BETTER POLICIES FOR BETTER LIVES

The next production revolution

Prepared for the conference

SHAPING THE STRATEGY FOR TOMORROWS PRODUCTION

Copenhagen, 27 February 2015

CONTENTS

This paper was prepared by the OECD Secretariat (Directorate of Science, Technology and Innovation) as a background document for the conference 'Shaping The Strategy for Tomorrows Production'. The opinions expressed and arguments employed are those of the OECD Secretariat in developing its work on the 'Next Production Revolution'. The paper does not represent the official views of the OECD or of its member countries nor of The Production Council.

The objective of the OECD work on the 'Next Production Revolution' in 2015-2016 is to examine and better understand the pathways – both technological and non-technological – of future prospects for growth, innovation and productivity across the economy. The ambition is to better understand the key structural changes in both manufacturing and services that could occur and assess the implications these technological changes and the resulting business dynamics will have for a wide range of policies. The work does not aim to forecast what will happen in the future as this is an impossible task in a world characterised by increasing levels of volatility, uncertainty, and complexity. The aim is rather to formulate robust policy recommendations on how economies can fully benefit from the emerging new opportunities, and prepare for the challenges of the next production revolution.

EXECUTIVE SUMMARY

Major science and technology-driven changes in production of goods and services are occurring now. Others – possibly more significant still - are on the horizon. Information and communication technologies (ICTs) such as the 'Internet of Things', 3D printing, industrial biotechnology and nanotechnology have the potential to dramatically change the outlook of production in the next 10 to 15 years. This may support a new industrial revolution. The convergence between the different technologies is particularly likely to distinguish this revolution from 'normal' technological advances and is therefore expected to result in disruptive changes.

The next production revolution has the potential to completely change how production will be organised on a global scale. Different technologies reduce economies of scale in production and therefore change the topography of global value chains (GVCs). While more pessimistic scenarios have traditionally predicted a bleak future for production in OECD economies, it is increasingly suggested that this next production revolution could generate new and important opportunities for OECD countries. Emerging economies are also looking at the possible advent of a next production revolution, not only to safeguard their industrial competitiveness in times when they gradually lose their (labour) cost advantage, but also because it might help them to upgrade and move away from lower value added activities in production.

Harnessing a possible next production revolution is high on the policy agenda in OECD and emerging economies. Previous industrial revolutions have energised national economies and increased the standard of living of millions of people. Likewise, the next production revolution could have far-reaching impacts on productivity, income distribution, well-being and the environment. These impacts are likely to vary across industries, countries and sections of the workforce and some impacts may be hard to foresee. The more governments understand the possible developments, the better prepared they will be able to cope with associated risks and reap the potential benefits.

In many countries, ensuring a strong manufacturing sector is an important policy challenge that can contribute to these goals. A productive manufacturing sector continues to be important because of its central role in OECD economies by orchestrating GVCs across different countries, industries and products. In addition, manufacturing is still a key source of technological progress generating spillovers to other sectors and as the driver of much international trade. But at the same time, the services sector has become a more dynamic part of the economy, as ICTs have helped to create new and more efficient businesses, boosted productivity growth and facilitated international trade in services.

The next production revolution will bring about important economic and social changes which have important implications for policy making. For example, what will be the impact on labour markets; will production still create jobs in the future, where will these jobs be created and what type of jobs will they be? Tapping into the next industrial revolution requires action on many levels and in many different areas. In particular, unlocking the potential of emerging and enabling technologies requires policy development along a number of fronts, from commercialisation to regulation and the supply of skills through education.

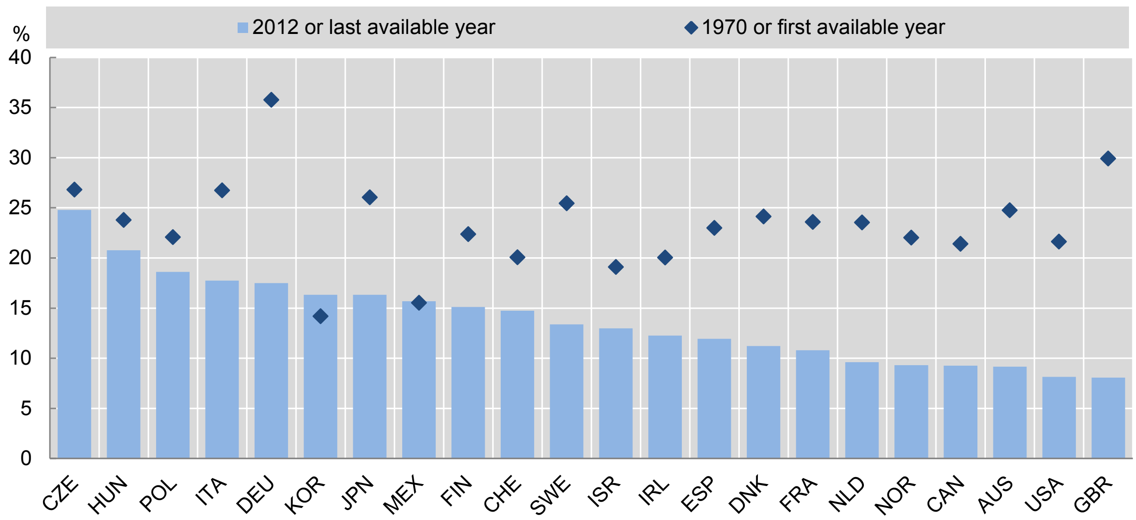
PRODUCTION TODAY

Is OECD manufacturing (and thus production) in decline?

Frequent reporting on company restructurings, downsizing, plant closures, job losses, etc. suggests that OECD manufacturing is an industry in decline. The reality is however different: while manufacturing has indeed been strongly restructured over the past decades, in absolute terms manufacturing activities in OECD economies are still important and growing today.

Nonetheless, all OECD economies have been characterised by a long-term trend of deindustrialisation (OECD, 2015a). The relative importance of manufacturing in national economies has decreased particularly in terms of employment: the share of manufacturing in total employment was in 2012 on average 15% or below in most OECD countries (Figure 1). This trend seems to be a natural consequence of economic development with OECD economies increasingly being characterised by a growing tertiarisation (i.e. the growing importance of services).

Figure 1: Manufacturing share in total employment, selected OECD economies, 1970 and 2012

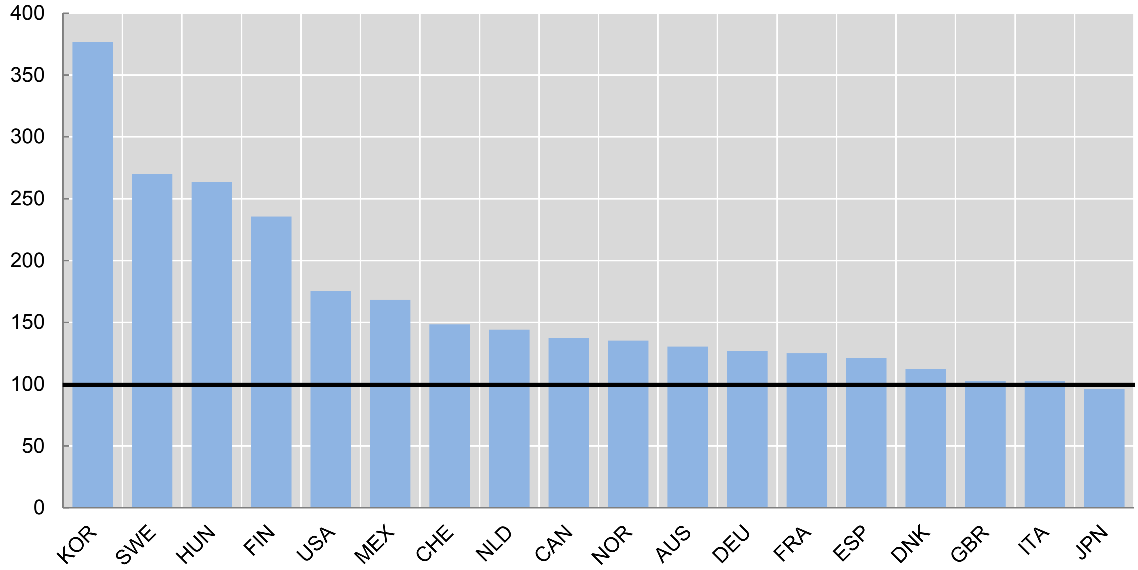


Source: OECD (2015a), Manufacturing or services: That is (not) the question (forthcoming)

In contrast to the falling number of manufacturing jobs, output in manufacturing in OECD countries has continued to increase, reflecting strong productivity growth (Figure 2). In several countries, the rate of growth of output in the manufacturing sector, measured by real value added, has equalled or exceeded that of GDP. Strong productivity growth has also resulted in prices of manufacturing products increasing less than for other products.

