an unusual measurement are unclear and a number of alternative gauges have been used, standard gauge began to emerge when George Stevenson was building his early public railways in England in the 1820s and has gradually become the dominant gauge since then. Having a standard gauge is clearly useful for manufacturers of rolling stock and to facilitate connections between railways in different regions and countries. Whilst there may be a number of advantages in having larger or smaller gauges, the cost and disruption caused by the changeover to a different gauge would be enormous.

Path dependence is not always as long term as the railway example. In some cases, new technology creates an opportunity for a new standard to be set. This is illustrated by the development of the standard video format in the 1980s (when VHS won the format war over the rival Betamax system) and the success of Sony's Blu-

Ray format over Toshiba's HD-DVD player in 2008 (see opening scenario to this chapter). Even over a relatively short period, the advantages of having a single technical standard generally outweigh the benefits of having a choice between alternative systems. It should not be assumed, however, that path dependence necessarily precludes the option of an alternative system or prevents switching between systems. An example of the former is the persistence of Apple in a market dominated by Microsoft (mainly because of Apple computers' specialized uses); examples of the latter are converters that allow switching between 115V and 220V electricity supplies or between UK and continental European electric plugs.

The advantages of standardization are reinforced by the concept of *lock-in*. Once a particular standard becomes established, consumers and suppliers of complementary products, such as films in Blu-Ray format, become locked into this format. Not only are the costs of changing to an alternative format high for producers, they are also high for consumers. How many of us have collections of old 33 rpm (or even 78 rpm) vinyl records, cassette tape recordings, or videos we can no longer play or afford to replace? Similar issues arise when an organization is choosing a new computer system, which is now typically a networked system used throughout the organization. Regardless of whether the system turns out to be the most effective, the initial decision creates lock-in effects which favour continued use of the system even when the technology is becoming outdated – unless relatively low-cost upgrades are available. Markets for technological products and services are often characterized by high fixed (sunk) costs in the form of set-up and switching costs, which help to reinforce the advantages of standardization, whereas the variable costs of producing multiple copies of films or software in a standard format are low.

Practical insight 10.5: The QWERTY keyboard

The standard typewriter keyboard has an apparently peculiar arrangement of letters, often known by the first six letters of the top line of letters 'QWERTY'. The first commercially successful typewriters to have this arrangement were produced by the Remington Company in the 1870s. Little did they know that the arrangement would become the standard for millions of computers around the English-speaking world, as well as the system taught on typing and computer courses, explained in typewriting manuals, and used in a variety of computer programs. Although thought to have been designed this way to achieve maximum typing speed, the arrangement has been criticized as inferior to alternative layouts such as the Dvorak keyboard. Whatever its relative merits, the QWERTY keyboard represents a prime example of path dependence and lock-in. Given that keyboards are now normally independent components which can easily be replaced, manufacturers could presumably devise alternative layouts at relative low cost. From the user's perspective, however, lock-in may be a more difficult problem to overcome.[18]

Question: How difficult do you think it would be to introduce an alternative, more efficient keyboard layout?

The benefits of standardization also increase where networks are involved. Examples of technological networks include the internet and worldwide web, intranets within organizations, fixed telephone systems, and mobile phone networks. Network effects may also arise where compatibility or interoperability between hardware and software or between system and application software is required. This is the case with Microsoft's dominant Windows operating system, which is discussed in the context of competition theory in the case study in chapter 9. Microsoft achieved dominance over its main rival, Apple, in the early 1980s after its deal to supply IBM, the dominant hardware producer at the time, with its DOS operating system. Although more difficult to use than Apple's system at that time, the Microsoft system gradually became established as the industry standard. This standard became a platform for Microsoft's and its competitors' software, a position which it has largely maintained to this day. This example illustrates path dependence from the time Microsoft made its deal with IBM, the lock-in of consumers and competitors because of the need for compatibility, and the self-reinforcing network effects which are a particular benefit to users of Windows-compatible programs and files.[19] Further discussion of network effects can be found in section 10.3.3 below. Another example of path dependence and lock-in which has stood the test of time is the well-known QWERTY keyboard (see Practical Insight 10.5).

