Chapter 1
A Look Inside the Economic Growth Engine

Economic growth has been a powerful force for reducing poverty, creating jobs and improving general living standards. However, it cannot be taken for granted. Before the 18th century the world economy saw little growth. Poverty was widespread and any substantial improvement in living standards for more than the privileged few was beyond imagining. Since then, the world economy has grown at an unprecedented pace – greatly improving the quality of life and generating widespread material prosperity. Even so, some national economies have seen faster and more sustained growth than others, leaving wide disparities in the prosperity of nations today.

What explains the variations in growth observed throughout history? Scholars have long puzzled over this. The onset of gradually faster growth in the second half of the 18th century prompted the first theories of economic growth – as proposed, for example, by Adam Smith, David Ricardo, Thomas Robert Malthus and John Stuart Mill.[1] Important insights have emerged since then. One central insight is that lasting economic growth relies on continuous technological progress. Indeed, the last three centuries have seen a series of innovative breakthroughs in different fields of technology that have profoundly transformed productive activity and spurred the growth of new industries.

Against this background, this report asks what role the intellectual property (IP) system plays in the growth process. It does so in two parts. First, it reviews the nature of economic growth throughout history and explores the channels through which different IP rights affect growth outcomes – a task performed in this opening chapter. Second, it studies the role of IP more concretely in the case of three historical breakthrough innovations – airplanes, antibiotics and semiconductors – as well as three current innovations with seeming breakthrough potential: 3D printing, nanotechnology and robotics. These case studies will form the core of chapters 2 and 3, respectively.

This opening chapter takes a look inside the economic growth engine. It starts by establishing key stylized facts about economic growth throughout history (section 1.1). It then explores the channels through which innovation drives long-term growth (section 1.2). Against this background, the chapter takes a closer look at the innovation process, exploring how frontier innovations come about and how they disseminate within and across economies (section 1.3). With these building blocks laid, the discussion moves on to consider the various ways in which different IP rights affect innovation and knowledge diffusion outcomes (section 1.4). The final section ponders what growth prospects the future may hold in the wake of the recent financial crisis (section 1.5).

1.1 – Economic growth throughout history

For much of human history, economic growth was simply unknown. By today's standards, living conditions were dismal and they stayed largely the same from one generation to the next. This changed gradually some 200 years ago with the onset of the first industrial revolution, powered by steam engines, cotton spinning and railroads.[2] Since then, sustained economic growth has become the new normal, even if it has not been uniformly spread across time and space.

This section seeks to set the scene by reviewing growth performance over the past two centuries. In particular, a careful analysis of available data and historical studies point to four stylized facts:

1. Growth at the frontier took off in the early 19th century and accelerated in the post-Second World War era.
2. Economic growth has led services to displace agriculture as the main economic activity and has prompted increased urbanization.
3. Diverging growth performance has increased the gap between the poorest and richest economies.
4. Over the past decades, economic growth has gone hand in hand with rising inequality within countries, but fast growth in China and India has been an equalizing force in the world's income distribution and has caused absolute poverty to decline.

1. For a review, see Samuelson (1978).

2. See Gordon (2012).

The following discussion elaborates on these four stylized facts in turn.

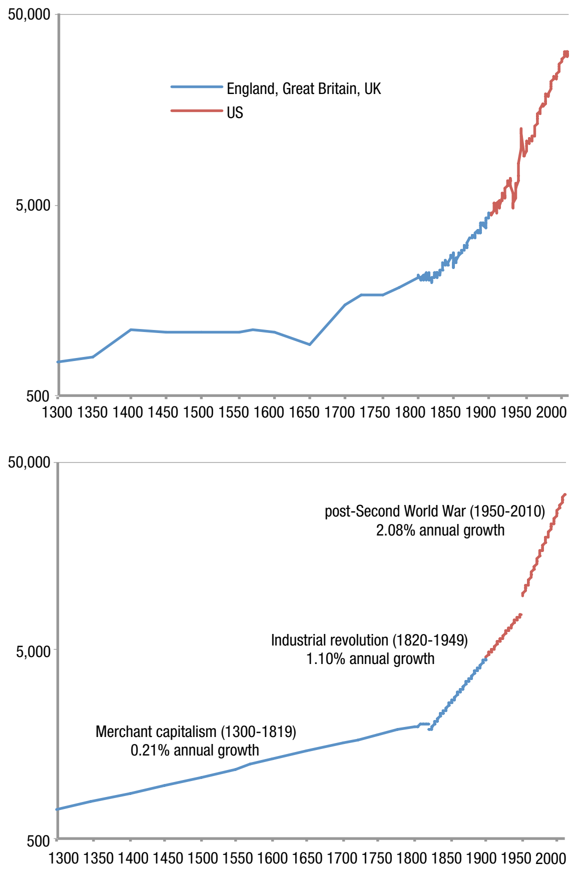
Stylized fact #1
Growth at the frontier took off in the early 19th century and accelerated in the post-Second World War era.

Studying growth performance going back centuries is challenging. Advanced economies only started compiling national accounts – enabling the measurement of gross domestic product (GDP) – in the first half of the 20th century. Most developing economies only did so much later. Economic historians have estimated GDP values for the time before official data became available, making use of historical production, wage, tax and other data records. For selected economies, there are thus estimates of economic output available going back two and more centuries. These estimates are far from perfect. As one moves into the distant past, their margin of error is bound to increase. In addition, as section 1.2 will further explain, comparing GDP values across time raises difficult questions about how to account for changes in the nature and quality of goods and services produced. In all likelihood, comparisons of GDP values over the long run are bound to substantially underestimate improvements in the material standard of living, as they do not fully capture the benefits associated with the arrival of new technology.[3]

Notwithstanding these problems, the work of economic historians is the only source of empirical information on long-run growth performance and it thus bears careful consideration. Relying on the most comprehensive set of historical estimates available – those generated by the Maddison Project – figure 1.1 depicts the evolution of GDP per capita at the frontier since 1300.[4] The frontier is captured by the economy showing the highest economic output per capita at a given point in time. For the purpose of figure 1.1, these are taken to be England, Great Britain and the United Kingdom (UK) up to 1900, and the United States (US) thereafter.[5]

Figure 1.1: Growth at the frontier over seven centuries

Real GDP per capita, 1300-2000, logarithmic scale



Notes: GDP values are in 1990 international dollars, adjusted for differences in purchasing power across countries. For 'England, Great Britain, UK', estimates apply to England up to 1700, to Great Britain from 1700 to 1850, and to the UK from 1851 onwards. Annual growth rates are the slopes of the logarithmic trend lines for the three periods.

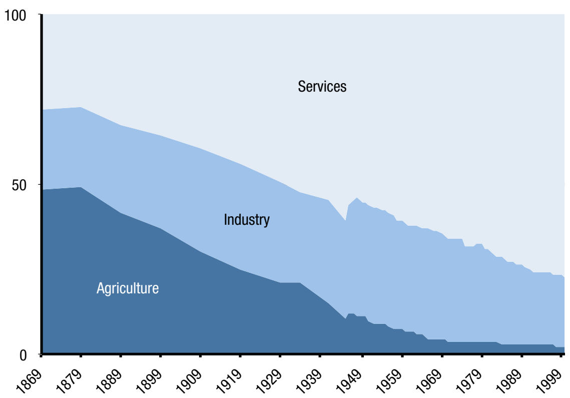
Source: The Maddison Project, *www.ggdc.net/maddison/maddison-project/home.htm*, 2013 version.

3. See DeLong (1998) and Coyle (2014).
4. See Bolt and van Zanden (2014).
5. This approach follows Gordon (2012).

The figure's lower panel divides the seven centuries into three growth periods and shows trend lines depicting average growth of per capita GDP during these periods. The first period – labeled "merchant capitalism" following Kuznets' (1967) original terminology – saw only little and sporadic growth, averaging around 0.21 percent per year.[6] The onset of the industrial revolution then led to a sharp increase in the annual rate of growth, to 1.10 percent.[7] To underline the significance of this growth pickup, 0.21 percent annual growth implies a doubling of income every 331 years, whereas 1.10 percent growth implies the same every 64 years. Finally, in the post-Second World War era, growth accelerated further to 2.08 percent per year – implying a doubling of income every 34 years. In light of centuries of history, the growth performance since 1950 thus emerges as both spectacular and exceptional.

Figure 1.2: The rise of services

Share of US employment in different sectors, 1869-2000, in percent



Notes: "Agriculture" includes agriculture, forestry and fishing; "industry" includes manufacturing, mining and construction; "services" includes transportation and public utilities, wholesale trade, retail trade, finance, insurance, real estate and government as well as the "services" category of the Bureau of Economic Analysis (BEA). Data for 1929 and earlier refer to the Kendrick estimates, as explained in US Bureau of the Census (1975).

Source: BEA, National Income and Product Accounts, table 6.8B, and US Bureau of the Census (1975).

