Technological innovation, productivity and sustainability

ERICSSON

Introduction

Since the Industrial Revolution, technological innovation has followed a pattern of invention of general-purpose technologies (GPTs) followed by extended periods of adoption and refinement. While these innovations, including the steam engine, electrification, and the internal combustion engine, enabled massive productivity gains, they were powered, to a very large extent, by carbon-based fuels. Today, the revolution continues with information and communication technology (ICT), driven by innovations in computing and communications. If managed correctly, ICT promises to be a source of tools to reduce the use of fossil fuels and improve sustainability across economic, social, and environmental domains.

Taking a long view of the history of technological innovation, one can observe the mechanisms linking productivity growth, living standards, and climate change, including:

1. Productivity gains from general-purpose technologies leading to positive economic impacts over long periods of time.

2. Mechanization, the process behind huge economic gains and rising living standards during the Industrial Revolution, substituting machines powered by fossil fuels for human effort.

3. The shift from mechanization to digitalization breaking the pattern of productivity gains linked to fuel consumption, raising the potential for sustainable economic growth.

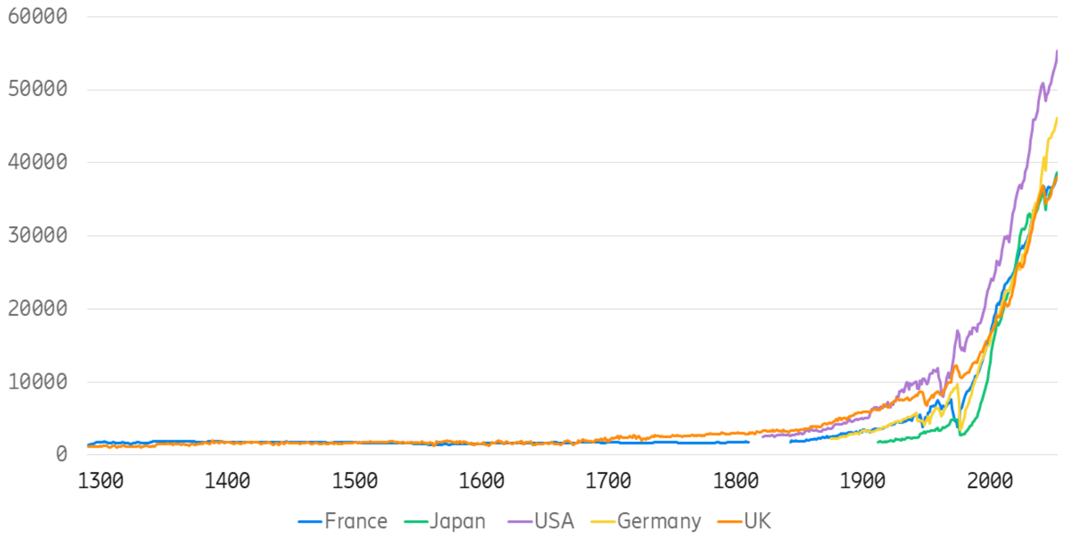
Realizing the potential of ICT to help overcome climate change, dealing with structural changes in employment, and addressing the United Nations' Sustainable Development Goals (SDGs) all require a balance between market-based economies, and regulatory and policy frameworks that can anticipate and diminish rebound effects.

When COVID-19 caused a global pandemic in early 2020, it hit the world economy hard with negative growth in most countries. This affected every aspect of people's lives including health, jobs, financial security, social relations, and trust. However, there have been a number of similar and even worse crises in the past, and the world economy has always managed to recover. Economic development is likely to speed up as a consequence of the pandemic forcing the world to move online and thus accelerating digital transformation. Moreover, this current crisis generates opportunities for a climate-neutral recovery by attracting and steering investment into new technology aimed at the transition to a renewable energy system. As the post-COVID recovery gathers strength, it is crucial that governments prioritize inclusion and job creation for youth, women, and low-income workers, that is, those hit hardest during lockdowns and other economic restrictions.[1]

Technological innovation

Over the last century, most of the world has experienced spectacular economic development with rapidly rising living standards. The economic growth that has enabled this can be traced to the Industrial Revolution in the UK, Western Europe, and the US. Figure 1 shows GDP per capita in France, Germany, Japan, the UK, and the US between 1300 and 2018, clearly indicating that GDP per capita began to increase significantly at the beginning of the 19th century.

Figure 1: GDP per capita in France, Germany, Japan, the UK, and the US between 1300–2018 (USD in 2011 prices)



Sources: Maddison Project database (2020)[2]; Broadberry et al. (2015)[3]; Conference Board (2020)[4]; Fukao et al. (2015)[5]; McCusker (2006)[6]; Pfister (2011)[7]; Prados de la Escosura (2009)[8]; Ridolfi (2016)[9]; Scheidel and Friesen (2009)[10]; Sutch (2006)[11].

Note: Data for the UK before 1700 is based solely on estimates for England. Data for the US is only available for the period 1800–2018. Data for Japan is only available for the period 1885–2018. Data for Germany is only available for the period 1850–2018. Data for France is missing for the period 1790–1819.

At the heart of the Industrial Revolution, technological innovation contributed to economic growth by increasing productivity. The mechanization of production, enabled by steam engines, electricity, and the internal combustion engine, made a rapid increase in living standards possible for many people.

Unfortunately, the GPTs also came with a hidden cost in the form of increasing emissions of carbon dioxide and other greenhouse gases, which in turn led to the accelerating climate change we have today. In 1990, the United Nations Intergovernmental Panel on Climate Change (IPCC) affirmed that there is a greenhouse effect that is warming the earth and that carbon dioxide is responsible for more than half of the effect[12].

In the 20th century, first the vacuum tube and then the transistor became the building blocks of electronics and the ICT revolution. Telephony, sound recording, radio, and television broadcasting and digital computing were either enabled or greatly improved. Today most people find it hard to imagine a life without PCs, tablets, smartphones, or the internet. Beyond lifestyle enhancements, ICT has contributed substantially to industrial productivity and the growth of the service economy over the last decades.

Productivity Growth

In economics, productivity is the ratio of outputs to inputs and thus measures the efficiency of production. Inputs of capital and labor are used to produce outputs of goods and services. Productivity can be measured as labor productivity or total factor productivity (see glossary in section 8). Higher productivity makes it possible to either produce more with the same level of resources or to maintain the same level of production with less resources.

Productivity growth is crucial for a country's welfare and standard of living. If an economic system can create high productivity growth rates, factor resources will be released making it possible to improve other important issues such as health, pollution, security, and education. Markets, and the institutions they are based on, have been successful in promoting productivity development over long periods of time. However, markets seldom work as efficiently as theory would indicate. There are many market failures such as the neglect of pollution and carbon emissions. Thus, strong institutions and a robust regulatory framework are needed to obtain equitable societal outcomes in a market economy.