At the same time, emerging economies have become important players in global manufacturing. Within a short time, China has become the largest manufacturer in the world accounting in 2013 for almost a quarter of all value created in global manufacturing. OECD economies still produced about 55% of manufacturing value added in that year, but this is down from almost 85% in 1970.

Figure 2: Manufacturing output, selected OECD economies, 1970 and 2012
value added in constant prices, 1970 = 100



Source: OECD (2015a), Manufacturing or services: That is (not) the question (forthcoming)

The changing characteristics of OECD production

The continuous and deep restructuring of OECD manufacturing has dramatically changed the character of production in OECD economies. Production today is using manufacturing methods and technologies which often did not exist 20 to 30 years ago; products nowadays include a growing knowledge and services (thus: intangible) content, while manufacturing companies have come a long way from the traditional image of the large vertically integrated conglomerates with production concentrated in one location.

Production has become increasingly fragmented internationally as companies have located subsequent stages of their production processes in a growing number of countries across the globe (OECD, 2013a). Within these GVCs, more labour-intensive activities (often pure production and/or assembly) have typically been offshored from OECD economies to low-labour-cost economies. In addition to their lower labour costs, emerging economies like China, India and Brazil are attractive for foreign investors because of their large and growing home markets.

In their continuing search for higher efficiency, manufacturers have also increasingly outsourced/offshored (supporting) services activities to independent suppliers. Activities like finance, transport, cleaning, etc. are nowadays often contracted out to specialised service providers (domestically or internationally) within GVCs. This has resulted in important productivity and efficiency gains as well as lower input prices for 'leaner' manufacturers.

The remaining manufacturing activities in OECD are often world-class and very advanced; they are heavily based on different knowledge inputs (computerised information, innovative property and economic competencies, etc.) across a broad set of technologies (OECD, 2013b). With intense global competition, OECD producers are often positioned in the higher-value upstream (e.g. R&D, design, prototyping, etc.) and downstream (e.g. marketing, logistics) activities of production. Case studies for individual products, including the well-known studies of different Apple products, have documented important differences in the extent to which value added is captured by countries within GVCs. Emerging economies are however also increasingly targeting these higher value added production activities within their upgrading strategies.

Products increasingly represent bundles of advanced goods and services; a growing number of manufactured products owe in fact a large part of their success to their design and services associated with the product. A company like Rolls Royce does not only sell cars but 'solutions, outcomes or experiences' to better meet the needs of customers and to differentiate from competitors. Other manufacturing companies have little or no manufacturing in-house; indeed, in some cases companies have completely abandoned the physical production of manufactured goods (e.g. Apple and Dyson are well-known examples of so-called Factoryless Goods Producers) (OECD, 2015a).

OECD production is about manufacturing and (business) services

Production in OECD economies today is no longer just about manufacturing. While manufacturing still matters and occupies a central role in OECD economies by orchestrating GVCs across different countries, industries and products, value creation in OECD production increasingly stems from pre- and post- production activities.

Manufacturing drives to a large extent the productivity growth in national economies as its growth rates in productivity are much higher than in other industries. This strong productivity performance of manufacturing is closely linked to its higher innovative performance: for example, manufacturing industries account for the majority of R&D investments in OECD economies (which often generate benefits in other industries). In addition, manufacturing also accounts for the majority of international trade.

Production in OECD economies increasingly thrives on services inputs for value creation; manufacturing GVCs for example cannot function efficiently without quality logistics, telecommunications, business services, etc. These types of business services, typically characterised by a high ICT content, increasingly display the progressive characteristics of manufacturing (i.e. they are productive, innovative and internationally tradable) and directly contribute to the competitiveness of production activities.

Differences between manufacturing and services have become increasingly blurred. Manufacturing industries increasingly sell and buy services, while services have become very similar to manufacturing industries. The growing and complex interactions between manufacturing and services additionally call for a more integrated view on manufacturing and services in company strategies and policy discussions.

Denmark in global production

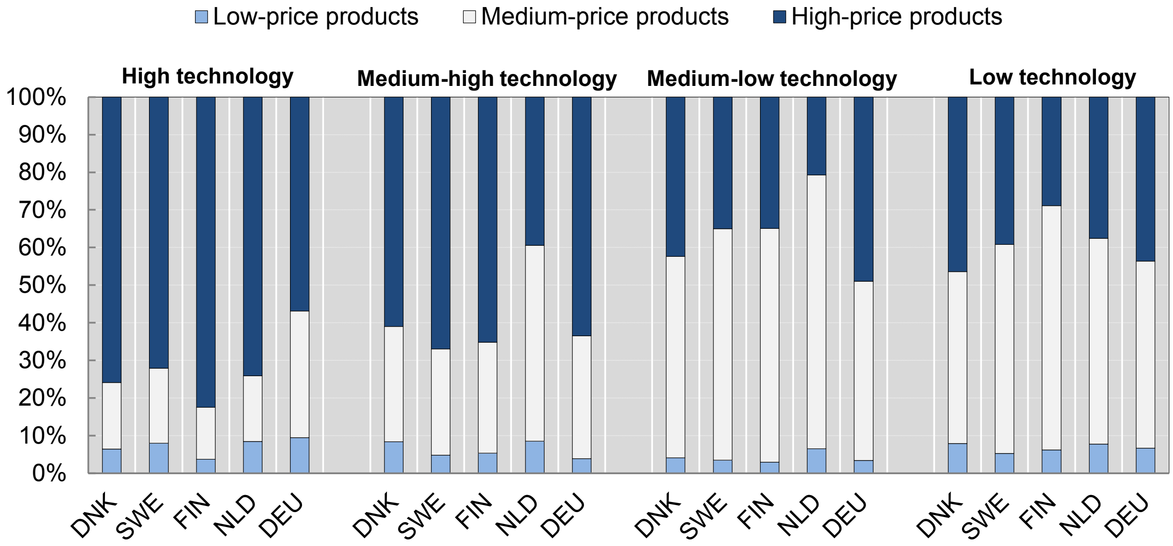
Due to its size, Denmark is a rather small player in global production, although a number of Danish companies are world leaders in well-defined niches across different industries. In light of the increasing competition from emerging economies production, Denmark has increasingly focused on more knowledge intensive products and services to compensate for its (labour) cost disadvantage.

Just like other OECD economies, Denmark has been characterised by a long-term trend of deindustrialisation with manufacturing industries accounting nowadays for about 12% of both GDP and total employment. In absolute terms, manufacturing output has however increased reflecting strong productivity growth in Danish manufacturing during the past decades (Figures 1 and 2).

Danish companies are active across a broad range of manufacturing industries, with the most important sectors (in terms of value added) being food, pharmaceuticals, machinery, electrical equipment, furniture and metal industries. Business services have become increasingly important within the Danish economy with transport and logistics, telecommunications and professional/business services as most important. Services inputs are important inputs into Danish manufacturing, with almost one third of the value of Denmark's manufacturing exports being created in service industries.

Danish companies have acquired a strong position on international markets in food, machinery, electrical equipment, furniture and metal industries, highlighting Denmark's comparative advantage in these sectors. The relative higher price at which Danish products are sold on international markets suggests Denmark competes on terms other than price. Higher quality products based on knowledge based assets like R&D, design, branding, etc. are an important factor in the international competitiveness of Denmark. Relative to other countries this is particularly true in lower-technology industries like food and furniture (Figure 3).