Stylized fact #2
Economic growth has led services to displace agriculture as the main economic activity and has prompted increased urbanization

In medieval societies, agriculture was the center of economic activity. The onset of more rapid economic growth in the early 19th century led to a gradual transformation of economic output, initially away from agriculture and toward industry and services, and – at a later stage – entirely toward services. Figure 1.2 illustrates this transformation for the US, looking at the employment shares of the three main economic sectors since the mid-19th century. In 1869, agriculture accounted for close to half of total employment, with industry and services accounting for around a quarter each.[8] In the 131 years that followed, agriculture lost its dominance and by 2000 it accounted for a mere 2.4 of total employment. The share of industry first expanded to reach a peak of 34.4 percent in 1953, but then fell to 20.4 percent in 2000. The service sector has seen the most dynamic growth. By 1934 it already accounted for more than half of total employment, and by 2000 for more than three-quarters.

A similar picture emerges when looking at the value-added share of each sector in GDP. In 2010, services made up 73.6 percent of economic output in high-income countries, with industry accounting for 25.0 percent and agriculture 1.4 percent.[9] In a nutshell, economic growth has converted the agrarian societies of a few centuries ago into today's services-based economies.

6. Broadberry *et al* (2011) attribute 14th-century growth in GDP per capita to the population decline associated with the Black Death. Similarly, growth in the second half of the 17th century coincided with a declining population.
7. Figure 1.1 follows Maddison (2001) in adopting 1820 as the year marking the transition from the "merchant capitalism" era to the "industrial revolution" era.
8. The choice of 1869 as the starting year in figure 1.1 simply reflects data availability. Historical studies suggest that the structural shift toward industry and services started much earlier. For example, Broadberry *et al* (2011) estimate that the share of agriculture in English GDP fell from 49.1 percent in 1381 to 26.8 percent in 1700, while the services share rose from 23.1 to 34.0 percent over the same period.
9. As reported in the World Bank's World Development Indicators database.

This structural shift had a profound impact on economic geography. Labor freed by the agricultural sector agglomerated in urban areas, which offered not only job opportunities but also access to health, education, retail markets, transportation, entertainment and other amenities. Urbanization accelerated markedly with the onset of the industrial revolution in the 19th century. The United Kingdom – the frontier economy of the 19th century – saw the share of the total population living in cities of 5,000 or more inhabitants rise from one-fifth in 1800 to two-thirds in 1900.[10] London emerged as the world's largest city, reaching one million inhabitants around 1800 and growing to 5.6 million inhabitants by 1891.[11] By comparison, Paris only reached the one million mark in the mid-19th century, New York in 1871, and Berlin in 1880.[12] Indeed, urbanization took longer in other advanced economies. In the US, the urban population share stood at a relatively modest 31.3 percent in 1900, and it surpassed the two-thirds threshold only in the second half of the 20th century.[13] Still, by 2010 close to four-fifths of the population in all high-income countries lived in urban areas.[14]

Stylized fact #3
Diverging growth paths have increased the gap between the poorest and richest countries

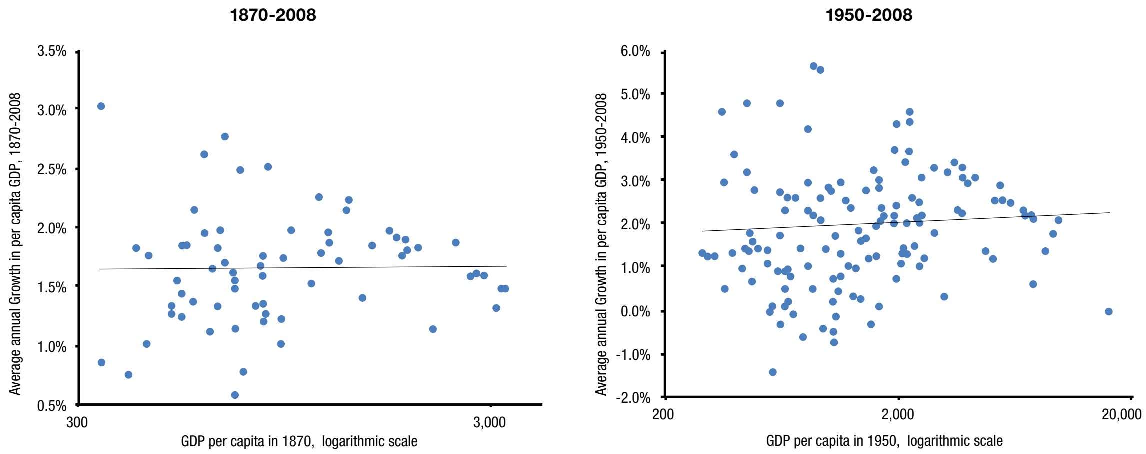
Has economic growth been evenly spread across the world? In particular, how have economies outside the frontier group fared since growth started to accelerate in the 19th century? The short answer is that there has been "divergence, big time" – as famously noted by Pritchett (1997). In 1870 – the earliest year for which data for a wide range of economies are available – GDP per capita of the richest economy was around 10 times that of the poorest economy; by 2008 the gap had widened to a factor of 126.[15] While selected once-poor economies – notably in East Asia – were able to catch up with the frontier group, no such general process of convergence has taken place across the world. Figure 1.3 illustrates this point by plotting initial income against subsequent growth for all economies, as far as available data go. If incomes had converged, one would expect the scatter plots to show a negative correlation, indicating faster growth in initially poorer economies. However, there is no such negative correlation – neither during the full 1870-2008 period nor during the shorter post-Second World War period.[16]

Sustained growth at the frontier and the lack of convergence by non-frontier economies have led to sharp differences in absolute income levels across the world. To illustrate this point, consider the experience of Germany and Ecuador. In 1870, Germany had a per capita income of United States dollar (USD) 1,839 compared with Ecuador's income of USD 411– a difference of USD 1,428. From 1870 to 2008, average annual growth in both economies was largely the same, around 1.8 percent. As a result, Germany's per capita income increased to USD 20,801 in 2008 and Ecuador's to USD 5,005. In turn, the absolute difference in income levels increased elevenfold, to USD 15,796.[17]

10. See Bairoch and Goertz (1986).
11. As derived from London's historical census data, available at *data.london.gov.uk/dataset/historic-census-population*.
12. See Watson (1993).
13. As derived from US Bureau of Census data, available at *www.census.gov/population/www/censusdata/files/table-4.pdf*. Using a threshold of cities with 2,500 or more inhabitants, the urban population share stood at 63.1 percent in 1960.
14. As reported in the World Bank's World Development Indicators database.
15. These estimates rely on the Maddison Project database (see also figure 1.3). In that database, Australia was the richest and the Republic of Korea the poorest country in 1870, and the US was the richest and the Democratic Republic of the Congo the poorest country in 2008.
16. The slopes of the linear regression lines shown in figure 1.3 are not statistically different from zero. Note, however, that there has been long-run income convergence among high-income economies (Pritchett, 1997).
17. All figures in this example are in 1990 international dollars and come from the Maddison Project database.

Figure 1.3: Poorer economies have not grown faster than richer economies

Initial income versus subsequent growth



Notes: GDP values are in 1990 international dollars, adjusting for differences in purchasing power across countries. The left panel includes all 67 economies for which the Maddison Project database provides GDP per capita estimates for 1870. The right panel includes 138 economies for which 1950 GDP per capita figures were available; it excludes three small oil producing economies – Equatorial Guinea, Kuwait and Qatar – as their growth performance was heavily influenced by cyclical factors either at the beginning or at the end of the 1950–2008 period.

Source: The Maddison Project, *www.ggdc.net/maddison/maddison-project/home.htm*, 2013 version.

In addition, initial differences in per capita incomes have largely persisted over time. Eight of the ten richest economies in 1870 are still among the ten richest economies of 2008. Only Hong Kong and Singapore were able to break into the top ten.[18] To be clear, most economies outside the frontier group have also seen sustained economic growth, promoting far better living standards for their citizens than in the 19th century. However, growth patterns across the world have not narrowed inequalities in the prosperity of nations; they have widened them.

Stylized fact #4

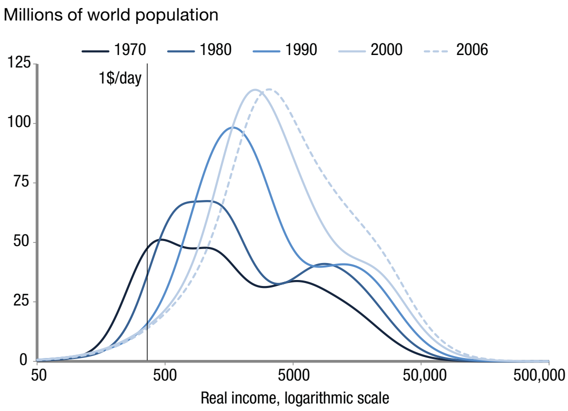
Over the past decades, economic growth has gone hand in hand with rising inequality within countries, but fast growth in China and India has been an equalizing force in the world's income distribution and has caused absolute poverty to decline

If nations' incomes have diverged, does this mean that the world has become a more unequal place? Not necessarily, for two reasons. First, the above analysis treats each country the same, ignoring that some countries are far more populous than others. Second, it does not consider changes in the distribution of income within countries, which affects the prosperity of the average citizen.