10.2.4 Open-source technologies

Technologies that are developed through a process of public cooperation are known as *open-source technologies*. The open-source phenomenon is becoming an important alternative way of doing business. Perhaps the best known examples are in the form of open-source software, such as the Linux operating system, Mozilla Fox web browser (the rebirth of Netscape), Apache, which powers many web servers, and Sendmail, which handles a large proportion of e-mail traffic. The open-source approach can also be found in the area of product development, as for example Collabnet's coordination of collaborative software projects or, on a smaller scale, BMW's invitation to its customers to co-design the 'telematic' features of its cars (safety, phone, tracking devices and other electronic equipment connected to computerized networks). In principle, open-source technologies are examples of collective action that can be found in a variety of fields, ranging from open-source on-line encyclopaedias (such as Wikipedia) to community social projects. In each case, members of the public contribute their time and expertise voluntarily to the development of the open-source project, improving and refining it over a period of time. The open-source nature of the project may then be protected by copyright restrictions to ensure it remains freely available. Some projects may be more coordinated, others may operate on a freer basis, but the outcome is always the result of collective effort.

Open source products and projects are *public goods*; that is, there is non-rivalry and non-exclusion. The use of open-source software or a community facility by one individual does not decrease the benefit to other users (non-rivalry) and, once it is available, everyone can benefit (non-exclusion). Like other public goods, open-source projects may suffer from the free-rider problem, where some potential contributors shirk and still enjoy the benefits, but they may also achieve significant positive externalities – benefits to all users, not just to those who contribute towards the project's development. Whilst the public benefits are often considerable, it is not always clear why an individual contributor is motivated to do so. However, if the collective benefits to all contributors exceed the private costs of their individual contributions, this may provide sufficient incentive. Other incentives may include the desire to improve on existing (closed-source) products or the satisfaction of helping to create something that brings benefits to society.[20]

10.2.5 The evolution of technology markets

It is by no means certain whether new product development in technology markets is demand-driven or supply-driven. Is the consumer urging electronics manufacturers to produce high definition DVD players because of the poor quality of existing DVD players, or are research and development departments always trying to push forward the technological boundaries? Research by Paul Geroski suggests that new products are driven by supply-side technological developments.[21] In the early stages of the development of a new market, there is often competition to create an industry standard. Over a period of time a dominant standard emerges and competition gradually brings improvements to the industry standard. As a product approaches maturity, process improvements often become more important than product improvements and dominant firms concentrate on trying to reduce their costs. Product innovation then comes mainly from newer firms or firms outside the mainstream. This pattern was evident in the 1980s when new personal computer manufacturers such as Compaq started to challenge IBM in the PC market, despite IBM-compatibility setting the dominant industry standard at that time.

On the other hand Danny Quah argues that, unless there is sufficient demand for a new product or new technology, it is unlikely to take off.[22] China, he argues, has been at the forefront of technological development throughout much of its history and was the world’s most advanced industrial economy in the Middle Ages. However, according to Quah, for the next three or four hundred years, until recently, China fell behind Europe and America, largely because its feudal system did not provide the right demand conditions for the market to take off. Demand drivers may be at work at various stages of the development process. The internet, for example, was initially developed to meet the specialized needs of academics and the military, but as the technology improved it was gradually made available to businesses and the general public. However, it is unlikely that the internet would have continued to develop as it did if the public had not been keen to use the new technology.

10.2.6 Incentives and technological change

The system of incentives in a country is likely to have an impact on its technological development. In general terms, incentives are created by a country’s institutional structure, including both formal and informal institutions. Perhaps the most important formal institutions in this context are the rules relating to intellectual property rights. Without the protection provided by patents, copyrights, licences, and trademarks, the incentive to innovate is considerably weakened, as the returns needed to justify the investment will quickly be lost to competitors. On the other hand, an overly protective patent could give the patent holder monopoly rights for an extended period of time and slow down potential diffusion. A balance therefore needs to be found between these two extremes. The commercialization of intellectual property (IP) developed by universities, research institutes, and new graduates is also becoming an important issue, leading to the development of science parks and business incubation units. In addition, informal institutions may be influential in encouraging innovation, particularly attitudes towards entrepreneurship and the taking of risks, and the possibility of significant rewards.