Figure 3: Exports by technology and price level, selected OECD economies, 2012



Note: see OECD (2013a) for a description of the methodology used.
Source: OECD calculations based on CEPII BACI database

GVCs are nowadays crucial for the international competitiveness of companies and economies, as they allow for the efficient sourcing of better and/or cheaper inputs from abroad. One-third of the value of Danish exports represents foreign inputs, i.e. parts and components imported from abroad to be included in Danish exports. This reflects in part the more general observation that smaller countries typically show higher foreign content of their exports since their domestic sourcing opportunities are more limited than in larger countries (OECD, 2013a). The OECD Trade in Value Added database shows that Denmark is largely integrated into GVCs in transport and telecommunications services and to a lesser extent in manufacturing industries like food, chemicals, machinery and electrical equipment (OECD, 2013a).

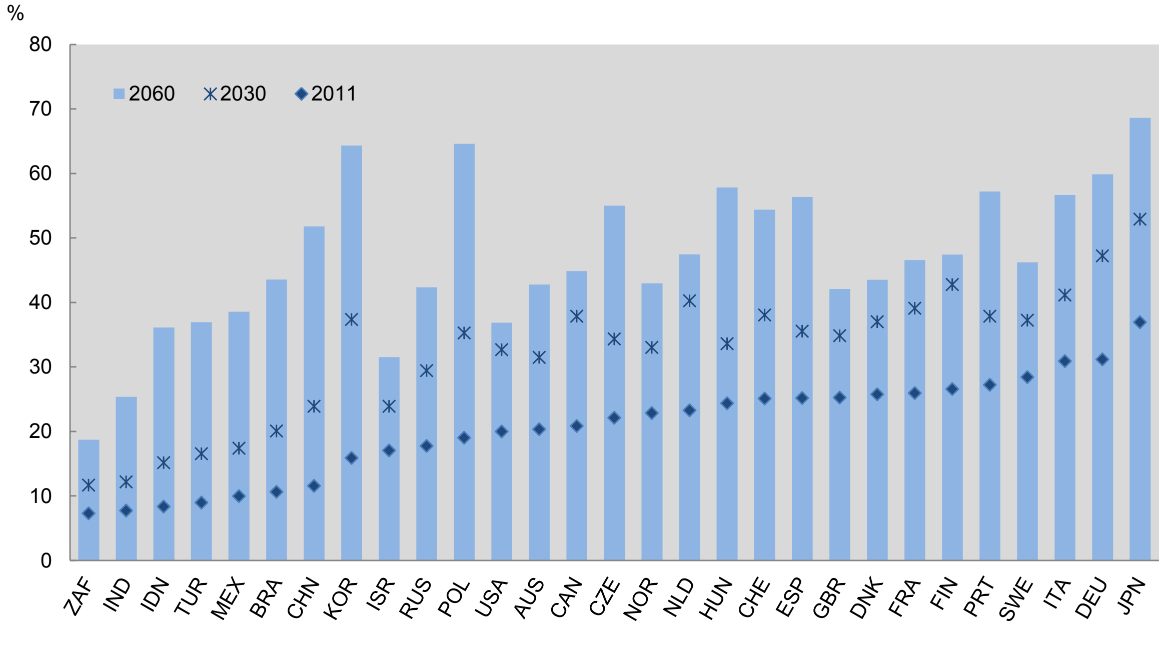
Megatrends will change future production

A number of so-called megatrends are expected to further (re-)shape global production in the next decades. As important drivers of future opportunities and challenges, these global and broad, non-industry-specific trends will increasingly affect the way production will be organised, where production will be located and which types of products will be demanded. While already present now and starting to drive current change, these transformative global trends could potentially act as game changers for production in OECD economies and beyond.

Changing demographics, e.g. in population size and composition, are expected to significantly impact production activities in the future, both because of supply and demand factors. Due to the decline in fertility rates and generalized gains in longevity, projections suggest that ageing over the next 50 years will result in old-age dependency ratios (i.e. percent of the population older than 65 as a share of population aged 15-64) more than doubling in some countries (Figure 4). Apart from its macro-economic effects – a smaller labour supply, increased fiscal pressure in some areas and an ageing workforce may in addition lead to skill mismatches and even shortages as production activities in OECD economies are characterised by high skill intensity. It can also be expected that an ageing population will change consumer demand towards particular products and services (e.g. health) due to changes in tastes, incomes and household size and composition.

Figure 4: Old age dependency ratio, selected OECD and BRIICS countries, 2011, 2030 and 2060

Per cent of the population older than 65 as a share of population aged 15-64



Source: OECD (2012), Looking to 2060: A Global Vision of Long-Term Growth

Population growth combined with rising general prosperity in emerging economies will lead to changing patterns of international demand (see discussion on emerging middle class). In addition, emerging economies will be increasingly confronted with growing flows of migration within countries (i.e. from rural areas to cities) and internationally (towards other countries, e.g. developed countries). Estimates show that the urban population in Asia will increase from 1.36 billion in 2010 to 2.64 billion by 2030 while in Africa it will rise from 294 million to 742 million, and from 394 million to over 600 million in Latin America and the Caribbean (United Nations, 2011). This growing urbanisation will create major societal challenges to which future production will need to adjust in terms of location but also for example by providing solutions for housing, mobility, etc. (UNIDO, 2013)

The green and sustainability imperative: With demand for some natural resources outstripping available and future supplies, shortages of natural resources are predicted to emerge in many regions across the world. The issue of peak oil (i.e. the point in time at which global oil production declines) has been hotly debated in recent years because of the discovery of shale oil (and gas). The global resource challenge is however not only about oil, since imbalances between demand and supply are also growing for energy at large, water, fish stocks, minerals (e.g. zinc, indium, etc.) and also food.

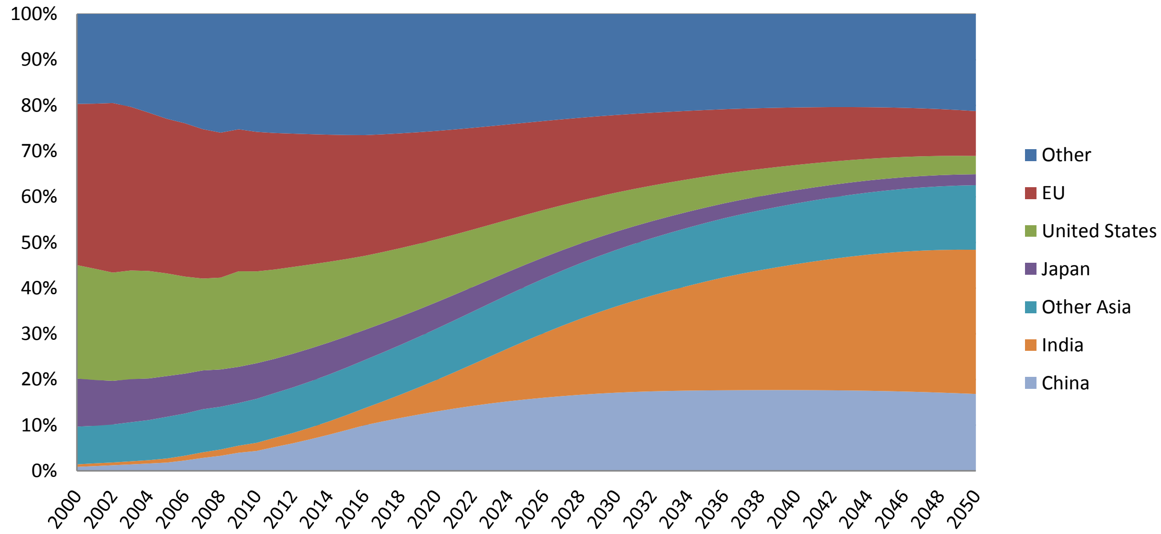
Increases in population and economic growth will result in even larger resource demands from across the globe, making the global resource challenge more acute. In addition, the challenge of climate change will have major impacts on economies and societies following the rise of average temperatures due to the growing presence of greenhouse gasses in the atmosphere. There is a growing demand/pressure to become more sustainable along the value/supply/production chain and new technologies are expected to help address these challenges (see below). As (some) production activities are energy- and resource intensive, the development of more sustainable products and processes will become more important.

Continuing (economic) globalisation: The emergence of GVCs have resulted in a growing interconnectedness between countries with significant flows of goods, services, capital, people and technology. Lower trade and investment barriers, falling transport costs and advances in information and communication technologies (ICT) have made it easier to offshore activities over longer distances. At the same time, GVCs have allowed countries to integrate more rapidly in the global economy. This has resulted in GVCs becoming longer and more complex over time, with production processes spanning a growing number of countries, increasingly in emerging economies.