18. As previously, these comparisons are based on GDP per capita figures from the Maddison Project database.

To assess whether the world has become a more or less equal place, one needs to analyze how the distribution of income across all citizens in the world – rather than countries – has evolved over time. Sala-i-Martin (2006) performed precisely such an analysis. Using data on GDP per capita and the national income distribution of 138 countries, this study estimated the world distribution of income going back to 1970.[19] It reached three conclusions. First, most countries have seen growing income inequalities among their citizens. Second, despite this and despite the growing divergence of incomes across countries, world income inequality has fallen. This conclusion may at first appear counterintuitive. However, it is explained by the fast growth of populous and initially poor Asian economies, notably China and India, which saw their incomes converge to those of the advanced economies. Subsequent research, relying on different data and alternative estimation approaches, has been more cautious about concluding that overall world inequality has fallen.[20] However, it has confirmed the equalizing force that the growth of large Asian economies has exerted on the global distribution of income.

Figure 1.4: Growth has reduced extreme poverty



Notes: The lines depict the world distribution of income in different years, whereby the area under each line und above the horizontal axis represents world population in any given year. Real income is measured in 2000 international dollars, adjusting for differences in purchasing power across countries.

Source: Pinkovskiy and Sala-i-Martin (2009).

Third, economic growth has substantially reduced levels of extreme poverty – as captured by income of one dollar a day or less. Figure 1.4 – relying on an update to Sala-i-Martin's estimates – depicts the world distribution of income since 1970 as well as the one-dollar-a-day threshold. It shows how economic growth has shifted the world income distribution to the right. Especially fast growth in large and initially poor Asian economies has transformed its shape into a single-peak distribution. In the process, the extreme poverty headcount fell from 403 million 1970 to 152 million in 2006. In addition, in 1970 most poor people lived in Asia, whereas by 2006 they were mostly found in Africa. Other studies, at times using different poverty thresholds, have arrived at different estimates of poverty levels.[21] However, they uniformly document the substantial reduction in extreme poverty and its geographical shift.

1.2 – How innovation drives economic growth

Why has the growth performance of economies varied so much over time and across the world? What fuels the economic growth engine? Few questions in economics have generated so much research. This section reviews the main drivers of economic growth, seeking to identify in particular the main channels through which innovation generates growth. It focuses on the long-term determinants of economic growth, ignoring business-cycle fluctuations that lead an economy to temporarily deviate from its fundamental growth path (see section 1.5 for further discussion).

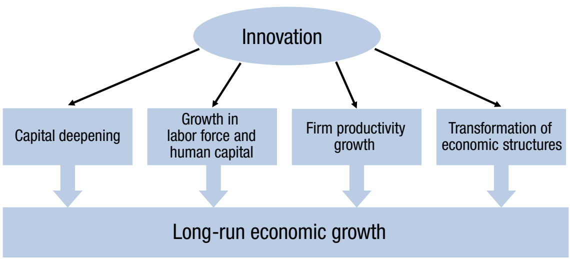
The most common "workhorse" that economists use to isolate the sources of long-term growth is the so-called growth accounting framework, usually attributed to the Nobel prize-winning economist Robert Solow.[22] This framework decomposes output growth into two components: first, a component attributable to the accumulation of production factors – mainly capital and labor, later expanded to include human capital; and second, a component capturing an economy's overall productivity growth, also referred to as total factor productivity (TFP) growth.

19. Sala-i-Martin (2006) imputes missing data points through econometric forecasting and by relying on data from neighboring countries.
20. Lakner and Milanovic (2013), for example, employ survey data to capture countries' average incomes, rather than the national accounts data employed by Sala-i-Martin (2006). They estimate a higher Gini coefficient than Sala-i-Martin which has hardly fallen over time. See also Pinkovskiy (2013).
21. See, for example, Chen and Ravallion (2004).
22. See Solow (1956; 1957).

The growth accounting framework goes some way to explain why some nations have grown faster than others.[23] For example, empirical studies have pointed to high rates of investment and the absorption of surplus rural labor into the formal labor force as key explanations for the rapid growth of several East Asian economies over the past decades.[24] However, in trying to understand how technological innovation has driven growth, the growth accounting framework faces two important limitations. First, even though technological innovation is often thought to be a key determinant of TFP growth, it can also have profound effects on factor accumulation, as further explained below. Second, empirical studies typically capture TFP growth as the residual growth left after accounting for the influence of production factors. As such, they cannot offer any insight into the precise forces that lead economies to become more productive.

Obtaining such causal insights is challenging. Technological innovation has complex effects on the behavior of firms and workers and the structure of economies. Nonetheless, one can broadly distinguish four transmission channels – as illustrated in figure 1.5.[25] This section elaborates on these transmission channels.

Figure 1.5: Innovation spurs growth through different channels



Capital deepening

Firms invest in new capital equipment based on the future income they expect those investments to generate. The introduction of new technologies can raise investment returns and lead firms to undertake new investments. Similarly, new technologies affect the decisions of governments to invest in public goods, especially the provision of an economy's infrastructure. Indeed, neoclassical growth theory predicts that without any technological progress, diminishing returns on capital investment set in and economic growth converges to zero.[26]

Historically, the introduction of major breakthrough technologies has often unleashed investment booms, driving expansions in economic output. For example, the arrival of railway technology in the 19th century prompted massive infrastructure investments that, in themselves, drove sizeable output fluctuations.[27] More recently, as information and communication technologies (ICTs) took off in the 1990s, studies show that US firms throughout the economy rapidly increased their ICT capital stock, especially when compared with other fixed capital assets.[28] In addition, intangible asset investments – the establishment of new business processes, databases and other knowledge-based activities – have become an important component of overall investments and are also linked to the introduction of new technologies.

Growth in labor force and human capital

Historically, technological innovation has been a key force behind the expansion of the workforce. First and foremost, advances in health technology have prompted a dramatic increase in life expectancy. For example, in 1800 average life expectancy at birth was below 40 years in all developed economies; by 2011 it had risen above 75 years, with Japan seeing the highest average of 83 years.[29] By reducing the burden of chronic disease and disability, technology has also contributed to a progressively healthier – and thus economically more productive – workforce.

23. See, for example, Mankiw *et al* (1992) for econometric evidence.
24. See Young (1995; 2003), although Nelson and Pack (1999) argue that high rates of investment were only possible because those successful East Asian economies learned how to use new technologies effectively.
25. Maddison (1997) offers a similar categorization.
26. See Solow (1956).
27. See chapter 5 in O'Brien (1977).
28. See, for example, Stiroh (2002).
29. See Roser (2015).

Innovation has been instrumental in facilitating greater adult participation in the workforce. For example, the introduction of refrigeration, indoor plumbing, the washing machine, supermarkets and other innovations freed family members – especially women – from routine household tasks, enabling them to enter into formal employment. Similarly, the arrival of speedy mass transportation reduced geographical barriers in the labor market. These factors have also promoted access to education, increasing the quality of the labor force. Advances in educational technology, in turn, have widened and deepened educational achievements, further augmenting the economy's human capital base.

Firm productivity growth

Innovation can affect the productivity of firms through a variety of channels. *Process innovations* can increase the efficiency with which inputs – especially labor – are converted into output. Often, such efficiencies result from the deployment of new capital equipment, as described above. The resulting productivity enhancements free up resources that can be used to expand output – in the same firm, in the same sector, or elsewhere in the economy. Similarly, process innovations that lead firms to reap greater economies of scale lead to greater output with the same level of capital and labor input.

Product innovation has more varied effects on productivity. One form of such innovation is the quality upgrading of existing products – for example, the introduction of more powerful computers, longer-lasting batteries and more energy-efficient refrigerators. If firms manage to produce the same output level with the same inputs but the output is of superior quality, product innovation directly leads to improved firm productivity. While conceptually this is straightforward, measuring quality improvements in economy-wide output poses a substantial challenge, as explained in box 1.1.

A second form of product innovation is the introduction of new products that did not previously exist. Such products could either be sufficiently distinct varieties of existing products – for example, a new car model – or more fundamental breakthroughs such as the first tablet computer. Since the firm introducing the new product did not produce it previously, one cannot evaluate how such innovations directly affect the firm's productivity. As in the case of quality improvements, correctly measuring the growth of economic output when new products enter the marketplace can be challenging (see box 1.1).

Ultimately, the productivity effects of new products depend crucially on whether buyers of new products are final consumers or other firms which use the products as a production input. In the case of the former, consumers of new products invariably adjust their consumption basket, leading to changes in the composition of output. How such changes affect productivity is uncertain. However, since consumers voluntarily purchase the newly available products, their welfare is bound to increase.

New products that serve as intermediate inputs for other firms may give rise to important productivity gains.[30] Indeed, the introduction of electricity, affordable long-distance travel, telecommunication, computing and many other goods and services has historically led to substantial productivity gains in firms across a wide range of sectors.

Finally, just as process and product innovations can raise a firm's productivity performance, so can they render the functions of government more efficient. In recent history, for example, the introduction of ICTs in the delivery of government services – often labeled 'e-government' – has markedly improved the quality and cost-effectiveness of these services.[31]

30. Grossman and Helpman (1991) model such productivity gains as an increase in the diversity of intermediate inputs.
31. The Australian Government has published a comprehensive study describing the quality and efficiency gains from e-government, available at *www.finance.gov.au/agimo-archive/__data/assets/file/0012/16032/benefits.pdf*.

Box 1.1: Capturing new goods and services in GDP statistics

Measuring economic growth relies on the efforts of statisticians to quantify overall economic output. Since one cannot meaningfully add quantities of oranges and apples – let alone quantities of tablet computers, taxi rides and doctor visits – statistician rely on the market valuation of these quantities. Multiplying quantity times price for each good and service, and adding the resulting valuations together yields an economy's GDP.