Governments and organizations such as the European Union may also play a role in providing incentives. Governments can intervene by providing tax and other financial incentives when private financial institutions are reluctant to support new ventures. Short-term government intervention may help to provide seed capital or a protective environment for a new venture, but success in the longer term will depend on the market for the product. Competition provides an important element of the incentive structure, creating the rewards for success. Indeed, the level of technological sophistication, both in relation to products and organizational processes, has a key impact on an organization's competitiveness both at home at abroad. Research suggests a significant correlation between the level of technology (measured by R&D and patents) and international competitiveness as indicated by the trade performance of a variety of industrial sectors.[23] It should be noted, however, that countries with remarkably different government policies, competitive environments, and institutional structures, such as the USA and Japan, have been able to achieve significant technological development in recent years.

10.3 Technology and economic performance

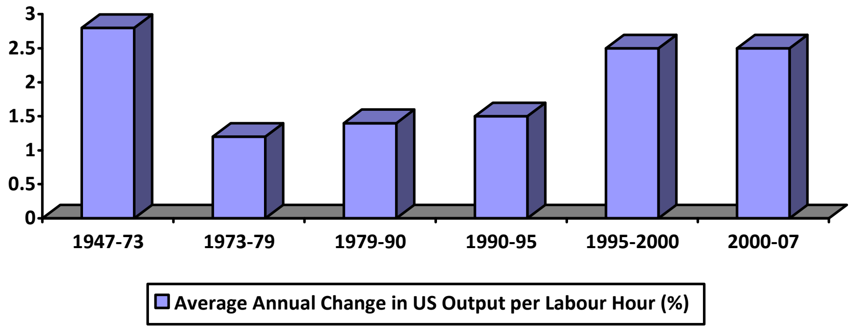
10.3.1 Technology, productivity, and economic growth

There are basically two ways in which an economy can achieve economic growth: either by increasing inputs such as labour, capital, and raw materials, or by increasing the productivity of its inputs. Thus, for example, China's manufacturing industries along its prosperous eastern seaboard have attracted labour from its northern and western regions to help maintain their rapidly expanding output. However, whilst an increase in the quantity of labour may be necessary in the early stages of new economic development, such a policy is unsustainable in the long term as even China's massive human resources are insufficient to sustain the country's recent rate of growth. In the longer term, continued economic growth requires higher productivity: output increasing at a faster rate than inputs. Indeed, increased labour and other inputs only account for part of China's recent economic growth. A growth rate of around 10 per cent per annum since the early 1990s would not have been possible without considerable productivity growth. Whether China will be able to sustain this growth rate in the future is a matter of debate; this issue is considered in Practical Insight 10.6.

Productivity is achieved through improvements in the capacity or quality of inputs, for example as a result of improvements in education and training or advances in technology. Whilst improvements in human capital are clearly of vital importance, technology has played a pivotal role in productivity improvements in many sectors since the Industrial Revolution. The term productivity is most commonly used to describe *labour productivity*, measured by output per worker or per hour worked; note the important difference between these two measures, as an increase in the number of hours worked will raise the former but may even reduce the latter. In studies at the national level, *total factor productivity* is often used, though because of the difficulty in measuring the productivity of other inputs such as capital, it is sometimes measured as the residual – the amount by which an increase in output exceeds an increase in inputs. Using this method of measurement, however, total factor productivity may not be fully evident during the early stages of technological innovation, such as in the US economy when the ICT revolution was accelerating in the early 1990s, or when an economy is slowing down, as in the US in the early 2000s, despite the continuing pace of technological change.