Throughout history, new technology has been an important driver of productivity, and consequently, economic development. The concept of GPTs can be used to distinguish truly revolutionary technologies. Whole eras of technological progress are driven by a few

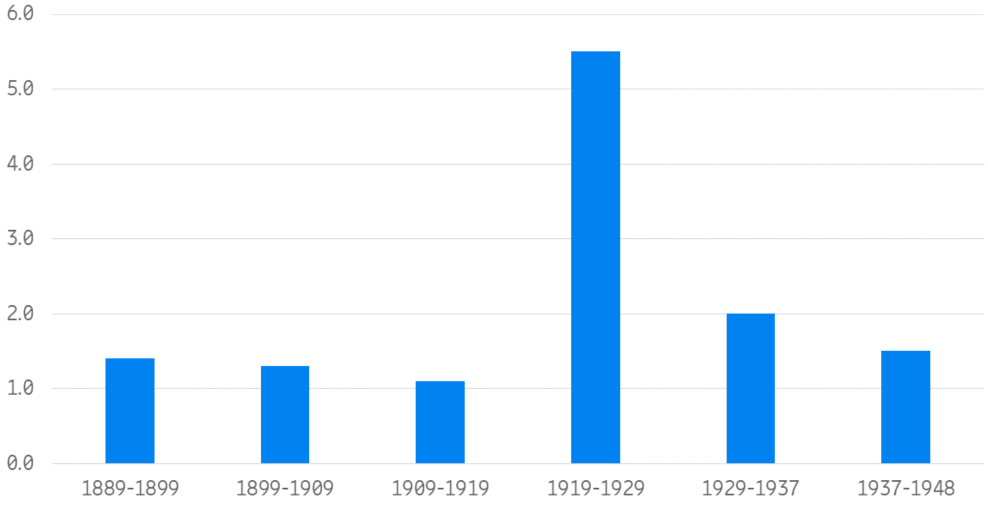
GPTs characterized by pervasiveness, inherent potential for technological improvements, and innovative complementarities giving rise to increasing returns to scale.[13 14]There have been four major technological breakthroughs since the beginning of the Industrial Revolution that can be distinguished based on these criteria, namely the steam engine, electrification, the internal combustion engine and ICT.[15]

The increase in standards of living started after the development of the steam engine in the 18th century and continued during the development of the internal combustion engine and electrification in the 19th century (see figure 1). A number of studies suggest that there is evidence that these innovations drove economic development, but that such economic development often happened with a time lag.[16]

The first widely used steam engine was invented by Thomas Newcomen in 1712. An important development was added by James Watt, who introduced the separate condenser in 1765. However, it was not until the second half of the 19th century that steam started to have a substantial impact on productivity growth in the UK, that is 140 years after Newcomen's invention.[17] Moreover, it was not until about 1850 when the Corliss steam engine was introduced in the manufacturing process, that steam started to have a substantial impact on productivity in the US.[18]

Similar findings regarding a lagged effect on productivity have been made for the electrification process. Michael Faraday discovered electromagnetic induction in 1831. However, the first commercial power stations were not introduced until the 1880s. It took considerable time for manufacturing to adopt the new technology and use it efficiently.[19] Electricity paved the way for a thorough rationalization of factory construction designs.[20] The first electric motors that were introduced only replaced steam engines and continued to turn long line shafts, with each shaft driving a number of individual machines connected with belts. However, it was soon discovered that connecting a single scaled-down electric motor to each machine increased energy efficiency and the flexibility of production. In order to meet the demands of electrified manufacturing, a high-voltage AC grid with the ability to efficiently distribute electricity needed to be built out. This process took time, and it was only in the 1920s that productivity in US manufacturing started to increase substantially (see figure 2).

Figure 2: Compound annual growth rates of labor productivity in US manufacturing, between 1889–1948.



Source: Kendrick (1961) [21]

Most economists would agree that innovation based on new technology was one of the driving forces of productivity growth. Nevertheless, innovation does not always lead directly to increased productivity. In medieval China, many innovations including paper, printing, and the bill of exchange were made, but people were not able to use their inventions in productive ways.[22] When the sovereign was in financial difficulty, confiscation of property was carried out. Weak institutions, such as ownership rights, also apply to a number of other countries in history, and this shows that institutional structures and organizational change are crucial for realizing productivity gains from new technology. This is one of the main reasons that productivity did not take off in all countries at the same time during the Industrial Revolution.

From Industrial Revolution to ICT

In 1947, Bardeen, Brattain, and Shockley, at Bell Laboratories, New Jersey, invented the transistor, which became the basis for solid-state integrated circuits. This in turn enabled a host of new technologies forming what is now called information and communications technology (ICT). These innovations followed Moore's law, which refers to an observation made by Gordon Moore in 1965 that the number of transistors in an integrated circuit double every year. In 1975, he adjusted the doubling period to two years, a rate that has more or less held since then.[23] Integration in microprocessors has gone from less than 200 transistors per square mm to more than 20 million in 50 years. This phenomenon has relentlessly driven down costs on the consumer as well as industrial goods.

Despite substantial corporate investments in computers and other technology in the 1970s and 1980s, productivity growth slowed down in most countries. The 1973 oil crisis was a significant contributing factor to the slowdown. Throughout the 1980s, it was unclear to what extent ICT was impacting economic growth at the macro level. This was famously remarked by Nobel Prize Laureate Robert Solow: "You can see the computer age everywhere but in the productivity statistics".[24] However, since economic and productivity growth took off in the US in the mid-1990s, there has been a plethora of studies showing links between ICT and economic development.

ICT accounted for 1.5 percentage points of the 2.6 percent growth rate per year of labor productivity in the US business sector from 1996–99.[25] Economist Robert Gordon was skeptical and asserted that the productivity revival in the US was primarily driven by exceptionally rapid productivity growth in the production of computer hardware, peripherals, and telecommunications equipment, while productivity growth in the rest of the economy remained sluggish.[26] But as more data became available, it grew increasingly evident that the productivity effects of ICT were substantial in most industries. The relative contribution of ICT to labor productivity growth remained high from 2004–12, during and after the global financial crisis.[27]

While the rate of productivity growth increased sharply in the U.S. after 1995, the growth rate remained sluggish in many countries in Western Europe. Both ICT capital deepening and total factor productivity (TFP) increased more slowly in Europe than in the US. The productivity slowdown in Europe was primarily caused by a lower TFP growth in services.[28] Nevertheless, an assessment of capital investment in ICT worldwide for the past decade indicates that, on average, it has contributed 15 percent of annual GDP growth (0.4 percentage points of 2.7 percent)[29] while emitting approximately 1.4 percent of the global carbon dioxide.[30]

Initially, many studies focused on ICT in general, but there was also evidence from the economic impact of mobile communication by itself. A quantitative overview provided evidence that telecommunications networks had positive effects on economic growth in general. [31] Moreover, fixed telephones were already found to making a strong contribution to economic development in the 1980s. [32] There is evidence of a significant positive causal link between telecommunication infrastructure and aggregate output in 21 OECD countries from 1970–90.[33] [34]

Cellular telephony and mobile broadband are good examples of technological innovations, which have undergone constant improvements and increasing adoption since their respective introductions. In 1990, the dawn of cellular telephony, many less-developed economies had very low penetration rates of fixed telephony—a small fraction of that in more developed nations. North America had 54 fixed lines per hundred persons and the aggregated OECD member countries had 38.[35] At the same time, many developing countries had less than one per 100 persons, and globally the rate was just under 10. Now, the cost of provisioning a cellular telephone subscription and handset is a small fraction of the cost of installing a copper local loop. An estimated three-quarters of the world's population owns or has access to a mobile phone. As the capabilities of mobile communications expand with every generation, nearly two-thirds of individuals have a subscription to mobile broadband.[36]