Calculating so-called *nominal GDP* values for any given year is relatively straightforward. However, difficulties arise if one wants to track economic output over time. To begin with, changes in nominal GDP may reflect changes in underlying quantities, changes in prices, or both. For example, a high inflation rate might lead to a sizeable increase in nominal GDP, even if quantities remain unchanged. For this reason, statisticians have devised the concept of *real GDP*, which measures the physical quantity of economic output using the prices of a given base year.

However, an intricate problem arises from product innovation that prompts new goods and services to enter the marketplace. If those new goods and services do not relate to any previous ones, prices from a previous base year are not available. The only way to include them in real GDP calculations is to update the base year. But which year to choose is not obvious. The prices of new goods and services will often decline rapidly, and quantities grow quickly, in the first years after their introduction; choosing an early base year might then overstate real GDP growth. For this and other reasons, statistical offices in many countries have introduced so-called chain-weighted approaches to real GDP measurement, whereby the base year is implicitly updated every year.

If new goods and services reflect quality improvements on previously existing ones, prices from a previous base year do exist.[32] However, comparing the quantities of the new goods and services to those of the old ones would be misleading. For example, if quantities were expressed in boxes of strawberries, one would naturally adjust for a change in the weight of boxes from one year to the next. Similarly, if one were to count boxes of computers, one should adjust for the increase in the computing power of each box from one year to the next.[33] Statisticians have devised methods for making such quality adjustments. Using so-called matched-model and hedonic techniques, one can estimate hypothetical price indices that capture changes in the price of goods and services, holding their quality characteristics constant. These price indices are then used to deflate nominal GDP values, yielding a measure of real GDP that accounts for quality improvements.[34]

Chain-weighting and hedonic techniques are important tools to accommodate product innovation in GDP measurement. However, they are not perfect.[35] Above all, they rely on the ability of statistical offices to quantify and collect data on a large array of quality attributes of goods and services. Even the best-resourced offices only perform hedonic adjustments for a limited set of goods and services. Moreover, certain quality gains do not easily lend themselves to quantification – such as innovations leading to improved safety, security, sustainability and overall quality of life.

Finally, it is important to point out that real GDP growth only partially captures the welfare gains associated with product innovation. This is partly because of imperfect measurement, as just described. More importantly, GDP growth just seeks to measure how output evolves over time, not how consumers – and society at large – value any output expansion. While there are good reasons why one would expect output and welfare to correlate, they are fundamentally different concepts.

Sources: Landefeld and Parker (1997), Landefeld and Grimm (2000) and United Nations (2009).

32. In practice, the distinction between a new good and a good of superior quality can be ambiguous. For example, new functionality in a product may be considered a quality improvement; however, if the new functionality is sufficiently important and leads to new uses of the product, it may be regarded as an entirely new product. This ambiguity further complicates measurement efforts. See OECD (2001).
33. This example is taken from Landefeld and Grimm (2000).
34. Another important measurement challenge is which types of creative and innovative activities of companies should be accounted for as intermediate consumption and which as asset investments. For example, the *System of National Accounts 2008* recognizes R&D spending and software as fixed asset investments (see *unstats.un.org/unsd/nationalaccount/sna2008.asp*). Other intangible asset investments may follow in future.
35. For a review of methodological criticisms, see Hulten (2003).

Transformation of economic structures

Innovation has far-reaching effects on the growth performance of firms. Equally if not more important, new technologies are often at the root of profound structural transformation. In the medium to long term, such structural transformation affects an economy's productivity performance through a variety of channels.

First, new technologies can change the face of industries, leading to the exit of some firms and the entry of others. In addition, the intensity of competition may change. In many cases, these changes prompt growth-enhancing efficiency gains and redeployment of production factors. Vibrant competition can spur technology dissemination and future innovation.[36] However, such an outcome is not certain. Technology may well lead to more concentrated industry structures, sometimes even prompting the concern – and intervention – of competition authorities.[37]

Second, technological innovation often unleashes a reorganization of supply chains. Typically, such reorganization involves greater specialization, with firms developing unique expertise or producing specialized inputs that serve a variety of companies, within and across industries. Increased specialization can generate important efficiencies that translate into economy-wide productivity gains. Technological innovation has also facilitated the globalization of supply chains. The participation of a wider and more diverse range of international suppliers amplifies the productivity gains associated with greater specialization.

Third, as technological innovation gives rise to new economic activity, it prompts the decline of older activity. For example, the arrival of automobiles replaced travel by horses, obviating the need for large numbers of workers to clean the streets of horse manure. Similarly, the introduction of telephone technology enabling direct dialing obviated the need for manual switchboard operators. In the short to medium term, such technological disruption may create hardship for those whose tasks have become redundant. However, in the longer term, the redeployment of workers in growing sectors of the economy represents one of the most important ways through which innovation can generate output growth.

As shown in figure 1.2, in practice technological progress has prompted a substantial shift away from agriculture and industry toward the service sector. This has largely reflected substantially faster historical rates of productivity growth in agriculture and industry, compared with labor-intensive services.[38] Accordingly – if somewhat counterintuitively – agriculture and industry have freed workers who have found employment in a growing service sector.[39] From this perspective, a shrinking share of industry in output has not necessarily been a worrying sign of "deindustrialization" – as is sometimes claimed – but a natural byproduct of technological progress.

1.3 – Frontier innovation and diffusion

The discussion above has shown the central role of innovation in driving long-term growth. But which innovations account precisely for how much growth? The infographic at the end of this report depicts some of the most important technological breakthroughs over the past 200 years, along the frontier growth path shown in figure 1.1. It is meant as an illustration, and the selection of technologies is clearly subjective.

36. Aghion *et al* (2005) formally explore how competition and innovation interact. See also the discussion of endogenous growth in section 1.3
37. Examples of industries shaped by new technologies that have faced the scrutiny of competition authorities include telecommunications (AT&T), computer operating systems (Microsoft) and online search (Google).
38. See Baumol (1967) and Baumol *et al* (1985), though the latter article also points to heterogeneity within the service sector, with some service activities such as communications and broadcasting having seen fast productivity growth.
39. In addition to technology, the rise of the service sector arguably also reflects the rising demand for services – including education, health, travel and entertainment services – as economies grow richer.

Box 1.2: Quantifying the growth impact of past innovations

Studies seeking to quantify the growth impact of specific innovations have mostly relied on the growth accounting framework outlined in section 1.2. In particular, they capture the growth contribution through two components: (i) capital deepening measured by the growth of capital inputs associated with a particular innovation and (ii) TFP growth in the sector that produces the goods underlying the innovation.

Two studies which have adopted this framework are Crafts (2004) for the impact of steam technology on British economic growth during the late 18th and 19th century, and Oliner and Sichel (2003) for the impact of ICTs on US growth in the last quarter of the 20th century. Table 1 presents their estimates, which are expressed as annual percentage contributions to labor productivity growth.

Crafts' study captures capital deepening by the growth in horsepower associated with steam technology. Although James Watt's steam engine was patented in 1769, Craft's estimates suggest that its contribution to labor productivity growth was not higher than 0.02 percent per year until 1830. It then rose to 0.04 percent (1830-50), 0.12 percent (1850-70) and 0.14 (1870-1910). These estimates illustrate both the delayed and long-lasting impact of the steam engine.

Oliner and Sichel's study measures capital deepening by the growth of ICT capital – computer hardware, software and communication equipment. Their estimates suggest a higher overall contribution to growth than from steam technology, especially in the second half of the 1990s. In addition, most of the growth contribution is due to capital deepening – the greater use of ICTs throughout the economy. As in the case of the steam engine, the growth impact of ICTs took time to materialize, though the delay is much shorter in comparison.

The above estimates are bound to underestimate the true growth impetus from the new technologies. Above all, the estimation approach only captures TFP growth in the technology-producing sectors. It ignores possible productivity spillovers in other sectors of the economy. In the case of steam technology, Crafts believes such spillovers may have been significant after 1850. At the same time, cyclical effects may bias the estimates presented in table 1 and may, in particular, cause an overestimate of the ICT contribution in the second half of the 1990s (Gordon, 2000).

Table 1: Growth contributions from steam technology and ICTs

	Steam technology in Britain					ICTs in the US		
	1760-1800	1800-30	1830-50	1850-70	1870-1910	1974-90	1991-95	1996-2001
Capital deepening	0.004	0.02	0.02	0.06	0.09	0.41	0.46	1.02
TFP	0.005	0.001	0.02	0.06	0.05	0.27	0.41	0.77
Total contribution	0.01	0.02	0.04	0.12	0.14	0.68	0.87	1.79

Source: Oliner and Sichel (2003) and Crafts (2004).

Unfortunately, it is difficult to make a precise link between historical growth performance and different innovations, for at least two reasons. First, the multitude and complexity of the transmission channels outlined in section 1.2 and the simultaneous impact of various technologies make it difficult to isolate the contribution of a single innovation. Second, the adoption of technologies takes time and the technologies themselves evolve, rendering any attempt at causal attribution problematic. Notwithstanding these difficulties, some studies have at least partially quantified the growth contributions of selected historical innovations in some countries (see box 1.2).