Nevertheless, productivity improvements provide a significant element of the explanation for the long-run superior economic performance of the world's most successful economies, whether large or small.[24] However, it is important to distinguish between the many incremental innovations that help to increase productivity and economic growth on a regular basis and the more fundamental innovation which occurs at particular points in time. Innovations such as the steam engine, electricity, or the computer are sometimes described as *general-purpose technology* – technology which has a number of applications which are discovered over a period of time. Countries that have developed an innovative environment are able to generate continual improvements in productivity through a series of incremental innovations, whereas fundamental innovation in the form of a new general purpose technology may initially cause a decline in productivity as resources are transferred from old technologies to new ones and old industries start to decline before the new industries have become established. This appears to have been the case with US labour productivity after the introduction of computer technology in the 1970s, but productivity then began to increase as the new general purpose technology and its applications came into general use (see Figure 10.3).[25]

Figure 10.3: US productivity growth in the non-farm business sector, 1947-2007



Source: US Bureau of Labor Statistics

Practical insight 10.6: When will China overtake the United States?

Table 10.2 indicates that the US economy was roughly twice as big as the Chinese economy in 2007, valued on a purchasing power parity basis (see section 4.4.1). It was in fact just over four times as big on an official exchange rate basis though, given that the Chinese renminbi was almost certainly undervalued, purchasing power parity probably provides a more reliable indicator. However, the Chinese economy grew over three times as quickly as the US economy between 1990 and 2006, so at this rate China is clearly catching up with the United States. Using the following formula, it can be calculated that it will take China approximately 11 years from 2007 (i.e. 2018) to become the world's largest economy.

$$GDP_n = GDP_0 (1 + g)^n$$

Where GDP_n is GDP in *n* years, GDP_0 is GDP now, and *g* is the percentage growth rate expressed as a decimal.

Of course, this calculation assumes that both the Chinese and US economies will continue to growth at a constant average annual rate. In practice, this will depend on a number of factors. As the Chinese economy is coming from behind, it has been able to acquire technology from more developed countries, so most of its productivity improvements have resulted from technology transfer rather than home-grown innovation. This will become more difficult as China develops, so for this and other reasons its growth rate will almost certainly slow down.

Questions: What factors are likely to determine how long it will take for the Chinese economy to become the world's largest economy? Why will it take much longer for China's GDP per capita to catch up with the United States?

Table 10.2: The Chinese and US economies

	GDP ($US trillion) PPP basis 2007	GDP per Capita ($US), PPP basis 2007	Average Annual GDP Growth Rate 1990-2006 (%)
China	6.99	5,300	9.8
United States	13.84	45,800	3.0

Source: CIA WorldFactbook and IMF

10.3.2 The role technology in theories of economic growth

A number of attempts have been made to explain why long-run economic growth occurs and why some economies grow faster than others. However, in recent years two explanations have dominated the debate. The first body of theory is known as neoclassical growth theory and is built on the work of Robert Solow.[26] Solow argued that about 80 per cent of US economic growth during the first half of the twentieth century could be explained by technical progress, with 20 per cent resulting from increases or improvements in labour and capital. Technical (or technological) progress should be interpreted loosely to include changes in work practices and business organization, among other things, as well as technological innovation. However, neoclassical growth theory regards technological progress as an *exogenous* factor, something which is not specifically explained in the theory but which is a crucial determinant of economic growth. As the capital stock of a country depreciates, new investment is needed to ensure continued economic growth. The level of investment required to maintain constant economic growth depends on population growth and improvements in labour productivity as well as the rate of capital depreciation.

From the 1980s onwards, Paul Romer[27], Robert Lucas[28] and others developed what has become known as *new growth theory* or *endogenous growth theory* as a way of explaining how economic growth occurs. In their model, technological progress is determined endogenously (within the model) as the outcome of a number of processes at work in an economy, in particular the level of technological knowledge and quality of human capital. Within this approach, the focus of attention turns to the way in which government policy, education, competition, intellectual property rights and other factors create incentives to generate technological innovation. An important implication of endogenous growth theory is that, unlike neoclassical theory where capital depreciation leads to decreasing returns from capital investment, the conditions leading to endogenous growth may create increasing returns as various factors interact with each other to create a climate of continual innovation. The creation of knowledge is a prime example of increasing returns, as even research and development by private firms creates spin-off benefits for other firms and the economy as a whole. Clearly, technological progress plays an important role in both theories, but the concept of increasing returns presents a new way of thinking about how economies grow – an idea which is used extensively in complexity theory (see sections 1.2 and 9.3.5).