Assessing investment in mobile telecommunication infrastructure from 1990–2007 reveals it made a considerable contribution to economic and productivity growth. [37] A number of studies have also focused on the economic impact of fixed broadband. After a country had introduced fixed broadband, GDP per capita was 2.7 to 3.9 percent higher on average than before the introduction. Moreover, a 10 percentage-point increase in broadband penetration was associated with increased annual growth per capita of 0.9 to 1.5 percentage points. [38] A doubling of broadband speed contributed 0.3 percentage points to growth compared with growth in the base year.[39]

Economic data from 135 countries contains strong evidence for a statistically significant effect of mobile broadband on GDP, both when first introduced and gradually over time as it diffuses throughout different economies. From 2002–2014, the data showed that, on average, a 10 percent increase in the mobile broadband adoption ratio caused a 0.8 percent increase in GDP[40]. In 2019 terms, this is equivalent to adding over USD 700 billion to world GDP.

The results also showed that the effect from mobile broadband is considerably larger and more significant in low-income countries than in high-income countries.[41] Research has demonstrated this digital divide across countries in terms of computer and internet penetration.[42] Thus, there is considerable potential for low-income countries to reduce the gap with high-income countries by investing in mobile broadband infrastructure. About one-third of the world's population is still unconnected. Providing connectivity in combination with educational investments would help in reducing poverty. In addition, there is early evidence of a link between the Internet of Things (IoT), that is, connectivity beyond consumer devices, such as smartphones and tablets, and productivity.[43] Research has shown that a 10 percentage point increase in the growth of cellular IoT connections per inhabitant was associated with a 0.23 percentage point increase in total factor productivity growth[44].

There is also substantial evidence to show that ICT has had extensive effects, which have not been captured by GDP. People substitute zero-price online services (for example, Spotify, YouTube, and Wikipedia) for goods with a price (for example, CDs, DVDs, and bound encyclopedia sets).[45] As a result, the total contribution of these sectors to GDP may decrease even while consumers get access to digital goods and services with higher utility. The shift from buying physical CDs toward subscribing to streaming music services implies an unmeasured price decrease of 85 percent per song.

Estimates show that in 2019, the global quality-adjusted value from streamed music was USD 76 billion compared to actual revenues of USD 11 billion. [46] Thus, the shift from consuming music in physical form to streaming music services creates an enormous consumer surplus that is not recorded in GDP. A decrease in prices most often implies that some people will be better off, that is, the consumers, and others worse off, for example, some music companies and artists.

5G is likely to have a large impact on productivity over the next decade. It can be viewed as a flexible innovation platform meeting diverse user needs both for consumers and industries. Some use cases will be improved, such as mobile broadband, fixed wireless, and massive and critical IoT. This will likely have a direct effect on GDP. It is extremely difficult to precisely estimate how large these effects from 5G will be. PwC uses a bottom-up approach and estimates the impact from 5G in different sectors such as healthcare, smart utilities, consumer and media, industrial manufacturing, and financial services. By aggregation, PwC finds that 5G could add USD 1.3 trillion to global GDP by 2030.[47] As 5G diffuses throughout the economy, it will drive additional innovations in areas such as advanced automation and control, driverless cars, drones, collaborative robotics, smart metering, smart grid automation, VR/AR, traffic safety and control, and so on. These innovations can be viewed as lagged effects from investments in 5G and will continue to drive economic development for decades.

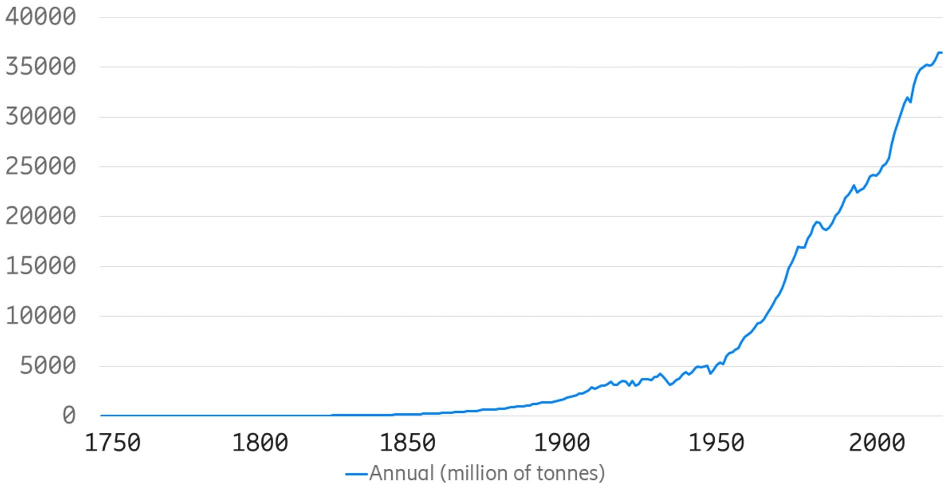
Another innovation area, which has been receiving a significant amount of attention is artificial intelligence (AI). According to the OECD, AI is understood as "… a machine-based system that can, for a given set of human-defined objectives, make predictions, recommendations, or decisions influencing real or virtual environments. AI systems are designed to operate with varying levels of autonomy." [48] While this definition gets many things right, it should be pointed out that AI is not a system. It is an expanding taxonomy of related programming techniques—or algorithms—which perform a range of logical operations that make decisions applicable in many domains. Examples include strategy games (such as go and chess), image processing, speech recognition, fault finding/solving, and industrial automation. The impact of AI is greatest when it is applied to other emerging innovations. AI is progressively allowing tasks that were solely done by humans to be automated, contributing to structural change in economies as they improve productivity. AI is likely to affect productivity growth substantially, but its full impact on economic development has yet to be properly evaluated.[49]

Impact on the environment

General-purpose technologies have contributed significantly to productivity and standards of living since the eve of the Industrial Revolution. However, global economic development leading to increased use of fossil fuels has become a burden for the environment and in particular for the climate with the increase of carbon emissions leading to higher average global temperatures, which is a threat to the stability of our societies and of the economic system.

Figure 3 shows that carbon emissions accelerated during the second half of the 20th century. However, according to figure 4, carbon emissions per capita have not increased as much as total emissions. The increase of the world population from approximately 3 billion in 1960 to 7.7 billion in 2019 has had a substantial impact on total carbon emissions in absolute figures.