More generally, economists have gained important insights regarding two questions that are critical for understanding the innovation-growth nexus:

- How does frontier innovation come about?
- How do technologies diffuse across economies?

This section summarizes key insights that have emerged regarding these two questions.

How does frontier innovation come about?

At the beginning of the 19th century, technological innovation was largely performed by individual inventors and small-scale entrepreneurs. By the 20th century, modern innovation systems emerged, whereby a variety of organizations collectively push the knowledge frontier – including scientific institutions, large R&D-intensive firms and entrepreneurial startups.

Technological breakthroughs have largely occurred as a result of three forces. First, scientific discoveries have been instrumental in providing the foundations for commercial innovations. To name but one example, the development of the liquid-crystal display relied on scientific advances in the field of organic chemistry. Second, the needs of government – especially in the area of defense – have been a key impetus for the development of many technologies that found application throughout the economy later on. Finally, the needs of the marketplace and competitive market forces have prompted firms to invest in the development of new technology to gain an edge over their rivals.

Box 1.3: Intangible asset investments

Endogenous growth theory highlights the importance of intangible asset investments in knowledge-intensive industries. However, measuring their amounts and comparing them to tangible asset investments has always been challenging. Company financial statements and national accounts have traditionally treated intangible activities as intermediate inputs rather than investment. Conventional measures of business investment focus on tangible assets such as plant and equipment, buildings and vehicles.

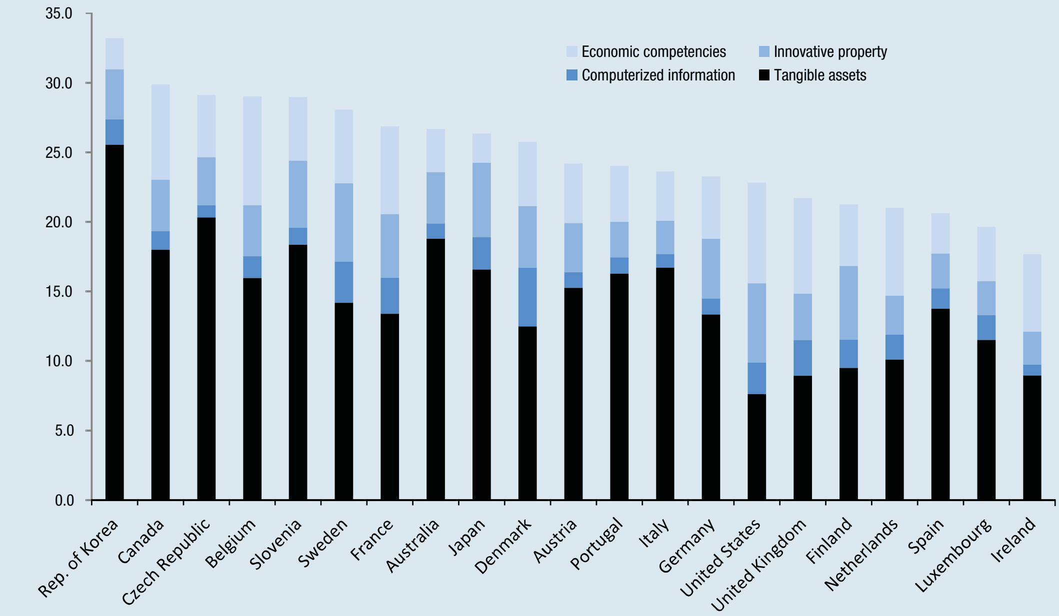
To establish a more complete picture of business investment, researchers have constructed a new measurement framework that breaks intangible assets down into the following components (Corrado *et al*, 2012):

1. Computerized information
   - software
   - databases
2. Innovative property
   - mineral exploration
   - scientific R&D
   - entertainment and artistic originals
   - new products/systems in financial services
   - design and other new products/systems
3. Economic competencies
   - brand equity (advertising; market research)
   - firm-specific resources (employer-provided training; organizational structure).

Estimates of intangible asset investments relying on this framework are now available for a large number of advanced economies (see figure 1.6). They consistently show that intangible assets account for sizeable shares of total business investments – exceeding 50 percent in Denmark, Finland, France, the Netherlands, the UK and the US.

Figure 1.6: Intangible asset investments account for substantial shares of total business investment

Investment as a percent of value added, 2010



Note: For Canada, Japan and the Republic of Korea estimates refer to 2008.

Source: OECD (2013), figure 1.28.

Explaining why economies invest in innovation and what implications those investments have for an economy's growth path has been a fertile field in economics. Interestingly, neoclassical growth theory – which was among the first attempts to formally model the growth process – did not consider how technological progress comes about; it merely demonstrated that growth would come to a standstill without it. This drawback provided the impetus for *endogenous growth theory*, which explicitly incorporated incentives for innovation into models of economic growth. In particular, in formal models of endogenous growth, firms invest in R&D to generate future profits and to avoid being overtaken by competitors, mainly by introducing new and better-quality products. Competition between firms then generates a dynamic innovation race that leads to sustained increases in productivity. These models capture a key characteristic of today's knowledge-intensive industries: firms invest in intangible assets – not only R&D, but also design, software, workers' skills and organizational know-how – and they frequently launch new products that replace older ones. Indeed, available data underscore the importance of investments in intangible assets as a share of total business investments (see box 1.3).

However, some economists have criticized endogenous growth theory as too mechanistic.[40] In particular, while acknowledging that the fruits of innovative activity are uncertain, endogenous growth models assume that they fall within a predetermined probability distribution. However, many innovative breakthroughs of far-reaching importance have been accidental in nature – meaning that they do not fall within a range of outcomes known in advance.

Motivated by such criticism, a second strand of the growth literature – *evolutionary growth theory* – emphasizes the specific historical circumstances of innovative activity and the complexity of interrelationships, with causal mechanisms changing over time.[41] In evolutionary growth theory, firms cannot foresee all technological possibilities and resort to "rules of thumb" when they engage in innovation. The path of technological progress is determined by a selection process in which market forces and other economic institutions play a key role.

40. See Nelson and Winter (1982) for a key contribution and Verspagen (2004) for a review of the literature.
41. See Verspagen (2004).

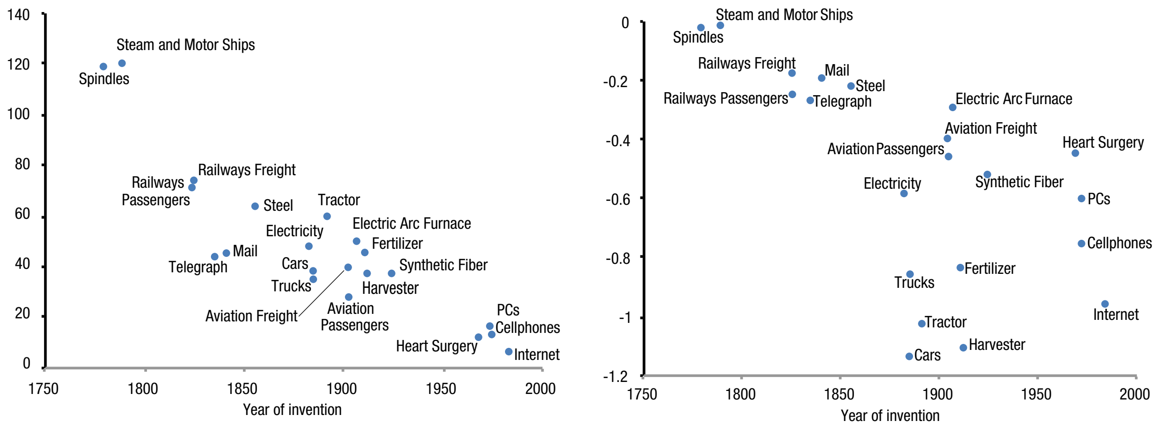
In the evolutionary approach, innovation takes place incrementally and the direction of change only becomes clear over time. Despite occasional "eureka" moments and drastic steps forward, even major historical breakthroughs took years and decades to develop, requiring many incremental steps. In addition, their economy-wide impact relied on firms learning how to use a new technology, undertaking capital investments, and reorganizing business operations. Indeed, the arrival of new technologies typically spurs organizational and business model innovations that, in themselves, are responsible for major productivity gains. The infographic at the end of this report lists just-in-time manufacturing and the bar code as examples of major innovations falling into this category.

Incremental innovation is also critical for the flourishing of so-called general purpose technologies (GPTs).[42] While there is no uniform definition, GPTs generally refer to technologies that have a wide variety of uses and find application in a large range of economic sectors, and that exhibit strong complementarities with existing or potential new technologies, providing fertile grounds for follow-on innovation. Most treatments of GPTs include the steam engine, railways, the motor vehicle, electricity and ICTs as key examples.[43] Historical studies of GPTs have demonstrated their importance for stimulating growth, but have also found that their growth stimulus often occurs with a long delay – estimated, for example, at 80 years for the steam engine (see box 1.2) and 40 years for electricity.[44] Recent endogenous growth research has linked the emergence and adoption of GPTs to long-run cycles of economic growth, providing an explanation for the growth spurts and slowdowns observed throughout history. Interestingly, the prediction of growth cycles mirrors the concept of "long waves" – also called Kondratiev waves – which feature in early evolutionary approaches, especially the work of Joseph Schumpeter.[45]

42. Bresnahan and Trajtenberg (1995) coined the term "GPT", though it is similar to the concepts of "basic innovation" and "technology paradigm" employed in the evolutionary growth literature (Verspagen, 2004).
43. However, there is no consensus even on these five technologies. For example, Crafts and Mills (2004) raise doubts as to whether the steam engine should be considered a GPT.
44. See Crafts (2004) for the steam engine and David (1990) for electricity.
45. See Schumpeter (1939). In fact, it was Schumpeter who coined the term Kondratiev wave, after the Soviet economist Nikolai Kondratiev, who first drew attention to long-run fluctuations in economic output.