10.3.3 Network effects and increasing returns

Networks are an important feature of technology markets; examples include telephones, faxes, the internet and intranets, radio and television, electronic exchanges such as Ebay, credit cards and electronic banking systems, and software that is interoperable with operating systems on hardware such as computers, games consoles, or DVD players. Business and social networks are also common. Network effects are the benefits to individual users that arise as the number of users increases. Having a telephone is of little value if no-one else has one, but its usefulness increases exponentially when there are millions of users around the world. This is an example of increasing returns, as the returns or benefits to each individual increase as the size of the network increases. Network effects are sometimes described as *network externalities* because prices charged for the use of a network do not necessarily fully internalize the benefits to all users, as the addition of a new user creates positive externalities for other users; the benefits to the owner of the network may, however, be fully internalized.

It should be noted that networks may grow rapidly as they approach a critical mass of users, but the more profitable connections are likely to be made first, leaving network growth to slow down as the remaining connections become less profitable. Whilst increasing returns may continue, their rate of increase is likely to slow down and returns may even start to decrease if the network's size leads to inefficiencies or other negative effects for users. In general, however, networks are likely to generate positive *feedback effects*, where the actions of individual users or interactions between users create benefits for the network as a whole, helping to produce increasing returns. Network effects, which are particularly important in technology markets, are therefore likely to reinforce the impact of technology in generating endogenous growth.

10.4 The knowledge economy

10.4.1 A new economy?

The ten-year upturn in the US economy which occurred throughout the 1990s was unprecedented both in its duration and in the fact that economic growth accelerated during the second half of the decade when one would normally have expected a downturn in the cycle. The most common explanation for this phenomenon was that the internet, whose use grew more rapidly in the USA than elsewhere, had facilitated a huge expansion in the ICT sector, which in turn had led to accelerating improvements in productivity and economic growth. This view was reinforced by the fact that inflation had remained low despite low unemployment, presumably because of falling costs and competition, and by the boom in the number of dedicated *dot.com* companies and their stock market valuations. The term *new economy* has been used to describe these ICT companies, not only the dot.coms (a number of which went out of business when their share prices collapsed in 2001), but also companies in the computer, telecommunications, and other branches of the ICT sector. The new economy seemed to represent the new technology and its superior ability to increase productivity and add value, as opposed to the 'old' economy of traditional manufacturing whose contribution to economic growth was declining.[29]

With hindsight, this characterization of the new economy seems out of place, not only because of the bursting of the dot.com bubble, but because ICT has increasingly spread to most parts of the developed economies, including many of the 'traditional' industries. Perhaps a more useful term to describe the 'new' economy that has grown out of the ICT revolution is the term *knowledge economy*. 'Knowledge' industries encompass not only computing and telecommunications but also the many manufacturing and services industries which use technological and other advanced forms of knowledge. Of course, knowledge industries have been in existence for centuries, but knowledge as a resource, embodied in educated and skilled workers and technology and other knowledge products, has become increasingly important in most modern developed and emerging economies. It has been estimated that knowledge industries, defined as high- and medium-tech manufacturing, high-tech services, financial services, business and communication services, health, education, and cultural industries, accounted for 41.4 per cent of total employment in the EU15 member states in 2005.[30]

10.4.2 Knowledge as a quasi-public good

If knowledge is fundamental to the process of technological change and the development of a modern economy, it is worth considering how it differs from more conventional resources. Most goods that are exchanged in a market economy are *private goods*. Private goods are normally both *rival* and *excludable*; that is, consumption of a good by one individual precludes consumption by others (rivalry) and particular consumers may be prevented from consuming the good if desired (excludability). This applies to resources such as labour, capital, raw materials, and manufactured components. Public goods, such as defence or law and order, are *non-rival* and *non-excludable*. Knowledge has many of the characteristics of a public good in that it is always non-rival and partially non-excludable. It may therefore be described as a *quasi-public* good. Although new knowledge is often generated by private individuals or businesses and competitors or customers can be denied access to it by intellectual property protection or password restrictions, once knowledge comes into the public domain it is non-rival; no matter how many people 'consume' it, each consumer has access to the same knowledge.[31]