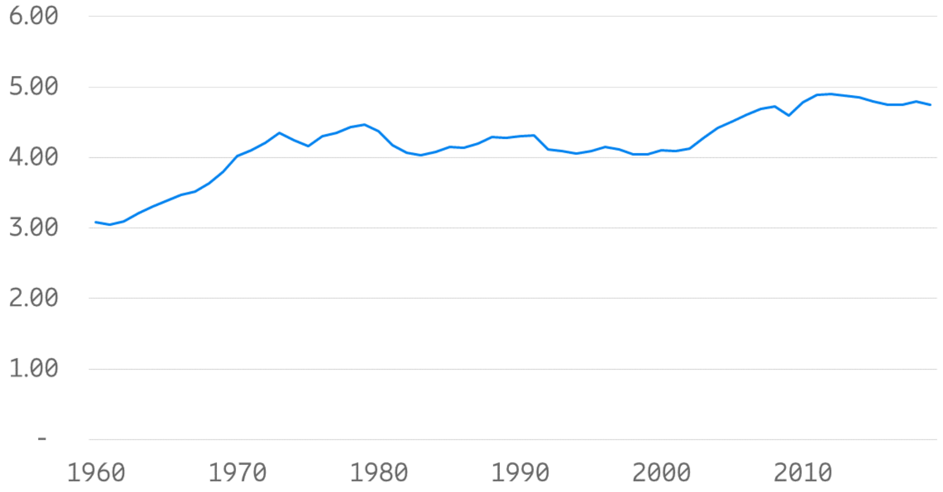
Figure 3: Annual production-based carbon emissions (million tonnes per year) in the world between 1750–2019



Source: Our World in Data (2020).[50]

Note: The production-based carbon emissions include emissions from fossil fuels and cement production only—land-use change is not included.

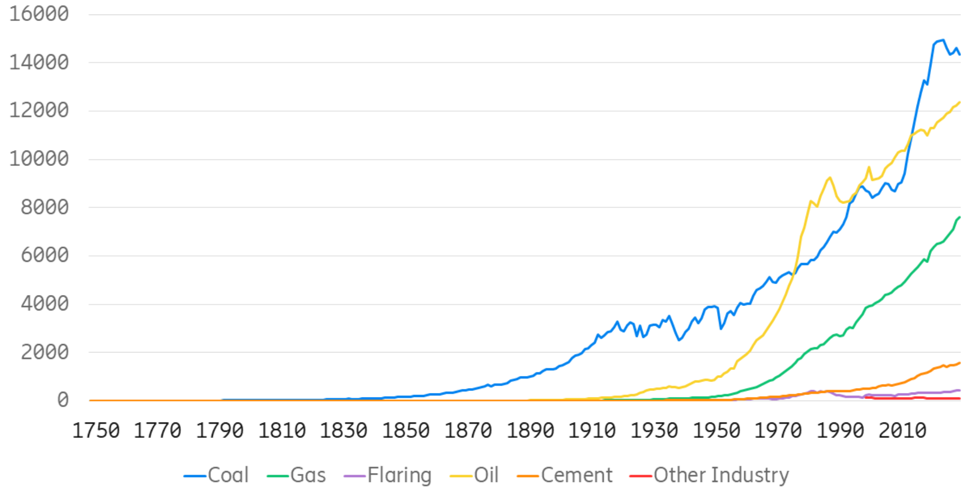
Figure 4: Carbon emissions (tonnes per year) per capita in the world between 1960–2019



Sources: Our World in Data (2021)[51] and World Bank (2021)[52]

At any given level of consumption, increases in productivity would translate to a reduction in resources used in production. Already in the 19th century, the English economist William Stanley Jevons observed that the consumption of coal soared, despite the improvement of the steam engine by James Watt.[53] Thus, productivity gains also have rebound effects, which lead to increased consumption, as higher productivity leads to lower prices and increased demand. For example, improved productivity in the manufacturing of consumer electronics leads to lower prices and increased demand for other products, resulting in the rebound effect: higher carbon emissions. However, the level of rebound also depends on the policy framework including carbon pricing, and should not be seen as an argument against productivity and efficiency by itself. With policies such as subsidies on electric cars, rebound effects could be positive for the environment as more consumers shift to electric cars. Moreover, the total spending on ICT products has increased and this could lead to a reversed rebound effect implying that less is consumed of other products and services.[54]

Figure 5: Sources of carbon emissions (million tonnes per year) in the world between 1750–2019

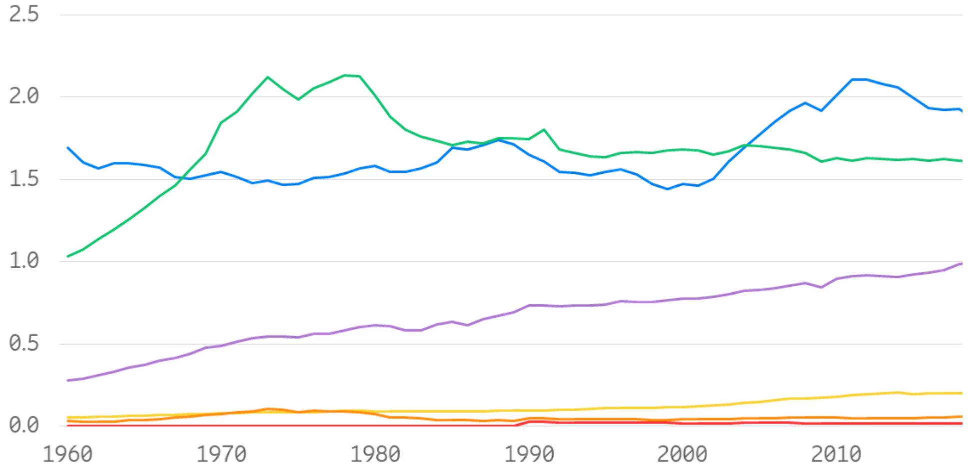


Source: Our World in Data (2021).[55]

Figure 5 shows the consumption of coal, oil, and gas being the main cause of carbon emissions globally. During the early Industrial Revolution, coal was the primary source of energy, but the total level of carbon emissions still remained modest. In the 1950s, carbon emissions accelerated dramatically due to rapidly increasing oil consumption, and in the late 1960s, oil became the largest driver of carbon emissions. However, in the last few decades coal has again become dominant, followed by consumption of oil and gas.

Figure 6 shows carbon dioxide development per capita for each type of fuel burned in 1960–2019. It is evident that emissions from coal and oil have not increased as much per capita, as part of the carbon emissions was driven by population growth. However, from a policy perspective, it is decarbonization in absolute figures in line with 1.5°C pathways, which is critical. [56]

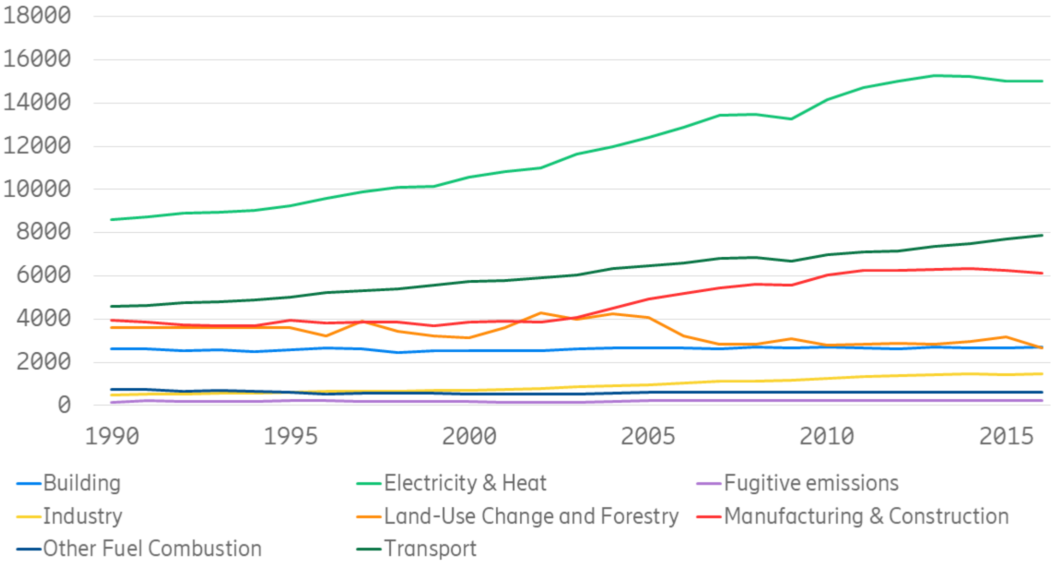
Figure 6: Carbon emissions (tonnes per year) per capita by type of fuel in the world between 1960–2019