Figure 1.7: Faster but less pervasive technology diffusion

Adoption lag since first invention, in years **Difference in penetration rates, in logs**



Notes: The adoption lag since first invention captures the average adoption lag across all countries for a given technology. The difference in penetration rates captures the average difference relative to average penetration in Comin and Mestieri's group of "Western countries". For presentational purposes, the two charts omit several technologies.

Source: Comin and Mestieri (2013).

While the more recent focus on GPTs thus suggests some convergence in endogenous growth and evolutionary theories, these two approaches still disagree on the essential nature of the growth process.[46] The former views it as a deterministic process which, at its core, remains stable over time. The latter views it as a process which is closely tied to the nature of technology and which therefore changes over time. This difference has important implications for designing growth-enhancing policies. While endogenous growth models can formulate policy recommendations on the basis of fundamental principles, evolutionary approaches caution that policies appropriate for one technological paradigm may not be so for another.

How do technologies diffuse across economies?

So far, the discussion has focused on the contributions of frontier innovations, regardless of their origin. However, innovations are rarely fully homegrown. Relying on international patent filing data, Eaton and Kortum (1994) estimate that within developed economies, ideas are highly mobile; even for a large economy like the US, they find that about half of productivity growth derives from foreign technology. But how easily does technology really diffuse across economies, especially to less developed ones?

This question is important. As described in section 1.1, the last 200 years have seen diverging levels of economic prosperity across the world. Given the importance of new technologies in driving long-run growth, could imperfect technology diffusion be one explanation for economic divergence?

Recent evidence on technology diffusion patterns points to a mixed picture. On the one hand, it suggests that more recent technological innovations have diffused more rapidly to low- and middle-income countries. Comin and Mestieri (2013) have assembled data covering 25 technological breakthroughs since the late 18th century and their adoption in up to 132 countries. They find that average adoption lags for those technologies have declined markedly over the past 200 years (see left panel in figure 1.7). Most dramatically, recent technologies such as mobile telephony and the Internet arrived in developing economies within a few years after their introduction in developed economies.

46. See Verspagen (2004).

On the other hand, Comin and Mestieri also look at how intensively different economies have used new technologies once they have been introduced. In particular, they estimate long-run penetration rates for the same set of technologies, and how differences in those penetration rates have evolved over time. On this measure, they find that more recent innovations have seen a greater gap in use between developed and developing economies (see right panel in figure 1.7). At first, this finding seems surprising, considering for example the remarkably wide adoption of mobile telephones and the Internet within most developing economies. However, those technologies have found even more uses in developed economies, and the use gap compared with earlier technologies turns out to be larger.[47]

Notwithstanding these general patterns, the extent of diffusion differs greatly across technologies and recipient countries. To begin with, there are a variety of diffusion channels, notably international trade, foreign direct investment (FDI), direct technology licensing, skilled worker migration and cross-border information flows. Some of these channels are more "fluid" than others. Where technology is directly embedded in goods and services, the import of those goods and services can go a long way toward reaping the benefit of new technology. For example, important health technologies – such as vaccines, antibiotics and mosquito nets – have seen wide adoption in low- and middle-income countries; they are credited with substantial improvements in the quality of life, even in poor countries that have seen little economic growth.[48]

However, a crucial element of successful technology diffusion in these cases is that technology recipients do not need to fully understand the technology in order to apply it. For many other technologies, such an understanding may be necessary and their successful application may require substantial organizational know-how as well as investments in complementary equipment and infrastructure. Economists have thus emphasized the critical role of *absorptive capacity* for successful technology diffusion. Effective absorptive capacity relies on human capital able to understand and apply technology, organizational and managerial know-how, and institutions that coordinate and mobilize resources for technology adoption. In many cases, absorptive capacity also entails the ability to undertake incremental technological and organizational innovation in order to adapt technology to local needs. Indeed, at the limit, the difference between absorptive capacity and innovative capacity blurs.

Some countries have been more successful at creating absorptive capacity than others. In particular, economists have argued that at least part of the success of the fast-growing East Asian countries lay in their ability to ignite a process of technological learning and absorption that provided the basis for economic catch-up.[49] However, what precise mix of policies is most conducive for developing absorptive capacity remains the subject of considerable debate. In particular, many policies that were seemingly successful in East Asia – for example, trade protection, state-directed lending and technology transfer requirements in FDI contracts – did not produce the same success when applied in other developing economies, notably many African and Latin American economies. This suggests that a successful policy mix may depend critically on the economic and institutional context of the developing economy in question and the contemporary technology paradigm, mirroring the policy caution expressed by evolutionary growth theory (see above).[50]

47. Comin and Mestieri (2013) go on to show that their estimates of technology diffusion patterns can explain 80 percent of the income divergence between poor and rich countries since 1820.
48. See Kenny (2011) and section 2.2 on the public health impact of antibiotics.
49. See Nelson and Pack (1999).
50. For a review of the debate on successful catch-up growth policies, see Fagerberg and Godinho (2004).

1.4 – Innovation and IP rights

As described in the previous section, individual inventors and small-scale entrepreneurs were the driving force behind innovation at the outset of the industrial revolution. Early economic writings thus had little scope to investigate the circumstances of innovative activity. For example, in his famous treatise on *The Wealth of Nations*, Adam Smith observed that "[a] great part of the machines [...] were originally the inventions of common workmen, who, being each of them employed in some very simple operation, naturally turned their thoughts towards finding out easier and readier methods of performing it."[51]

The arrival of more formal innovation systems in the 20th century stimulated scholarly thought on the nature of the innovation process and the role of governments in supporting innovative activities in market-based economies. Two important insights – attributed to Nobel prize-winning economist Kenneth Arrow – on the process of inventive activity galvanized economic thinking:[52]

- Inventive activity is risky. When embarking on a problem-solving exercise, it is uncertain whether a solution can really be found.
- Information on how to solve a problem possesses characteristics of what economists call a public good: many people can simultaneously use it, and the problem solver often cannot prevent reproduction of the information. This characteristic is also known as the *appropriability dilemma* of inventive activity.

Faced with these two fundamental difficulties, Arrow concluded that, left alone, markets would underinvest in inventive activity relative to what would be socially desirable. To avoid wasting resources should a problem-solving effort fail, firms operating in competitive markets may forgo inventive opportunities; and if competitors can immediately free ride on a successful solution, the inventing firm may reap little financial reward.

This market failure has given rise to various forms of government intervention that shape the face of modern innovation systems. These interventions broadly fall into three categories.[53] First, the government supports publicly-funded research taking place in universities and public research organizations (PROs). These institutions typically engage in basic research that pushes the scientific knowledge frontier, and for which commercial applications are not always within immediate sight. Second, the government funds R&D activities of private firms, by means of public procurement contracts, R&D subsidies, tax credits, prizes, soft loans and related mechanisms. Some forms of support target specific areas of technology, notably in the area of national defense, whereas others are technology-neutral and the direction of R&D reflects the decision of firms.

Finally, the government grants IP rights as a way of mobilizing private financing for privately undertaken R&D. This section will take a closer look at how different IP rights shape innovative activity. It draws on earlier World IP Reports that provide a more in-depth discussion of many of the considerations outlined below.[54]

IP rights and innovation incentives

IP laws enable individuals and organizations to obtain exclusive rights to inventive and creative output. Ownership of intellectual assets limits the extent to which competitors can free ride on these assets, enabling firms to profit from innovative efforts and addressing the appropriability dilemma at its heart. The most relevant IP forms that address appropriability problems are patents and utility models, industrial designs, plant variety rights, copyright and trade secrets.[55]

51. See Smith (1776).
52. See Arrow (1962).
53. See table 2.2 in WIPO (2011).
54. See WIPO (2011) and WIPO (2013).
55. Goodridge *et al* (2014) associate different forms of IP to the intangible asset investment framework outlined in Box 1.3. They find that half of UK knowledge investments in 2011 were protected by IP rights, notably copyright, trademarks and unregistered design rights.

Survey evidence confirms that many firms regard IP as important in securing returns on R&D investment. However, its importance differs markedly across industries. In some industries – notably, pharmaceuticals and chemicals – IP rights are central to firms' business models. In other industries, firms rely on alternative mechanisms of profiting from R&D, notably by introducing products faster than competitors and generating consumer goodwill through branding. In fact, the importance of branding highlights the indirect role that another IP form, namely trademarks, plays in fostering innovation. Through trademark protection, consumers have confidence that they are purchasing what they intend to purchase – a prerequisite for effective branding campaigns.

IP rights incentivize market forces to guide innovative activity. They allow decisions about which innovative opportunities to pursue to be taken in a decentralized way. To the extent that individuals and firms at the forefront of technology are best informed about the likely success of innovative projects, the IP system promotes an efficient allocation of resources for innovative activity.