Although the value of knowledge may depreciate if it is not kept up to date, new knowledge can immediately be shared with any number of users without necessarily diminishing its usefulness. The production and consumption of knowledge may therefore give rise to significant increasing returns to society as a whole. International spill-over effects will also spread the benefits to other countries keen and able to take advantage of it. Where knowledge is developed through open-source technologies such as the Linux operating system or the Wikipedia on-line encyclopaedia, it is intentionally non-excludable and is therefore a pure public good. However, even when knowledge is partially excludable, its non-rivalry characteristic makes it significantly different from conventional resources. For this reason, the knowledge economy may have greater potential to create dynamic endogenous growth than an economy based on more conventional resources.

10.4.3 Technological innovation and creativity

The story of technological innovation involves the generation of new ideas, designs, inventions, and discoveries which combine human effort, accumulated knowledge, and other resources over a period of time. This is a creative process. Creativity is of course not restricted to technological developments. It can be found in the arts and also in a wide range of business and social activity. A marketer who finds an imaginative way to promote a new product or a banker who develops an innovative financial product may be acting creatively. What is important is that, whilst the use of existing techniques or technologies in familiar ways may be routine, the continual adaptation or novel application of ideas and technologies is a creative activity.

Practical insight 10.7: A creative quarter for Middlesbrough?

The author's university town of Middlesbrough in North-East England has introduced a number of regeneration initiatives to overturn its legacy of urban decay following the decline of traditional heavy industries like shipbuilding. One of the more ambitious initiatives is the DigitalCity project.[32] This project is jointly sponsored by the University of Teesside, Middlesbrough Borough Council, the north-east regional development agency, One NorthEast, and a number of local business organizations. The DigitalCity project builds on the existing expertise of the University of Teesside in media technology and digital animation, and aims to combine this expertise with new and growing businesses by providing business units with close access to academic researchers. It will also serve as a vehicle for the commercialization of academic projects.

Although initially focused on the digital media, the intention is to promote creativity rather than purely technical expertise. Whilst initial developments involved the provision of specialist facilities on the university campus, the second phase of the project involves the establishment of a creative district in a previously run-down area of the town. This district has been named the 'BoHo Zone', aiming to combine Middlesbrough's (and its football team's) nickname, 'Boro', with the creative feel of London's famous Soho district. The BoHo Zone incorporates a building providing live-work accommodation for artists, specialists in digital media, and other creative professionals alongside refurbished historic buildings in the hope of establishing a supportive environment for creative activity of various kinds.

Question: To what extent do you think a creative community of this kind is viable and on what factors is its success in regenerating economic activity likely to depend?

Some researchers have argued that creativity, in its wider sense, is an important driver of local, regional, or even national economic development. Richard Florida has published extensively on this theme, arguing that the 'creative class', including creative professionals in a variety of fields, helps to stimulate the economic development of towns and cities and contributes to the economic success of nations.[33] Florida uses an index of creativity to indicate a region's creative and economic potential. The creativity index includes the 'creative class' share of the workforce, the proportion of high-tech industry, the number of patents per capita, and, more controversially, the proportion of gay people (the 'gay index') as a proxy for the degree of tolerance and openness. Whilst Florida's methodology and results have been criticized, the importance of creativity in technological innovation and economic development is nevertheless increasingly being recognized. Practical Insight 10.7 provides an example of an industrial town trying to recreate is creative history.

Discussion questions

1. What factors might need to be present to allow a technological adopter country to become a technological innovator?
2. What factors are likely to influence the progress of an invention from conception to full commercial development?
3. How important is path dependence in the technological development process?
4. To what extent is a high level of demand necessary to facilitate the development of technology markets?
5. What is the link between technology, productivity, and economic growth?
6. What is the significance of non-rivalry for the spread of knowledge?