Re-shoring instead of offshoring of activities has increasingly attracted attention in recent years. A number of factors on the supply side may motivate companies in the near future to bring activities closer to their main markets thereby changing the geography of GVCs in some industries (OECD 2013). Wage increases (for example in Eastern China) are quickly eroding the labour cost advantage of emerging economies, while long and complex GVCs have exposed companies to a growing degrees of supply risk in case of adverse shocks (e.g. natural disasters, political unrest, armed conflicts). In addition, management, logistical and operational problems including the protection of IPR, resulted often in significant 'hidden' costs (i.e. costs which were not take into account in the decision to offshore) and have in some cases made offshoring less/not profitable (Boston Consulting Group, 2014).

Demand factors will however still favour the location of production activities in emerging economies. China and India for example are the world's most populated countries and have high GDP growth and are quickly becoming important markets for firms in many industries. While global consumer demand had previously been concentrated in (rich) OECD economies, a new middle class is emerging in China and India (Figure 5). While this middle class worldwide could rise from 1.8 billion to 3.2 billion by 2020 and to 4.9 billion by 2030, almost 85% of this growth is expected to come from Asia. In 2000, Asia (excluding Japan) only accounted for 10% of the global middle-class spending; this could reach 40% by 2040 and almost 60% in the long term. It is expected that income increases in emerging economies will lead to a rise in consumption of basic consumer products and other product categories.

Figure 5: The rising middle class in emerging economies, 2000-2050



Source: Kharas (2010)

Towards advanced production: technologies that may revolutionise future production

Throughout history, new technologies have fundamentally changed how things are produced. For example, the steam engine, electricity and computers have drastically transformed the industrial landscape in the past. There is a growing debate that the world is on the brink of similar industrial revolution(s) and a reshuffling of production will take place in the next 10 to 15 years. It is argued that a number of cutting-edge technologies like nanotechnology, biotechnology, ICT, etc. will provide (partial) solutions for the challenges created by global megatrends in demographics, globalisation and sustainability. Indeed, while most of the technologies have been around for a while, one observes more recently the wider application of these technologies for business solutions. Accordingly, the competitiveness of companies and economies in future production will increasingly depend on the application of these advanced technologies in products and production processes.

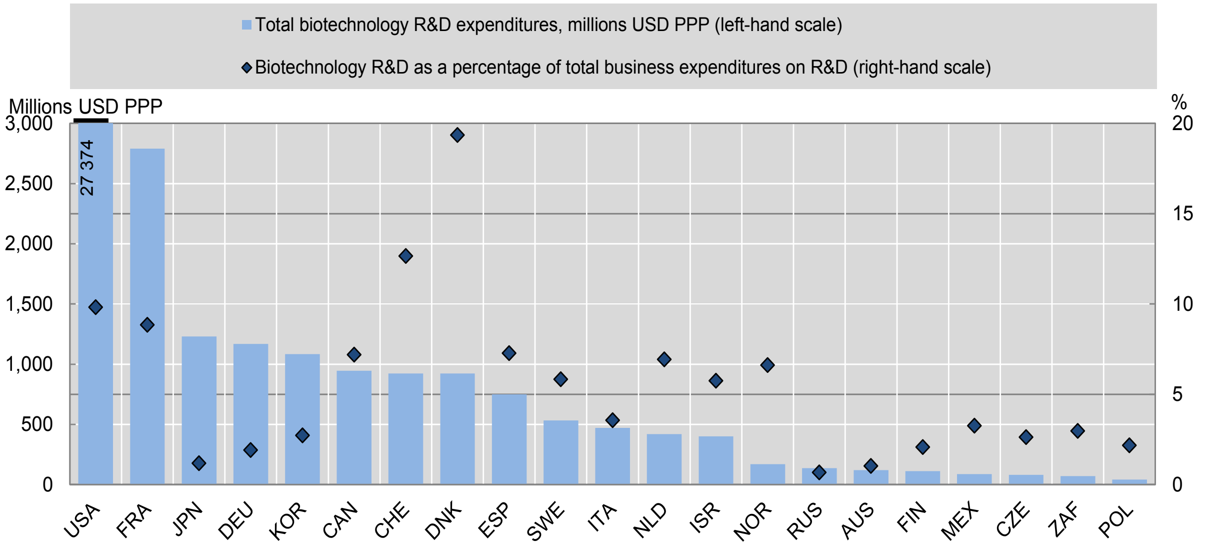
'Advanced manufacturing' is expected to increasingly dictate the characteristics of future products, as well as the production methods used in the future. The President's Council of Advisors on Science and Technology in the United States defines Advanced Manufacturing as "a family of activities that (a) depend on the use and coordination of information, automation, computation, software, sensing, and networking, and/or (b) make use of cutting edge materials and emerging capabilities enabled by the physical and biological sciences, for example nanotechnology, chemistry, and biology. This involves both new ways to manufacture existing products, and especially the manufacture of new products emerging from new advanced technologies."

Additive manufacturing encompasses multiple techniques that build products by adding material in layers - often under computer control; this stands in contrast with subtractive manufacturing – as we know now- which uses material and removes unnecessary excess to build the product. 3D printing is probably the most discussed technology within this group of production techniques as the technology behind 3D printing is starting to mature. It is currently used especially for rapid prototyping (as it allows for a shorter design process) as well as low-volume production like parts and customised products (e.g. jewellery, dental and medical material through bioprinting, etc.). 3D technology however still faces a number of obstacles (the number of materials used in 3D printing is limited, the lack of standards, issues related to intellectual property rights (IPR)); as such, it is hard to predict how fast this technology will be deployed and become mainstream for the production of different types of products in larger numbers. As it will allow for digital transportation, storage, creation and replication of products (with companies selling designs instead of physical products), 3D printing has the potential to spark a production revolution. Savings on the use of resources, reduced material waste, smaller transport flows of physical products, lower inventories, and more personalised and unique products are put forward as the main advantages of this group of technologies.

Nanotechnology is a group of technologies that allow for the manipulation, study or exploitation of very small (typically less than 100 nanometres) structures and systems (OECD, 2010). Nanotechnology contributes to novel materials, devices and products that have qualitatively different properties. For instance, nanotechnology has the potential to make products lighter, stronger, cheaper, faster, more resistant, more energy efficient, etc. Nanotech-related solutions are expected to increasingly impact production across a wide range of industries (e.g. chemistry, pharmaceuticals, metals, engineering, electronics) and can provide major competitive advantages for companies. More generally, it is expected that new applications in nanotechnology have the potential to affect virtually every area of economic activity while at the same time helping to address a range of societal and environmental challenges. While many nanotechnology sub-areas are still in an early and immature phase of development, commercial products are starting to emerge from nanoelectronics, nanomaterials, nanocoatings and nanomedicine.

Biotechnology is defined as the application of science, technology and engineering techniques in bioscience in order to alter the characteristics of existing species (living and non-living materials) and to develop completely new materials (i.e. synthetic biotechnology) for the production of knowledge, goods and services (OECD, 2009). The term biotechnology encompasses a broad collection of techniques, ranging from genomics, genetic engineering to cell and tissue engineering, process biotechnology, engineering of proteins and molecules, bioinformatics, etc. (OECD). Synthetic biology can be seen as a new way of biotechnology using standardised biological building blocks through engineering to produce new biobased materials. As climate change mitigation, energy security, resource depletion, sustainable economic growth are among the important drivers, the current industrial biotechnology boom is especially observed in the production of bio-electricity, biofuels and bio-based materials such as chemicals and plastics. It is however expected that industrial biotechnology is likely to have an increasing impact across a growing number of industries (e.g. pharmaceuticals, food and textiles). Just like in nanotechnology, large investments across the globe – with a strong position for Denmark (Figure 6) are pushing the boundaries in this field; important obstacles (e.g. scalability of research, IPR, regulations, public perception and risk governance) though are also hindering further progress in biotechnology.