While this has traditionally been the key economic rationale for protecting IP rights, there are several other ways in which IP rights can shape innovation outcomes. To begin with, while IP rights do not directly solve the problem of risk associated with inventive activity, they can improve the functioning of financial markets in mobilizing resources for risky innovation. In particular, evidence suggests that the grant of a patent at an early stage in the innovation process can serve to reassure investors that a start-up firm is in a position to generate profits if the innovation is successfully commercialized.[56]

In addition, although inventing sometimes means finding solutions to stand-alone problems, more often it is a cumulative process whereby researchers build on existing knowledge to develop new technologies or products. IP rights, especially patents, play an important role in the process of cumulative innovation. Patent applicants must disclose the problem-solving information underlying an invention. This promotes timely disclosure of new technological knowledge, and allows follow-on inventors to build on that knowledge.[57]

At the same time, patents may in certain circumstances create a barrier for follow-on innovation. Sometimes, the commercialization of an innovation requires use of third-party proprietary technology. Other right holders may refuse to license their technologies or may demand royalties that render the innovation unprofitable – leading to so-called hold-up problems. Even where they are willing to license, coordinating the participation of a large number of right holders may be too costly.

Finally, the grant of exclusive IP rights affords firms market power, viewed by economists as the ability to set prices above marginal production costs. In many cases, market power is limited by competition from substitute technologies or products. However, for radical innovations, market power may be substantial. The ability of companies to generate profits above competitive levels is part of the economic logic of the IP system. However, it also implies a distortion in the allocation of resources, as markets move away from the economic ideal of perfect competition. Above-marginal cost pricing can also slow the diffusion of technologies (see below). In policy design, this distortion is mitigated by the fact that most IP protection is time-bound; once expired, IP rights no longer restrict competition.[58]

IP rights, technology markets and diffusion

IP rights enable the licensing or transfer of intellectual assets – an increasingly important facet of modern innovation systems. Markets for technology facilitate specialization in the innovation process. Firms may be both more innovative and efficient by focusing on selected research, development, manufacturing, or marketing tasks. For example, a given firm may find it is particularly good at figuring out how to extend the life of batteries, but other companies might be better at turning the underlying inventions into components for different electronics products. Similarly, a firm may know how best to market an innovative product in its home market, but prefer to partner with another firm in an unfamiliar foreign market.[59]

56. See Graham *et al* (2009).
57. Evidence for the UK and the US suggests that technology in-licensing represents between 40 and 44 percent of total business enterprise spending on R&D. See Arora *et al* (2013).
58. Reflecting the different rationale for protection, trademark protection is not time-bound as long as owners renew their trademark registrations.
59. This argument mirrors the one on economy-wide specialization made in section 1.2.

IP facilitates the functioning of technology markets in several ways. In the absence of IP rights, firms would be reluctant to disclose secret but easy-to-copy technologies to other firms when negotiating licensing contracts. In addition, while intellectual assets can, in principle, be transferred through private contracts independent of any IP right, IP titles offer a delineation of these assets combined with an assurance of market exclusivity. IP rights thus convey important information than can assist the drawing up of contracts.[60]

Technology markets are also at the heart of so-called open innovation strategies. In many industries, firms face a trade-off between guarding and sharing knowledge. On the one hand, they need to earn a return on their R&D investment, which calls for preventing knowledge from leaking to competitors. On the other hand, absolute protection of all ideas may not always be in firms' best interest. They may be better innovators by collaborating with others, even if that involves some sharing of proprietary knowledge. In addition, technology sharing may also help in developing nascent markets for new products. IP rights are at the heart of the trade-off between guarding and sharing knowledge. They allow firms to flexibly control which technologies to share, with whom and on what terms.

Yet another important function of technology markets is to facilitate the commercialization of inventions coming out of scientific laboratories. The commercial potential of these inventions is often highly uncertain and they require substantial further investment to turn them into marketable technologies. Universities and PROs have neither the resources nor the expertise to undertake such investment. However, they can file patents on their inventions and license or transfer them to firms that do.

Finally, IP rights affect how technologies diffuse within and across countries. On the one hand, exclusive rights, by their nature, may hinder the diffusion of new technologies – at least in countries where those rights have effect. On the other hand, IP rights may enable technology diffusion, just as IP rights enable technology markets more generally. The ultimate role of IP rights, then, depends on the nature of the technology in question – in particular the degree to which it can be reverse-engineered – and the absorptive capacity of the recipient (see section 1.3).

60. For empirical evidence, see Gans *et al* (2008).

Trade secrets and worker mobility

An often-overlooked link between the IP system and innovation performance is through the mobility of knowledge workers. The diffusion of highly specialized and non-codified knowledge often relies on workers moving from one firm to another. However, to what extent are such workers allowed to use the knowledge they acquired as past employees, if such knowledge is secret? The legal answer to this question lies in so-called non-compete clauses included in employment contracts. These clauses restrict an employee from using information learned during employment in subsequent business efforts, at least for a certain period. However, the inclusion and content of non-compete clauses is subject to regulation, with different jurisdictions adopting different approaches.[61]

Policymakers face a trade-off in setting the ground rules for non-compete clauses. Allowing workers substantial leeway to take knowledge from one firm to another promotes the diffusion of knowledge, fueling the innovation system and promoting technology adoption.[62] At the same time, it may lead firms to forgo innovative activities for fear that the fruits of these activities might in the future leak to a competitor. Empirical evidence suggests that non-compete rules matter for the degree of worker mobility, especially for inventors with firm-specific skills and for those who specialize in narrow technical fields.[63] However, the economy-wide importance of such rules is still not well understood. They cover not only technological knowledge, but also organizational know-how and business practices. Their relevance is thus not limited to technology-intensive firms and includes, for example, firms in the service sector, which account for the predominant share of economic output in high-income economies (see section 1.1).

61. See Caenegem (2013).
62. Gilson (1999) argues that the non-enforcement of post-employment non-compete clauses in California has been a significant factor driving innovation in Silicon Valley firms.
63. See Marx *et al* (2009).

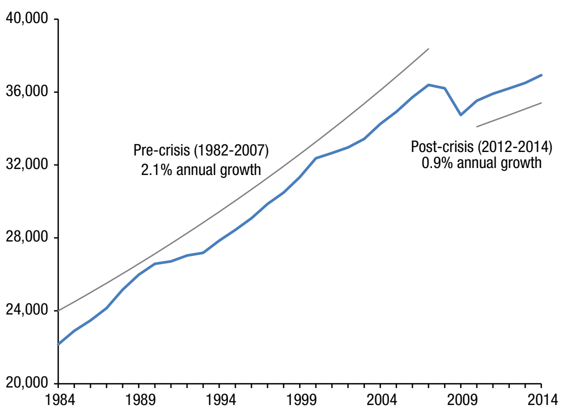
1.5 – Future prospects for innovation-driven growth

The first stylized fact in section 1.1 characterized the growth performance at the frontier after the Second World War as both spectacular and exceptional. Yet growth since the onset of the global financial crisis in 2008 appears anything but spectacular. Figure 1.8 depicts the evolution of per capita GDP in high-income countries since the mid-1980s. Before the crisis, growth averaged 2.1 percent per year, matching the post-war rate of frontier growth shown in figure 1.1. Not only did the crisis prompt a sharp decline in economic output, average growth since 2010 has fallen to 0.9 percent.

Does the financial crisis mark the beginning of a new era of lower growth? Has the innovation-driven growth engine lost steam? While only time will provide the definitive answer, the last few years have seen lively scholarly debate on what growth prospects the future may hold. This final section synthesizes some of the key arguments put forward. It first presents the optimists' case that the recent growth decline is temporary and faster growth will return, then moves on to the pessimists' case why growth might be sustainably lower in the years and decades to come.

Figure 1.8: The end of spectacular post-Second World War growth?

Real GDP per capita in high-income OECD countries, 1984-2014



Notes: GDP values are in constant 2005 dollars. Annual growth rates are the slopes of the logarithmic trend lines for the two periods.

Source: World Bank World Development Indicators.

The optimists' case

The main reason why the growth decline may be temporary lies in the root cause of the crisis. In particular, the crisis was unleashed by the bursting of a debt-financed asset bubble that left the balance sheets of firms and households in distress.[64] The desire to repair balance sheets through greater savings has prompted a persistent shortfall of aggregate demand, leading to wide gaps between actual output and potential output. With interest rates having hit the zero lower bound, central banks have had difficulty closing this output gap through traditional monetary policy instruments. The post-financial crisis debt overhang has thus imposed a persistent drag on economic growth in developed economies.[65]

An optimist would submit that market forces will eventually eliminate persistent output gaps and economic growth will return to its long-term path determined by economies' fundamental productive capacities. Economic history has indeed seen prolonged downturns before, which caused scholars to predict the end of growth. For example, John Maynard Keynes observed in 1931: "We are suffering just now from a bad attack of economic pessimism. […] The prevailing world depression, the enormous anomaly of unemployment in a world full of wants […], blind us to what is going on under the surface to the true interpretation of the trend of things."[66]

In today's context, focusing on the long-run growth trend shown in figure 1.1 – rather than the "aberration" associated with the financial crisis – still paints an overwhelmingly positive outlook for future growth. In addition, looking at the potential for innovation to continuously sustain future growth, there are reasons to be optimistic.