Sources: Our World in Data (2021)[57] and World Bank (2021). [58]

Figure 7 shows the carbon emissions in the world by sector between 1990–2016. Electricity & Heat, Manufacturing & Construction, and Transport have accounted for the largest increases in carbon emissions in absolute figures. These three sectors accounted for almost 80 percent of carbon emissions in 2016.

Figure 7: Carbon emissions (million tonnes per year) in the world by sector between 1990–2016



Sources: Our World in Data (2021)[59]

The current situation concerning carbon emissions should be viewed as a gigantic market failure. In many countries, the cost of emitting carbon dioxide has been negligible for a long period of time. If there had been a tangible cost attached to carbon emissions at an earlier stage, it is probable that many more innovations would have focused on reducing such emissions. Today, it is evident that the consumption of coal, oil, and gas will have to be reduced. There are already many alternatives to these fossil fuels such as hydro, solar, wind, and nuclear power. There are also substantial opportunities for decreasing the energy intensity across society. All of these alternatives are subject to continuous innovation, incrementally improving their economic viability. Consequently, this transition does not mean that overall total consumption in economic terms necessarily must be reduced. In particular, increasing the consumption of different kinds of services (for example, education) and digital products would not have a large effect on global emissions and could offer significant economic opportunities.

ICT has an important role to play in the shift towards a consumption pattern based on less fossil resources. Carbon emissions from the ICT industry are generally quite low relative to other sectors. The ICT industry accounts for about 1.4 percent of total carbon emissions, a level, which stayed fairly constant between 2010–2015 in spite of the smartphone revolution and exponential data growth. [60] Ongoing research confirms that this trend has continued throughout the decade. For example, in the telecommunications company Telia Company, electricity consumption remained flat across its mobile networks since the pandemic started, despite a 20 percent data traffic increase. [61]

Moving forward, 5G has huge potential to support the continued exponential increase in data traffic without increasing energy consumption. [62] Moreover, the ICT sector can also reduce its carbon emissions by 45 percent by 2030 in line with the trajectory outlined by

ITU, GSMA, GESIO and SBTi.[63] In addition to driving its own energy and carbon reductions, ICT can also help decrease carbon emissions in other industries. Research from 2015 suggests that there is a potential for ICT solutions to reduce the global greenhouse gas emissions of already established technologies by 15 percent by 2030.[64] The additional potential of 5G and other emerging technologies has not been quantified, but it is clear that they will have an important role to play in the decarbonization of the energy system, and, with new opportunities emerging, also in sectors such as manufacturing and transportation.

ICT is also contributing considerably to productivity development, which is needed for the financing of the climate transformation. Enormous investment in renewable energy sources will be necessary in order to reduce the consumption of fossil fuels. Increases in productivity, driven partly by new ICT networks such as 5G, will be necessary to finance these investments. However, it is important to make sure that the rebound effects from productivity are directed to shift consumption from fossil fuels towards renewable resources.

Dematerialization refers to the absolute or relative reduction in the quantity of materials required to serve economic functions in society and thus implies doing more with less. There have already been interesting results from dematerialization in advanced countries. Innovations such as the internet and other digital technologies have contributed to dematerialized consumption in the US. Although results differ between countries, this implies that the total consumption (including imports) of different inputs such as metals, fertilizers, and building products could decrease, in absolute terms, despite a continued increase in real GDP.[65] ICT´s own material intensity is an important example of this development. For example, telecommunications media has evolved through time, from copper to coaxial cable, and fiber optics, with each evolution capable of transmitting more information through less material. In this view, the more productive and advanced an economy becomes, the more opportunities for a less resource-intensive economy, and consumption will emerge as long as rebound can be mastered.

Impact on employment

For more than two centuries, companies have been investing in labor-saving technologies to increase productivity. This has implied a reduced number of jobs in some industries, but also job creation in others, as higher productivity has led to lower prices and increased aggregate demand. For the last few years, there has been an international debate about whether innovations based on technologies such as 5G, AI, and IoT will result in jobless growth.

One of the most important reasons for a firm to invest in new technology is to increase its productivity, but there are also additional incentives such as to ensure the safety of its employees.[66] When a company increases its productivity by investing in new technology, it might replace some of its employees with new machinery.[67] In the short run, some workers will lose their jobs as production becomes more efficient. However, in a competitive market, higher productivity will also result in goods and services becoming cheaper, which means consumers will be left with more money to spend on other goods and services. Overall demand in the economy will increase which most likely will create jobs. Thus, the new technology might be reducing jobs in one industry, but increasing jobs in another. This is what economists refer to as structural change, which implies that there is a long-term shift in the fundamental structure of employment and output driven by the new technology. This does not only imply that employees move from one industry to another, but also that new industries are created.

Since early in the Industrial Revolution, employees have been opposed to new technology that might make their jobs obsolete. Already in 1811, there were riots in England by so-called Luddites opposing mechanization in the textile industry. [68] The upheaval was aimed against new machinery such as stocking and spinning frames in the textile industry.

History proved the Luddites wrong. The fear of jobs being replaced by machines was exaggerated. Instead, there was a continuous structural change in the economy, where machines based on better technology improved production processes and resulted in a reduced number of jobs in some industries. The most striking example is agriculture employing approximately 75 percent of all employees in the US in the late 19th century while the corresponding figure in early 2000 was 2 to 3 percent.[69] However, new labor-saving technologies increased productivity and lowered prices, which resulted in increased aggregate demand. Thus, the jobs lost in agriculture were replaced by new job opportunities in other industries driven by increased demand and new innovations.

Recently, it has been argued that automation would have a negative impact on jobs, which is much more far-reaching than before. The tasks that have been most difficult to automate are those demanding flexibility, judgment, and common sense. [70] These are skills that humans understand only innately. Nevertheless, computers, AI, and robotics have progressed into spheres of human activity that were considered out of reach only a few years ago.