Figure 6: Biotechnology R&D in the business sector, selected OECD and BRIICS countries, 2011



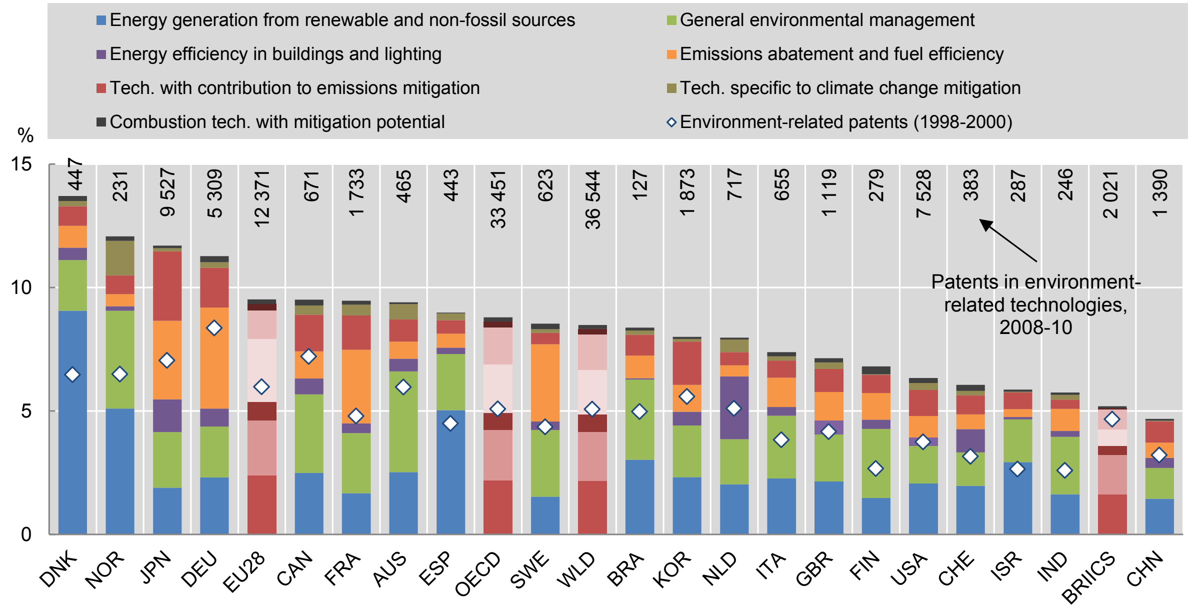
Source: OECD (2013c), OECD Science, Technology and Industry Scoreboard: Innovation for growth; http://dx.doi.org/10.1787/888932892043

Advanced materials are expected to be increassingly used in areas such as metals, ceramics, bio- and nanomaterials, nanotubes and grapheme, often dubbed ‘the material of the future’. Driven by advances in nano- and biotechnology among others, there is a continuing search for new materials to take advantage of improved characteristics (functionality, reliability, weight, energy efficiency, etc.) in products and production processes. New materials with new properties may stimulate innovation; the integration of “new” and “old” materials will allow for new designs and improved performance of products and processes with applications across a broad range of industries: steel, chemistry and plastics, metal, energy, textiles, etc. The future competitiveness in these industries will increasingly depend on the successful combination of design, new materials, engineering and manufacturing.

Green technologies are intended to increase resource and energy efficiency and/or minimise the generation of waste. Just as in the case of new and advanced materials, ‘green’ technologies directly benefit from advances in general purpose technologies like nanotechnology, biotechnology and ICT. The production of new nano- and bio-products will serve as direct inputs for the development of environmental and energy technologies. New materials are critical components of emerging technologies in clean energy, such as less expensive solar power and electric-car batteries that can go longer between charges. The use of ICT in production processes will enable production with a lower environmental impact than using conventional methods while at the same time contribute to the monitoring of environmental impacts. New technologies that extract natural gas and light tight oil from shale deposits are rapidly developing but still need to address a number of environmental issues (e.g. water contamination, induced seismicity, greenhouse gas emissions); manufacturing industries in countries with ample shale gas/oil are expected to strongly benefit from the expansion and diversification of energy sources. Denmark shows a strong performance in green technologies: while the United States, Japan and Germany own, not surprisingly, the largest patent portfolios in absolute terms, Denmark is the most specialised in environment-related patenting (Figure 7).

Figure 7: Patents in selected environmental technologies, selected OECD and BRIICS countries, 1998-2000 and 2008-2010

As a percentage of total Patent Cooperation Treaty patent applications



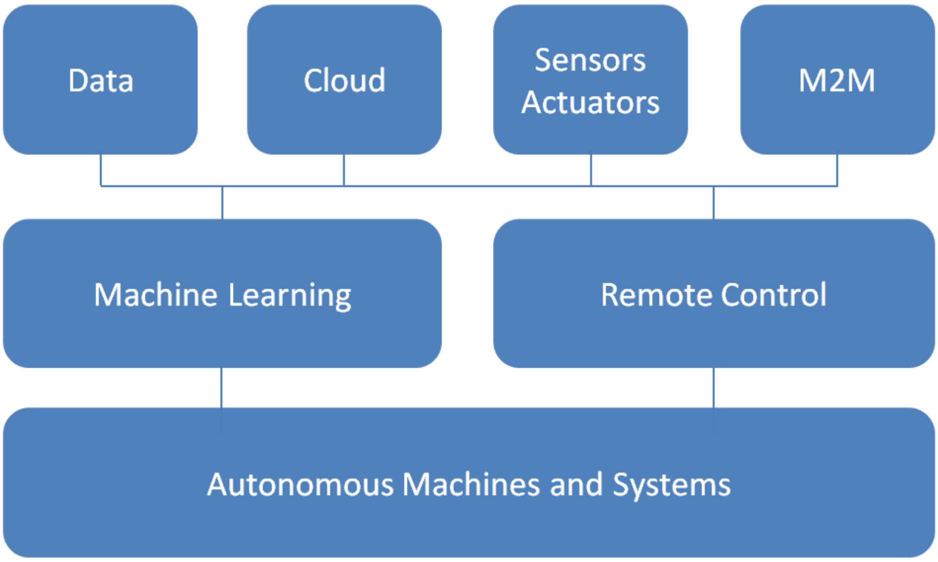
Source: OECD (2013c), OECD Science, Technology and Industry Scoreboard: Innovation for growth; http://dx.doi.org/10.1787/888932891929

ICT technologies are already widely used in modern production systems but new ICT applications are expected to dramatically change production in the coming years. Emerging digital technologies such as sensors, machine-to-machine communication (M2M), data analytics and artificial intelligence will transform or replace many products and production processes. New ICTs are expected to increase efficiency and productivity through e.g. better inventory management and resource/energy optimisation, create new products for new markets, drive the development of completely new business models and value chains, stimulate and facilitate breakthrough innovations, and as such becoming the cornerstone of future competitiveness.

Several ICTs are rapidly converging to the Internet of Things (IoT), which is expected to have profound implications not only for industrial processes, but also broader applications for consumer and home services, energy, transport systems, health care, infotainment and public services (OECD, 2015b). The basic idea behind the term IoT is that devices and objects will become increasingly connected to the internet. Oxford Economics estimates that the Industrial Internet of Things spans industries representing 62% of GDP among G20 economies, including manufacturing, mining, agriculture, oil and gas and utilities. But also companies in service industries like hospitals, warehouses and ports, logistics, transportation and healthcare will increasingly be impacted by the IoT. The Industrie 4.0 initiative in Germany is putting forward this digital production as a basis for the future economy and society

Four new ICT technologies can conceptually be considered as underpinning the development of the (industrial) IoT (Figure 8). Electronic, bio- and chemical sensors measure multiple physical properties and are the interface between the physical world and the world of electrical devices such as computers; accentuators reversely convert the electrical signal into a physical phenomenon (e.g. displays for quantities measured by sensors such as speedometers, temperature reading for thermostats, but also those that control the motion of a machine). As both sensors and accentuators are swiftly becoming smaller, cheaper and more sophisticated, they are increasingly used in production processes across a broad range of industries.