Suggested research topics

1. Select a specific country which can be described as either a technological adopter or technologically excluded. Identify the changes that would need to occur for the country to become either a technological innovator or technological adopter respectively.
2. Choose a specific example of a general purpose technology (or fundamental innovation) and identify the main influences on its development.
3. With reference to a specific industry, investigate the extent to which knowledge has become relatively more important than conventional resources in recent years.

Case study: The changing use of the internet

By the end of the 1990s, Microsoft had overtaken Netscape's early lead in the web browser market, using the dominant position of its Windows operating system as a platform to launch its Internet Explorer web browser software. By early 2009, Microsoft's Internet Explorer had around 75 per cent of the web browser market, with Mozilla Firefox (Netscape's open-source successor) in a distant second place with 18 per cent, Apple Safari (which can also be used on a Windows operating system) in third place with 4 per cent, and Opera in fourth place with 1 per cent of the market.[34]

During this period, internet usage increased dramatically and the worldwide web was increasingly being used as an interactive medium rather than simply to make information available. Examples of this trend include the use of blogs and podcasts, the development of social networking websites such as Facebook, Friends Reunited, or Twitter, and video-sharing websites such as YouTube – developments which have collectively been described as Web 2.0. The popularity of this type of website has encouraged a number of businesses to consider ways of using them as a tool for marketing their products or for making links and sharing ideas with other businesses. Web 2.0 technologies may prove particularly useful for small businesses, enabling them to develop support networks with similar or complementary businesses.

Alongside these developments, the internet is increasingly being used to create web platforms, where applications such as word processing and spreadsheets can be accessed via a web browser rather than as desk-top software. Microsoft launched a test version of its hybrid computer platform, Live Mesh, in April 2008, and Firefox offers its users similar facilities. The 'browser war' intensified in September 2008 when Google, better known for its internet search engine, launched its own free web browser, indicating its intention to challenge Microsoft in the battle for supremacy in web platform technology. Web platforms provide greater integration between web-based and conventional desk-top operations and allow documents to be stored on remote servers, enabling users to access files from anywhere via a web browser. This means there is no need to have particular software on each computer. These developments are likely to offer the prospect of fully integrated web services over the next few years.

Although web-based applications are not yet as sophisticated as conventional software, this may change as competition to provide integrated web platforms increases. The arrival of Google in the web browser market is also potentially significant, given Google's success as an internet search engine. Whether Microsoft will be able to retain its dominant position in the web browser market remains to be seen, but if web platforms become the norm, Microsoft's desk-top software may be under threat. Computers will still need an operating system, but the choice of operating system may be less important if users transfer to web-based applications. A new struggle to achieve the dominant standard will emerge among web platform providers, though Microsoft may still hold on to its committed MS Office users for some time to come.

Inevitably, there will be teething problems with the new technology and the full benefits of web-based applications may not emerge for some time. Security issues may also increase if everything is carried out online and the need to speed up internet connections may become a pressing issue. No doubt these concerns will gradually be resolved over a period of time. Whatever happens, however, business use of the web for networking and other computer-based activities is likely to increase substantially in the coming years. What is less certain is the impact these developments will have on the conduct of business, improvements in productivity, and economic growth.[35]

Case study questions

1. What potential benefits might social networking websites offer to small businesses?
2. Do you consider web platforms to be a fundamental or incremental innovation? Explain your answer.
3. Given that the full potential of web platforms is not likely to be achieved for some time, what does this tell us about the process of innovation?
4. There is considerable uncertainty about the way web platforms will develop. What are the main reasons for this uncertainty?
5. How are web platforms likely to affect work practices and productivity?
6. What benefits might arise to the web platform provider who achieves a dominant standard?
7. Are there any incumbent advantages to Microsoft when developing web-based applications, given the widespread familiarity with its Office software?
8. What are the implications of the increasing use of web-based applications and social networking websites for our access to knowledge?

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