By classifying occupations, Frey and Osborne have estimated the likelihood that various classifications would become automated in the future. In their study, occupations were classified as low, intermediate, and high risk.[71] They found that 47 percent of US employees were at risk of their jobs being automated within 10–20 years. Based on a similar methodology, additional findings suggested that 57 percent of all jobs in OECD countries are susceptible to automation. Moreover, this number rose to 69 percent in India and 77 percent in China.[72]

The study by Frey and Osborne is based on classifying occupations in the US with respect to the risk of being susceptible to automation by asking experts. Since occupations usually consist of a number of different tasks, the potential for automating entire occupations may be much lower. A study by the OECD using a task-based approach found that the risk of automation for jobs in 21 OECD countries was, on average, 9 percent.[73] Another important aspect that Frey and Osborne neglected was the possibility of new jobs being created. The transition to a low-carbon economy will create jobs. Even though the total effect might be modest, the effect in specific sectors might be substantial.[74] One such sector will be the renewable energy sector.[75] Study results suggest that, for China, spending on the clean energy economy will produce nearly 70 percent more jobs per unit of expenditure than an equal amount of spending on fossil fuels.[76]

There is also evidence of wage polarization, primarily in the US.[77] Wage growth was less rapid in routine-task intensive occupations compared to abstract task-intensive occupations. The share of the top percentile household income in the US increased from 10 to 23 percent from 1979–2012.[78] Moreover, 65 to 70 percent of households in 2014 earned the same or less than similar households in 2005 in 25 advanced economies.[79] There is also evidence that college wage premiums increased sharply in the US from 1980–2005.[80]

So far, the primary concern has been about low-skilled jobs being automated. However, there is evidence that the total share of GDP attributed to labor has fallen in the US and many other OECD countries.[81] McKinsey points out that an important difference with the automation that is taking place today based on ICT technology is that it could also start to replace high-skilled jobs.[82] AI has surpassed humans in the performance of certain tasks related to intelligence such as image recognition.[83] As AI drives digitalization in the labor market, it seems there is a particular risk that middle-skilled workers will be the group most susceptible to job loss due to technological change.[84] One important lesson from this trend will be the importance of creating systems for lifelong learning. As job roles change, workers will need training to become more flexible and adaptable in their work styles.[85]

Conclusion

For more than 200 years, companies have been investing in labor-saving technologies in order to increase productivity. Major technological innovations—general-purpose technologies—have made a large economic impact from the Industrial Revolution to the present. These innovations have improved the lives of billions of people, but have also contributed to environmental degradation and carbon emissions that have destabilized the climate and led to rising temperatures throughout the world.

While more investment in renewable energy resources is necessary to attain net-zero greenhouse gas emissions, ICT is key to achieving that target, as it can help overcome climate change in many ways. These include increasing efficiency as data processing and communications grow while carbon emissions level off or decline, and dematerialization due to substitution effects, for example, remote working instead of commuting to and from the office or business travel, media and entertainment consumed online instead of in print, and the digitalization of services. On average over the last decade, ICT investment has accounted for approximately 15 percent of total GDP growth worldwide .

Many developing countries are at levels of consumption that are lower than those in more advanced economies and are working hard to reduce poverty and improve living conditions. As productivity gains reduce costs, it is reasonable to expect significant increases in consumption due to rebound effects. Meanwhile, in the more advanced economies, dematerialization is increasingly evident, implying that the more advanced an economy becomes, the less the world's resources will be used there to maintain consumption if rebound effects are under control.

Developed countries will need to aid developing countries to jump into the low-carbon era, compressing or even skipping the lag between innovation and economic impact. This will be possible as technologically advanced countries work through the myriad of improvements to general-purpose technologies, allowing the developing world to leapfrog whole generations of technology.

Technological innovation plays an important role in addressing the challenges of global climate change. To leverage market forces in this process, policies must increasingly support regulations and treaties using bonus-malus mechanisms. Increasing subsidies on goods and services reducing greenhouse gas emissions balanced with penalties tied to such emissions are needed to secure the transition towards a decarbonized economy. The 1.5°C emission pathways can be obtained only if rebound effects are used to support decarbonization.

Glossary of economic terms

Bonus-Malus	A Latin phrase—meaning reward-penalty—used in business contracts and economics to describe an arrangement that specifies a payment for fulfilling a target and a cost for not fulfilling it.
Capital deepening	An increase in the capital labor ratio; a rise in capital intensity.
Fixed asset	A long-term tangible piece of property, plant, or equipment that a firm owns and uses in its operations to generate income. Fixed assets are not expected to be consumed or converted into cash within a year.
Gross domestic product (GDP)	Value added + taxes on products – subsidies on products.
Gross output	The total value of produced goods and services.
Intermediate inputs	The total value of goods and services, other than fixed assets, used as inputs into the production process. The inputs may be either transformed or used up by the production process. Land, labor, and capital are primary inputs and are not included among intermediate inputs.
Labor productivity	The ratio between a measure of output and a measure of labor input. Output can be measured as gross output or value-added, and labor input can be measured as hours worked or the number of persons employed.
Total factor productivity (TFP)	The portion of output not explained by the amounts of inputs used in production. TFP can be explained by new technology, organizational change, or measurement errors.

References

1 OECD (2020), OECD Employment Outlook 2020: Worker Security and the COVID-19 Crisis, OECD, Paris.

2 Maddison Project Database, version 2020. Bolt, Jutta and van Zanden, Jan Luiten (2020), “Maddison style estimates of the evolution of the world. A new 2020 update“, available online: https://www.rug.nl/ggdc/historicaldevelopment/maddison/releases/maddison-project-database-2020

3 Broadberry, Stephen N., Campbell, Bruce M., Klein, Alexander, Overton, Mark and van Leeuwen, Bas (2015), British Economic Growth 1270-1870, Cambridge University Press, Cambridge.

4 Conference Board (2020), Total Economy Database (TED), available online: https://conference-board.org/data/economydatabase

5 Fukao, Kyoji, Bassino, Jean-Pascal, Makino, Tatsuji, Paprzycki, Ralph, Settsu, Tokihiko, Takashima, Masanori, and Tokui, Joji (2015), Regional Inequality and Industrial Structure in Japan: 1874-2008, Maruzen Publishing, Tokyo.

6 McCusker, John J (2006), “Colonial Statistics“, in Carter, Susan, Gartner, Scott S., Haines, Michael R., Omstead, Alan L., Sutch, Richard and Wright, Gavin (Eds.), Historical Statistics of the United States: Earliest Time to the Present, Cambridge University Press, New York, V-671.

7 Pfister, Ulrich (2011). “Economic growth in Germany, 1500—1850“, Paper presented at the Conference on Quantifying Long Run Economic Development, 22-24 March, Venice.

8 Prados de la Escosura, Leonardo (2009), “Lost Decades? Economic Performance in Post-Independence Latin America“, Journal of Latin America Studies, vol. 41, pp. 279—307. (updated data)

9 Ridolfi, Leonardo (2016), The French economy in the longue durée. A study on real wages, working days and economic performance from Louis IX to the Revolution (1250-1789), Ph.D. Thesis, IMT School of Advanced Studies, Lucca.

10 Scheidel, Walter and Friesen, Steven J (2009), “The size of the economy and the distribution of income in the Roman Empire“, Journal of Roman Studies, vol 99, pp. 61—91.

11 Sutch, Richard (2006), “National Income and Product“, in Carter, Susan, Gartner, Scott S., Haines, Michael R., Omstead, Alan L., Sutch, Richard and Wright, Gavin (Eds.), Historical Statistics of the United States: Earliest Time to the Present, Cambridge University Press, New York, III-23-25.