Figure 8: ICT technologies converging to the Internet of Things



Source: OECD (2015b) The Digital Economy Outlook, forthcoming

The large flows of data from sensors - often referred to as 'big data', i.e. data of which the size is beyond the ability of typical database software tools to capture, store, manage, and analyse these data - are communicated M2M (Machine-to-Machine) and stored for further correlation and analysis to other machines and central computers. Connected and communicating machines allow improved monitoring of production processes remotely and provide instructions to one set of equipment based on activities at other set of equipment. As a result, remote operation has become possible in ways that were not practically possible before, where the machine does the majority of the tasks and the human interaction is limited to very specific actions. For example in mining it allows one remote operator to manage multiple ore transporters, where in the past each had to be staffed.

Driven by developments in data analytics and cloud computing (i.e. a service model for computing services based on a set of computing resources that can be accessed in a flexible, elastic, on-demand way with low management effort), machine learning algorithms have resulted in new levels of artificial intelligence. The use of data and analytics enables a wide range of smart applications that use machine learning algorithms to learn from previous situations and that can communicate the results of the learning to other machines. Data analytics will increasingly analyse large volumes of data from sensors in real time of which the results will be communicated within computerised production systems in order for machines to learn to adapt to changing conditions (OECD, 2015c).

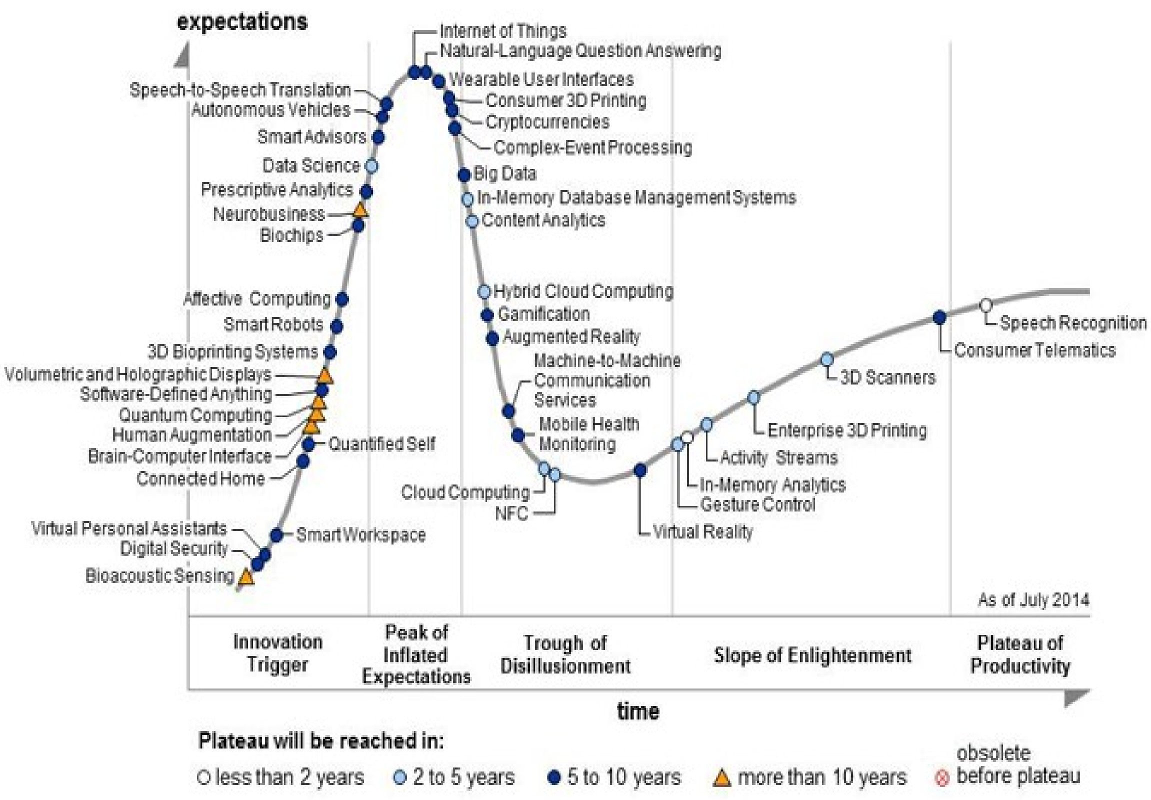
Increasing artificial intelligence will not only result in smart applications (e.g. data analysis in finance, health, etc.) it will also give rise to autonomous machines and systems. Robots have traditionally been used in industries where speed, precision, dexterity and ability to work in hazardous conditions is valued. Traditional robots, however, were efficient in very precisely defined environments, but setting up a robotic plant would take months if not years to precisely plan all the movements of the robots down to the millimetre. The IoT is expected to make robots flexible, self-learning and intelligent as machines increasingly combine big data analysis, cloud computing, M2M communication and sensors and actuators.

A current example of this development is the Philips shaver factory in Drachten (The Netherlands) which is almost fully robotic today, employing only one-tenth of the workforce employed in its factory in China that makes the same shavers. Foxconn, the Chinese Taipei based multinational electronics contract manufacturing company - most known for assembling Apple products, is looking into deploying over 1 million robots in its business in the coming years (OECD, 2015c). The IoT is also expected to give a multitude of new and smart products based on autonomous machines like for example Google's driverless cars. Many of the technologies underlying the IoT have still not seen large scale deployment but a lot is still to come.

Convergence between technologies will lead to disruptive changes

Emerging technologies like nano-, biotechnology and ICT have the potential to fundamentally change production over the next 10 to 15 years and the combination of different technologies may revolutionise products and production systems. All industries will be affected but impacts will be different across industries over time; while nano- and biotechnology bare more importance for manufacturing industries as well as agriculture, ICT developments will impact both manufacturing and services. As technologies are at different stages of maturity and are moving at different speeds, the exact timing and impacts are however difficult to forecast. Recognising that technologies are at the risk of becoming hyped, Gartner (2014) assessed the prospects of 2000 (mainly ICT) technologies grouped into 119 aggregated areas of interest in its Hype Cycle for Emerging Technologies (Figure 9). The analysis predicts the number of years until technologies will reach maturity and shows how expectations change during the different phases of technology life cycles.

Figure 9: Hype cycle for emerging technologies, 2014



Source: Gartner (2014)

The convergence between the different technologies is particularly likely to distinguish this revolution from 'normal' technological advances. The combination of different technologies in products and production processes can be expected to lead to disruptive changes as the results of one technology may leverage the outcome of other technologies. Green technologies typically operate at the intersection of these emerging technologies, with nano-, biotechnology, advanced materials and a wide range of ICT applications strongly contributing to the rapid development of environmental and energy technologies. The combination of ICT with bio- and nanotechnology has already given rise to so-called programmable matter that can adjust to different conditions (e.g. environmental). It is argued that over time 3D printing will significantly benefit from advances in biotechnology as the production of new bio-materials will significantly broaden the limited number of materials that nowadays can be used in 3D-printing. The blending of these technologies is expected to give rise to a multitude of new products, processes and applications over the next 15 years, many of which cannot be imagined today. Advances in the medical and pharmaceutical industries typically combine new results from nano- and biotechnologies as well as from different ICT technologies.

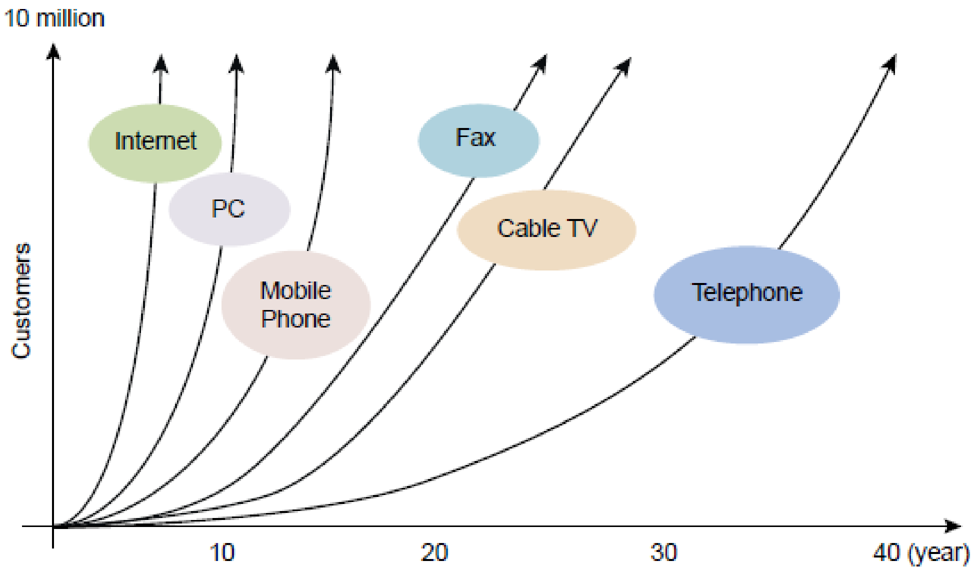
Key characteristics of future production