64. See Koo (2014).
65. See Lo and Rogoff (2015).
66. See Keynes (1931).

To begin with, never before has the world invested so many resources in pushing the global knowledge frontier. Figure 1.9 depicts trends in R&D expenditure for the world and for the six largest R&D-spending countries. It shows a consistent upward trend since the mid-1990s. While the financial crisis has left a mark in some countries, R&D spending was far less affected than economic output. Moreover, from relatively little R&D spending in the early 1990s, China overtook Japan in 2009 to become the second-largest R&D spender after the US. The emergence of China as an innovator – along with the rapid growth of R&D expenditure in the Republic of Korea – has increased the diversity of the global innovation landscape.

There also still appears to be significant potential for innovation to generate productivity gains and transform economic structures. ICTs have already made important contributions to growth (see box 1.2 and section 2.3). However, if history is any guide, there is more to come. The growth contributions of past GPTs have only occurred with decades-long delays (see section 1.3).[67] Indeed, the next generation of ICT innovations – centered on artificial intelligence – holds plenty of promise. Brynjolfsson and McAfee (2014), for example, characterize the impact of digital innovation as exponential, drawing on the parable of sequential doubling of rewards on a chessboard, with most of the second half of the chessboard yet to come. Among other considerations, ICTs have potential to raise productivity in the service sector, which has traditionally been considered a drag on growth.[68] Evidence for the US economy, for example, points to especially fast productivity growth in distribution services – an industry that has made intensive use of ICTs.[69]

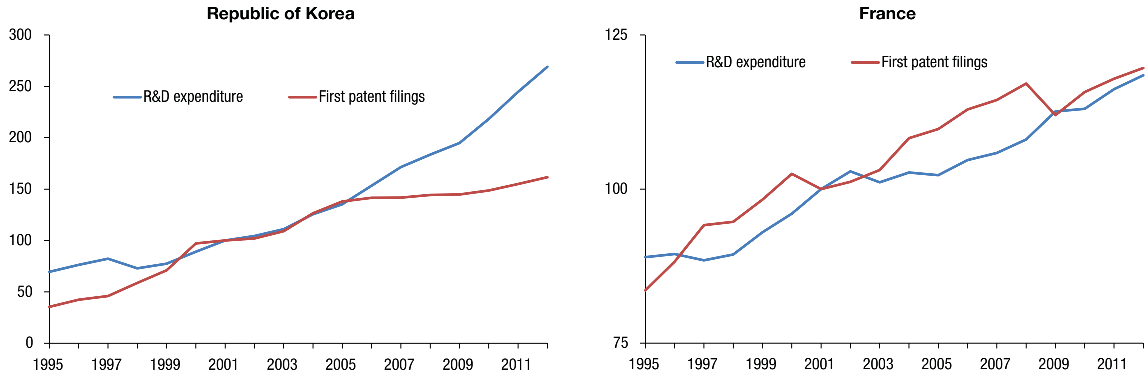
In addition, there are numerous other fields of innovation that hold promising potential for spurring future growth. These include the three fields discussed in chapter 3 – 3D printing, nanotechnology and robotics – as well as genetic engineering, new materials and various forms of renewable energy. New technologies have also dramatically improved the research tools that drive the process of scientific discovery. In particular, ICT-driven techniques such as big data analysis and complex simulations have opened new doors for research advances across many areas of technology. For optimists, the interplay between science and technology generates a self-reinforcing dynamic that seems unbounded.[70]

A somewhat different argument of the optimists' camp – partly in response to weak productivity performance in recent history, as explained below – is that today's GDP measurement framework misses the true impact of new technology. This argument comes in two forms. One is that the tools of statisticians increasingly fall short in capturing quality improvements and new forms of economic output (see box 1.1).[71] The other is that the very concept of GDP is ill-suited in capturing the societal welfare gains associated with today's innovation. In particular, many new technologies are highly expensive to develop but, once developed, relatively cheap to produce or can even be replicated for free. As such, they contribute little to economic output but may raise welfare disproportionately.[72]

67. See David (1990).
68. Owing to historically slower productivity growth in services than in manufacturing, Maddison (1997) characterized the growing share of services in economic output as a "significant structural drag".
69. See Jorgenson and Timmer (2011). More generally, Triplett and Bosworth (2003) find that since 1995 productivity growth in the US service sector has matched economy-wide productivity growth.
70. See Mokyr (2014).
71. McGuckin and Stiroh (2001) find that measurement problems in certain service industries that rely extensively on ICTs – such as finance, business services and wholesale trade – have implied a sizeable downward bias in estimates of US productivity growth.
72. See Mokyr (2014) and Glaeser (2014).

Figure 1.9: Innovation performance shows mixed trends

R&D expenditure and first patent filings, index (2001=100), 1995-2012



Notes: R&D expenditures are in constant 2005 dollars. In the case of R&D expenditure, the world aggregate refers to a group of 33 countries for which data for most years are available. The group includes all large OECD countries as well as China and Russia. Selected data points were extrapolated.

Source: OECD and WIPO Statistics Database.

The pessimists' case

The pessimists' case starts with doubts about whether market forces will be sufficient to eliminate the output gaps left by the financial crisis. The length of the economic downturn and the failure to restore full employment in many developed economies suggests that something fundamental has changed. These doubts have given rise to theories about so-called "secular stagnation" – a term introduced by economist Lawrence Summers in 2013.[73] A technical definition of secular stagnation is that only negative real interest rates would equate savings and investments with full employment. In the presence of low inflation and a zero lower bound on policy interest rates, output gaps persist, generating subdued growth – also referred to as "the new mediocre".[74]

There is considerable debate among macroeconomists regarding what may be behind secular stagnation. Demographic shifts and changes in the structure of financial markets have been cited as possible causes. Interestingly, some economists have also mentioned technology as an explanatory factor, arguing that the latest wave of ICT innovation has required relatively little investment.[75]

Concerns about secular stagnation do not *per se* question the potential of innovation to contribute to future growth. Nevertheless, persistent output gaps may negatively affect the transmission channels through which innovation generates growth. In particular, weak overall demand may lead firms to shun investment opportunities created by new technology, long spells of unemployment may lead workers to lose or not acquire skills, and fewer firm startups and "scale-ups" may slow the structural transformation of the economy.

Independent of secular stagnation concerns, the pessimists' camp also casts fundamental doubt on the potential for innovation to drive future growth. One ground for such doubt is an observed decline in TFP growth that started well before the onset of the crisis. Chiefly, the US economy saw a marked pick-up of TFP growth from 1995 to 2003, mainly attributed to ICTs (see box 1.2); however, since then TFP growth has been significantly slower.[76] More generally, analysis by the International Monetary Fund (IMF) confirms that potential output started to decline in the early 2000s across all advanced economies, mainly accounted for by a drop in TFP growth.[77]

73. See Summers (2014).
74. The term "new mediocre" is attributed to IMF Managing Director Christine Lagarde; see *www.imf.org/external/np/speeches/2014/100214.htm*.
75. For a summary, see the collection of essays edited by Teulings and Baldwin (2014).
76. See Fernald (2014).
77. See IMF (2015).

Could it be that the growth contribution of ICTs has been largely realized and, without any innovation of comparable significance on the horizon, future growth will disappoint? In a provocative article, economist Robert Gordon makes precisely this case.[78] He argues that ICTs have seen faster adoption and follow-on innovation compared with previous GPTs, with key productivity benefits such as the replacement of tedious and repetitive clerical labor by computer already occurring in the 1970s and 1980s. More recent ICT innovations have consisted of entertainment and communication devices that are smaller and smarter, but which do not radically spur economic productivity.

More generally, Gordon argues that it will be hard to match the achievements of earlier innovations. For example, the dramatic improvements in the speed of travel, life expectancy and long-distance communication could only happen once, with future improvements bound to be minor in comparison. Similarly, there is much less scope for innovation to increase labor force participation; if anything, demographic shifts in developed economies will lead to declining participation.

In addition, one may question the productivity of future innovative activity. Pushing the knowledge frontier is becoming progressively more difficult as the "low-hanging fruit" is plucked. In addition to real R&D expenditure, figure 1.9 shows trends in first patent filings – the patent metric that comes closest to the concept of a unique invention. Aside from China, since the mid-2000s most countries have seen faster growth in R&D expenditure than first patent filings, leading to a falling R&D yield. One should not read too much into these trends, as patent-filing trends may reflect shifts in patenting strategies. However, contrary to the 1980s and the second half of the 1990s, patenting trends do not suggest an upturn in R&D productivity in more recent history.[79]

Finally, the claim that GDP statistics fail to capture the true impact of innovation is hard to evaluate. The use of hedonic and other techniques has improved GDP measurement in those countries in which statistical offices are equipped to use them (see box 1.1). From this view, the quality of today's statistics should be better than decades ago. It is undoubtedly the case that GDP statistics do not capture the full welfare benefits new innovations offer, but the key question is whether the under-measurement problem is worse today than it was in the past. There is no convincing evidence that would suggest it is and establishing such evidence may well be impossible.[80]

78. See Gordon (2012).
79. See Fink *et al* (2015) for a more in-depth discussion of long-term patent filing trends. They identify greater internationalization as one important shift in patenting strategies.
80. See DeLong (1998).

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