12 Houghton, John T, Jenkins, Geoff J and Ephraums, Jim J (1990), Climate Change — The IPCC Scientific Assessment, Cambridge University Press, Cambridge.

13 Bresnahan, Timothy F. and Trajtenberg, Manuel (1995), “General Purpose Technologies ‘Engines of Growth’?“, Journal of Econometrics, vol. 65, pp. 83—108.

14 Helpman, Elhanan (1998), General Purpose Technologies and Economic Growth, MIT Press, Cambridge, MA.

15 OECD provides the following definition of ICT goods: "ICT goods must either be intended to fulfil the function of information processing and communication by electronic means, including transmission and display, or use electronic processing to detect, measure and/or record physical phenomena, or to control a physical process." (OECD (2011), OECD Guide to Measuring the Information Society 2011, OECD Publishing, Paris).

16 David, Paul A. (1990), "The Dynamo and the Computer: An Historical Perspective on the Modern Productivity Paradox", American Economic Review, vol. 80, pp. 355—361.

17 Crafts, Nicholas (2004), "Steam as a General Purpose Technology: A Growth Accounting Perspective", Economic Journal, vol. 114, pp. 338—351.

18 Rosenberg, Nathan and Trajtenberg, Manuel (2004), "A General-Purpose Technology at Work: The Corliss Steam Engine in the Late-Nineteenth-Century United States", Journal of Economic History, vol. 64, pp. 61—99.

19 David, Paul A. (1991), "Computer and Dynamo: The Modern Productivity Paradox in a Not-Too-Distant Mirror", in: Technology and Productivity: The Challenge for Economic Policy, OECD, Paris, pp. 315—347.

20 Devine, Warren (1983), From Shafts to Wires: Historical Perspective on Electrification", Journal of Economic History, vol. 43, pp. 347—372.

21 Kendrick, John W. (1961), Productivity trends in the United States, Princeton University Press, Princeton.

22 Baumol, William J. (1993), Entrepreneurship, Management, and the Structure of Payoffs, MIT Press, Cambridge, MA.

23 Moore, Gordon (1965), Cramming More Components onto Integrated Circuits, Electronics, vol. 38, pp. 114-117.

24 Solow, Robert (1987), "We'd Better Watch Out", New York Times Book Review, July 12, p. 36.

25 Oliner, Stephen D. and Sichel, Daniel E. (2000), "The Resurgence of Growth in the Late 1990s: Is Information Technology the Story?", Journal of Economic Perspectives, vol. 14, pp. 3—22.

26 Gordon, Robert J. (2000), "Does the 'New Economy Measure up to the Great Inventions of the Past?", Journal of Economic Perspective, vol. 14, pp. 49—74

27 Byrne, David M., Oliner, Stephen D. and Sichel, Daniel E. (2013), "Is the Information Technology Revolution Over?", FEDS Working Paper, no. 2012—36, Federal Reserve Board, Washington D.C.

28 van Ark, Bart, O'Mahony, Mary and Timmer, Marcel (2008), "The Productivity Gap between Europe and the United States: Trends and Causes", Journal of Economic Perspectives, vol. 22, pp. 25—44.

29 Calculations based on Conference Board (2021), Total Economy Database and World Bank (2021) World Development Indicators Database.

30 Malmodin, Jens and Lundén, Dag (2018), "The energy and carbon footprint of the global ICT and E&M sectors 2010-2015", Sustainability, vol. 10, pp. 1-31.

31 Bertschek, Irene, Briglauer, Wolfgang, Hüschelrath, Kai, Kauf, Benedikt and Niebel, Thomas (2015), "The Economic Impacts of Telecommunications Networks and Broadband Internet: A Survey", Review of Network Economics, vol. 14, pp. 201-227.

32 Hardy, Andrew P. (1980), "The role of the telephone in economic development", Telecommunications Policy, vol. 4, pp. 278–286.

33 Röller, Lars-Hendrik, and Waverman, Leonard (2001), "Telecommunications Infrastructure and Economic Development: A Simultaneous Approach", American Economic Review, vol. 91, pp. 909–923.

34 OECD is the Organization for Economic Co-operation and Development.

35 Our World in Data (2021), Research and data to make progress against the world's largest problems, available online: https://ourworldindata.org

36 Ericsson Mobility Report, June 2021.

37 Gruber, Harald and Koutroumpis, Pantelis (2011), "Mobile telecommunications and the impact on economic development", Economic Policy, vol. 26, pp. 387–426.

38 Czernich, Nina, Falck, Oliver, Kretschmer, Tobias and Woessman, Ludger (2011), "Broadband infrastructure and economic growth", Economic Journal, vol. 121, pp. 505–532.

39 Rohman, Ibrahim K. and Bohlin, Erik (2012), "Does broadband speed really matter for driving economic growth? Investigating OECD countries", International Journal of Management and Network Economics, vol. 2, pp. 336–356.

40 Edquist, Harald, Goodridge, Peter, Haskel, Jonathan, Li, Xuan and Lindquist, Edward (2018), "How important are mobile broadband networks for the global economic development?", Information Economics and Policy, vol. 45, pp. 16–29.

41 Countries are classified based on GNI per capita, provided by World Bank (World Bank (2018b), "World Bank GNI per capita Operational – Guidelines and Analytical Classifications", February, available online: https://datahelpdesk.worldbank.org/knowledgebase/articles/378834-how-does-the-world-bank-classify-countries). In 2014, countries with an average income per capita below USD 4,125 were classified as low-income countries.

42 Chin, Menzie D. and Fairlie, Robert W. (2007), "The determinants of the global digital divide: A cross-country analysis of computer and internet penetration", Oxford Economic Papers, vol. 59, pp. 16–44.

43 Licensed cellular IoT is defined as total unique SIM cards that have been registered on the mobile network at the end of the period enabling mobile data transmission between two or more machines. Licensed cellular IoT excludes computing devices in consumer electronics such as e-readers, smartphones, dongles and tablets.

44 Edquist, Harald, Goodridge, Peter and Haskel, Jonathan (2019), "The Internet of Things and economic growth in a panel of countries", Economics of Innovation and New Technology, vol. 30, pp. 262–283.

45 Brynjolfsson, Erik, Eggers, Felix and Gannamaneni, Avinash (2018), "Measuring Welfare with Massive Online Choice Experiments: A Brief Introduction", AEA Papers and Proceedings, vol. 108, pp. 473–476.

46 Edquist, Harald, Goodridge, Peter and Haskel, Jonathan (2020), "The economic impact of streaming beyond GDP", Applied Economics Letters, https://www.tandfonline.com/doi/abs/10.1080/13504851.2020.1869158

47 PWC (2021), The global economic impact of 5G – Powering your tomorrow, available online: https://www.pwc.com/gx/en/tmt/5g/global-economic-impact-5g.pdf

48 OECD (2021), Recommendation of the Council on Artificial Intelligence, OECD, Paris.

49 Brynjolfsson, Erik, Rock, Daniel and Syverson, Chad (2017), "Artificial Intelligence and the Modern Productivity Paradox: A Clash of Expectations and Statistics", NBER Working Paper, no. 24001, National Bureau of Economic Research, Cambridge, MA.