Global transformative megatrends in demographics, sustainability and globalisation will create new and growing demands for production in the future; advances in emerging technologies will help to address some of the challenges arising from these megatrends. 'Business as usual" is no longer an option for companies in a competitive environment that is different and rapidly evolving. Companies will apply new business models and strategies to take full advantage of the numerous opportunities offered by new technologies. As always, successful companies are those that understand the new forces at work and use them to their advantage. Likely features of future production are:

Complex: the competitive environment has become increasingly complex over time with production increasingly interconnected across a growing number of countries, consumers becoming more demanding, and technologies increasingly interdisciplinary, etc. (UNIDO, 2013). Superior integration capabilities will be crucial for the development of complex production through intricate designs, products and production processes. The ability to combine and integrate different technologies, to efficiently incorporate internal expertise with external knowledge (cfr. open innovation), to quickly intertwine the objectives and outcomes of the different in-house divisions (design, engineering, manufacturing, etc.) will become increasingly important in business models (OECD, 2013b).

Rapidly responsive: in addition to being confronted with increasing complexity, companies also face a competitive environment characterised by growing volatility. Product life cycles have become shorter over time, technology adoption rates have increased significantly, and the international fragmentation of production is impacted by different events along the value chain (Figure 10). Companies will need to be able to swiftly respond to changes in consumer demand, customer preferences, supply conditions, social requirements, etc. (UNIDO, 2013). Increased use of technologies like 3D printing will allow for more rapid prototyping and shorter design/development cycles; digital production will result in a more flexible organisation of production; the reconfiguration of supply chains with more localised production centres and to some extent duplication between different production facilities centres will increase the responsiveness when demand is volatile.

Figure 10: Speed of technology adoption



Source: Yim (2011) in UNIDO (2013)

Creative: amid global competition, the competitiveness of OECD economies strongly depends on their innovation capabilities. Future production will not only need to be innovative but increasingly creative: in combining different emerging technologies, in bundling goods with services, in demonstrating environmental awareness, in linking up with other partners including competitors, etc. Creativity will also be key for addressing the geographical change in consumer demand, as innovations that worked in developed economies are likely to be less successful in emerging economies; inclusive innovation models will be needed for lower income and excluded groups in developing countries.

Customised: with economies and cultures forecasted to increasingly shift from mass markets to millions of niche markets (see for example C. Anderson "The Long Tail"), a growing demand for customised products is likely. In contrast, today manufactures produce more standardised and commoditised products as scale economies do not allow for different product specifications. Emerging technologies such as additive manufacturing, new materials, ICT, nanotechnology, will allow for more personalised products while at the same time reducing the cost of small-volume production. In addition, services will increasingly be used to tailor products for different consumers. A retooling of business models incorporating technological and organisational changes will be needed to address the challenge(s) of mass customisation.

Digital: ICT applications will increasingly be used in production with some production processes becoming completely digital. The convergence of different ICT technologies will result in important efficiency and productivity gains, increase the responsiveness of companies to changing conditions, allow the integration of product design with manufacturing processes, change the delivery of products and services, etc. Direct digital manufacturing like 3D printing will allow the manufacturing of products directly from digital files in the future. The shift towards digital production will be observed both in developed and emerging economies: OECD economies see digital production as a new source of competitiveness of future production, while emerging economies like China will use digital production to increase productivity and compensate for their increasing (labour) cost structure.

Smart and intelligent: the larger use of digital technologies will drastically increase the information content of future production. The information stored and analysed within products will make them more intelligent allowing them to adapt to changing conditions. The increased use of artificial intelligence and autonomous robotics will enable production processes to auto-correct themselves to changing conditions. Due to improved sensor technologies, cheap computer power and the real-time use of algorithms, smart machines will not only be programmable but increasingly adjustable.

Distributed and localised: the organisation of production in long and complex GVCs to take advantage of optimal location factors across the globe has shown its advantages in terms of productivity, efficiency, scale economies, etc. On the other hand, the complexity of these international production networks has exposed companies to large levels of supply risk in the event of adverse shocks and has made them less agile to respond to changing preferences in consumer demand. In addition, consumer awareness for the negative effects of the transport flows of intermediates and final products within GVCs is growing. It is expected that a rebalancing of GVCs will happen and that accordingly the topography of production will become more varied and distributed. In addition to global hubs in GVCs, production will become increasingly concentrated in regional/local hubs closer to end markets both in developed and emerging economies. The changing geography of GVCs may in some industries result then in the reshoring (not necessarily to the home country, but rather to the broader region) of activities that were once offshored (OECD, 2013a).

Sustainable: because of climate change, biodiversity loss, and resource depletion, environmental sustainability will become increasingly important in future production in order to decrease resource and energy consumption and waste generation. Regulation imposed by governments will put more stringent conditions for products and production processes while also consumer demand for sustainable products is growing. Green technologies will be an important part of the solution through advances in nano, bio- and ICT technologies; in addition strategies for a circular economy will increasingly be applied to increase the re-use, remanufacturing and recycling of products. Companies increasingly apply cradle to cradle in the design of their products, where the reuse or recycling of each component and part is planned for at the design phase of the product. In addition, new business models based on sharing instead of owning products will result in less production (and waste) thereby increasing sustainability.

Bundling of goods and services: a large part of the future growth in production is expected to come from so-called 'manu-services' which involves combining advanced manufacturing with a range of different services. Services help not only to raise productivity and efficiency of production activities, but also differentiate, customise and up-grade products and develop closer and more longstanding relationships with customers. The bundling of services creates unique product characteristics and differentiates firms for their competitors. In addition, services make up an additional source of revenue and generate higher profit margins, which are perceived as more stable over time.

POLICY ISSUES AND CHALLENGES

A renewed interest for production in OECD economies

The policy debate in OECD economies has shown a renewed interest in production and manufacturing in recent years, often motivated by the potential need for rebalancing the economy. For example, the United Kingdom with its strong financial services sector was severely affected by the financial and economic crisis of 2007/2008, whereas some countries with strong and international manufacturing sectors experienced more limited impacts. In the United States which has witnessed major job losses in the past decades, the possibilities of a manufacturing renaissance have been intensively debated in direct relation to the potential impacts of re-shoring of activities by US companies.

A large number of countries - OECD and emerging economies - have undertaken strategic foresight studies on the future of manufacturing/production combining insights from key experts with broader engagement of different stakeholders. Although the scope, set-up, timing and methodology differed across countries, most of these studies had an important technology focus. Broadly speaking, the studies aimed at identifying the opportunities and challenges of emerging technologies for the structure and location of future production (Table 1). The results of such studies are often used in guiding the prioritisation of industries and technologies; in general, policy makers today tend to identify and target broad sectors and technologies instead of narrowly defined industries.

Table 1: Studies on future manufacturing/production, selected examples

Australia	2011	Trends in Manufacturing to 2020
China	2011	Advanced Manufacturing Technology in China: A Roadmap to 2050
China	2009	Technological Revolution and China's Future - Innovation 2050
EU	2007	Manufuture Workprogramme 'New Production'
EU	2010	High Level Group on Key Enabling Technologies
Germany	2010	Produktionforschung 2020
Japan	2011	Monozukuri White Papers
Sweden	2008	Production Research 2020: Strategic Agenda
United Kingdo	2013	The Future of Manufacturing
United States	2012	Emerging Global trends in Advanced Manufacturing
United States	2014	Report to the President: Accelerating U.S. Advanced Manufacturing

Note: UK Government Office for Science (2013a)

A number of countries have also implemented new initiatives/policies specifically targeted at future manufacturing and production. The United States for example launched a group of initiatives on Advanced Manufacturing focusing on the applications of nano-, bio and ICT technologies for business. Germany targets a 4^{th} industrial revolution with its initiative on Industrie 4.0, focusing on smart production and the Internet of Things, Data and Services. This initiative is a key part of the High-Tech Strategy 2020 Action Plan of the German government to pursue innovation objectives over a 10 to 15-year period.