50 Our World in Data (2021), Research and data to make progress against the world's largest problems, available online: https://ourworldindata.org

51 Our World in Data (2021), Research and data to make progress against the world's largest problems, available online: https://ourworldindata.org

52 World Bank (2021), "Population, total 1960–2019", available online: https://data.worldbank.org/indicator/SP.POP.TOTL

53 Jevons, Stanley W. (1865), "The Coal Question; An Inquiry concerning the Progress of the Nation, and probable Exhaustion of our Coal-mines", Macmillan and Co, London and Cambridge.

54 Håkansson, Cecilia and Finnveden, Göran (2015), " Indirect Rebound and Reverse Rebound Effects in the ICT-sector and Emissions of CO2", Paper presented at the 29th International Conference on Informatics for Environmental Protection (EnviroInfo 2015) and the Third International Conference on ICT for Sustainability (ICT4S 2015).

55 Our World in Data (2021), Research and data to make progress against the world's largest problems, available online: https://ourworldindata.org/.

56 According to IPCC, 1.5°C emission pathways are defined as those that, given current knowledge of the climate response, provide a one-in-two to two-in-three chance of warming either remaining below 1.5°C or returning to 1.5°C by around 2100 following an overshoot.

57 Our World in Data (2021), Research and data to make progress against the world's largest problems, available online: https://ourworldindata.org/

58 World Bank (2021), "Population, total 1960–2019", available online: https://data.worldbank.org/indicator/SP.POP.TOTL

59 Our World in Data (2021), Research and data to make progress against the world's largest problems, available online: https://ourworldindata.org

60 Malmodin, Jens and Lundén, Dag (2018), "The Energy and Carbon Footprint of the Global ICT and E&M Sectors 2010-2015, Sustainability, vol. 10, https://doi.org/10.3390/su10093027

61 Telia Company (2020), "Network Traffic has surged during the pandemic – But electricity consumption is largely unaffected", June 4, available online: https://www.teliacompany.com/sv/nyhetsrum/news-articles/2020/network-traffic-has-surged-during-the-pandemic--but-electricity-consumption-is-largely-unaffected

62 Ericsson (2020), Breaking the energy curve – An innovative approach to reducing mobile network energy use, available online: https://www.ericsson.com/495d5c/assets/local/about-ericsson/sustainability-and-corporate-responsibility/documents/2020/breaking-the-energy-curve-report.pdf

63 ITU (2020), "ICT industry to reduce greenhouse gas emissions by 45 per cent by 2030, Press Release, February 27, available online: www.itu.int/en/mediacentre/Pages/PR04-2020-ICT-industry-to-reduce-greenhouse-gas-emissions-by-45-percent-by-2030.aspx

64 Malmodin, Jens and Bergmark, Pernilla (2015), "Exploring the effect of ICT solutions on GHG emissions in 2030", Conference Paper, Third International Conference on ICT for Sustainability (ICT4S), September 7–9, Copenhagen.

65 McAfee, Andrew (2019), More from Less: The Surprising Story of How We Learned to Prosper Using Fewer Resources – And What Happens Next, Scribner, New York.

66 Baumol, William J. (2002), The Free-Market Innovation Machine: Analyzing the Growth Miracle of Capitalism, Princeton University Press, Princeton.

67 Brynjolfsson, Erik and McAfee, Andrew (2014), The Second Machine Age: Work, Progress, and Prosperity in a Time of Brilliant Technologies, W.W. Norton & Company, New York.

68 Sale, Kirkpatrick (1995), Rebels Against the Future – Lessons for the Computer Age, Quartet Books Limited, London.

69 The Economist (2009), Rethinking the Luddites, November 6th.

70 Autor, David H. (2015), "Why Are There Still So Many Jobs? The History and Future of Workplace Automation", Journal of Economic Perspectives, vol. 29, pp. 3–30.

71 Frey, Carl Benedikt and Osborne, Michal A. (2013), "The Future of Employment: How Susceptible are Jobs to Computerization?", Working Paper, University of Oxford, Oxford.

72 Citi GPS (2016), Technology at Work v2.0 – The Future Is Not What It Used to Be, Citigroup and Oxford Martin School.

73 Arntz, Melanie, Gregory, Terry and Zierahn, Ulrich (2016), "The Risk of Automation for Jobs in OECD Countries: A Comparative Analysis", OECD Social, Employment and Migration Working Paper, no. 189, OECD Publishing, Paris.

74 OECD (2017), Investing in Climate, Investing in Growth", OECD Publishing, Paris.

75 IRENA (2018), Global Energy Transformation – A Roadmap to 2050, International Renewable Energy Agency, IRENA, Abu Dhabi.

76 Chen, Ying (2019), "Renewable energy investment and employment in China", International Review of Applied Economics, vol. 33, pp. 312–334..

77 Autor, David (2014), "Polany's Paradox and the Shape of Employment Growth", NBER Working Paper 20485, Cambridge, MA.

78 Autor, David (2014), "Skills, Education and the Rise of Earnings Inequality Among the ´Other 99 Percent´", Science, vol. 344, pp. 843–851.

79 McKinsey (2016), "Poorer Than Their Parents? Flat or Falling Incomes in Advanced Economies", July, McKinsey Global Institute.

80 Goldin, Claudia and Katz, Lawrence F (2007), "The Race Between Education and Technology: The Evolution of the U.S. Educational Wage Differentials, 1890 to 2005", NBER Working Paper 12984, Cambridge MA.

81 Author, David, Dorn, David, Katz, Lawrence F. Patterson, Christina and Van Reenen, John (2020), "The Fall of the labor share and the rise of superstar firms", Quarterly Journal of Economics, vol 135, pp 645–709.

82 McKinsey (2017), "A Future that Works Automation, Employment and Productivity", January, McKinsey Global Institute.

83 Executive Office of the President (2016), Artificial Intelligence, Automation, and the Economy, Washington D.C.

84 Autor, David (2014c), The Polarization of Job Opportunities in the U.S. Labor Market: Implications for Employment and Earnings, Centre for American Progress, Washington D.C.

85 Ericsson (2018), Creative machines – How artificial intelligence will impact the future labor market, available on line: www.ericsson.com/en/reports-and-papers/consumerlab/reports/creative-machines

Authors

Stephen Carson is a Strategic Marketing Director in Ericsson Marketing and Communications. He specializes in network economics and is a writer and editor of the Ericsson Mobility Report. Stephen has been instrumental in developing the App Coverage framework as well as Total Cost of Ownership models for radio access networks. He has a B.A. from the University of California at Berkeley and an MBA from INSEAD at Fontainebleau in France.

Harald Edquist is Master Researcher Macroeconomics at Ericsson Research. His research focus on the impact of ICT technologies, such as IoT and 5G, on productivity, economic growth and jobs.

Harald has also been awarded the title Associate Professor in Economic History at the Stockholm School of Economics. Intangible investments and comparative productivity development are additional research interests.

Before joining Ericsson, Harald worked as a Research Director at the think tanks Forum for Reforms, Entrepreneurship and Sustainability (FORES) and the Centre for Business and Policy Studies (SNS). He has also been engaged in international research projects at the Research Institute of Industrial Economics (IFN), the Swiss Bank UBS and the OECD.

Ericsson Position Paper
Uen 284 23-3269
October 2021