Production and sustainable economic growth

Against the current backdrop of sluggish growth, policy makers are increasingly looking for new sources of growth. Innovation is the most important driver of economic growth in modern economies, more than inputs of capital and labour as the application of technology and science accounts for over half of all economic growth. Production has traditionally been an area in which increased innovation and productivity take place, hence the (renewed) policy interest for creating growth through production. Particularly the extent to which economies can take advantage of the new and emerging technologies in production will become increasingly important for the creation of sustainable economic growth across countries. Advances in these technologies will also help the transformation of production towards greater sustainability. The advent of a next production revolution may enhance productivity growth and at the same time address the growing demands for green growth.

The fact that nano-, bio- and ICT technologies are general purpose technologies and hence applicable across a broad range of industries, would make these technologies well placed to generate long-term productivity increases and thus economic growth. There is however no agreement about the prospects of innovation for future productivity. On the one hand, technological pessimists like Gordon (2012) argue that the current productivity slowdown may become permanent as recent and future innovations are insignificant compared to those that took place during previous industrial revolutions. In discussing the US productivity slowdown, Gordon identifies a number of "headwinds" that will hold back future growth. On the other hand, technological optimists argue that the productivity slowdown is not permanent and the underlying rate of technological progress has not decelerated. Others like Brynjolfsson and McAfee (2014) argue that advances in digital processing power will entail large productivity gains in the future. Recent OECD work also reports that despite the productivity slowdown over the 2000s, productivity growth at the global frontier has remained relatively robust; at the same time however, a rising gap in productivity growth between firms operating at the global frontier and other firms is observed since the beginning of the century (OECD, 2015e).

Production and manufacturing have typically been associated with innovation and productivity, but production activities have become increasingly separate from R&D and innovation activities in the global and interconnected economy. As evidence has shown that distance matters for knowledge and innovation, it is increasingly argued that this offshoring of production may in turn lower the innovation capabilities and thus the long-term productivity growth of economies. The loss of (core) manufacturing activities may erode adjacent activities in the value chain, both upstream and downstream including activities related to innovation and design (i.e. the so-called erosion-of-the-commons argument). Because of important feedback effects, companies will prefer to locate production and innovation activities; the implication is that OECD economies may struggle to retain innovative R&D-based and higher value added activities if they rely on these areas alone. Ceding capacities in manufacturing and production might thus result in the economy-wide loss of R&D and design capabilities in the longer term.

Production, employment and inequality

The number and the type of jobs involved in production activities have significantly changed over time as a result of increasing globalisation and skill-biased technological change. While the exact effects of both factors are still debated, it is clear that the growing integration of emerging economies in the global economy has led to the destruction of jobs, especially for lower-skilled workers in OECD economies. At the same time, newly created jobs in production have tended to be higher-skilled. More recently, also medium-skilled jobs have become increasingly impacted by GVCs and technological progress. Medium-skilled workers often have manual or cognitive tasks that lend themselves to automation or codification (e.g. book-keeping, monitoring processes and processing information). Since these tasks can be done by machines or offshored (as services), demand for medium-skilled workers has declined as have the returns to their skills.

Emerging technologies particularly in the field of ICT are predicted to further affect the labour market as the comparative advantage of human labour over smart machines is shifting. Brynjolfsson and McAfee (2014) argue that the New Digital Age will bring long-term benefits, but at the same time disruptive changes on the labour market. Middle-skill/income jobs are expected to remain the most vulnerable group as more and more routine jobs will be taken over by information technology. And since new and more intelligent machines will increasingly perform functions that once only humans could do, it is expected that the middle segment itself will become larger implying that more and more workers may be affected.

While there are different views on the implications of technological change for employment, IoT promises to increase their scale and reach. Indeed, ICT technologies may in the future also increasingly impact lower-skilled workers in service industries. While these jobs have until now been largely sheltered from international competition and technological advances, intelligent products and production systems might also start to replace these jobs in a future further away (e.g. driverless cars would decrease the need for tax and bus drivers).

In general, it is expected that production will create fewer jobs in the future and that these jobs will increasingly be high-skilled because of the growing importance of emerging technologies for future production. As production will become more digital and intelligent, it is expected that particularly digital skills will be crucial to keep and land high-value jobs in production. The widening inequality on labour markets risks thus to increase further with wages for lower- and medium-skilled workers stabilising or even declining, while these of (some) higher-skilled people increasing in future production. Some go further and suggest that in particular a small group of highly skilled may be disproportionally well rewarded since ICT technologies increasingly create 'winner takes all markets' thereby providing a specific advantage to the 'superstars' (Brynjolfsson and McAfee, 2014).

Policy discussion in some countries have recently focused on the potential of reshoring to bring jobs back home; a number of studies have projected large number of production jobs that could return in the next years. It is very hard to predict what exactly will happen but a couple of things have to be kept in mind in the discussion on reshoring and employment. First, although there are a number of companies that have re-shored activities in recent years, aggregate data do not yet show real evidence of a wide trend of reshoring. Second, if companies decide to relocate their activities, this does not necessarily mean that these activities will come back to the home country since companies are increasingly considering location choices from a regional perspective, rather than from a country perspective. Some argue for example that US activities form China will probably not return to the United States but rather to Mexico because of its short distance to the US market, lower labour costs, integration in NAFTA, etc. Lastly, activities that are brought back will most likely become more automated; since automation typically reduces the labour content of production, the job impact of reshoring will be smaller.

Is policy ready for the next production revolution?

The profound changes and complex uncertainties associated with the next production revolution can be expected to increasingly challenge government policies over the next 10 to 15 years. Current policies are most likely not designed to address the disruptive changes that will happen and to foster a competitive production sector for the future. But at the same time, it is clear that while governments have a number of policy levers at their disposal, they cannot shape production alone. Many of the pre-conditions are need in concert with efforts among stakeholders in business, education, research, etc. As the policy issues of a possible next production revolution are numerous, the following paragraphs will touch upon a non-exhaustive number of policy challenges.

Benefitting from the new technological trends that are central to the next production is dependent on a broad range of policy drivers. Enabling innovation in products, production processes, business models, etc. will be crucial for economies to reap the benefits from the next production revolution. Innovation creates economic growth and employment, while at the same time helps to address the megatrend-challenges of demographics, sustainability and globalisation. OECD (2010 and 2015d) has shown that policies that foster innovation are much broader than policies to fund basic R&D and support business R&D, financing for risk capital, etc. Attractive framework conditions, investments in human (skills), knowledge (R&D, design, etc.) and physical (infrastructure) capital, entrepreneurship policies, regulation, etc. are all examples of policies that matter for innovation. For example, new technologies typically create new business opportunities; in some cases, large firms will seize these new opportunities but more radical innovations are often undertaken by young and small firms. Allowing sufficient experimentation by new market players is thus needed to test the commercial potential of new products and business models, which in turn will drive the creation of economic growth and jobs.

The further development of emerging technologies is often hindered by a number of barriers, for example in terms of standards, IPR and the scaling up of R&D. As some of these barriers are the direct result of current policies, it will be primordial to identify and rectify these policies. Governments can also play an important role in increasing the social acceptance of new technologies; there are some indications that people increasingly distrust new technologies which is linked to ethical, legal, health (e.g. for nano- and biotechnology), security and privacy (e.g. for ICT) issues. The data-driven innovation underlying digital production calls for a number of issues relating to data availability and security to be addressed.

In a competitive environment that becomes increasingly complex and volatile, embracing new technologies of which the outcomes are often uncertain and sometimes ambiguous will result in increased levels of risk. Some technologies may be rejected by some countries as too risky but perhaps welcomed by other countries. It can thus be expected that risk attitude and the way risk and uncertainty is handled within economies, by business as well as government, will play an important role in drawing benefits from the next production revolution.

The next production revolution will not only create benefits; important challenges are expected to arise in the first place on the labour market. Policies will need to be designed to prepare workers for potentially disruptive changes in working conditions and reduce the adjustment costs of job losses and job displacement? Forecasts show that rising income inequality will become a bigger problem over the next 10 to 15 years, resulting in important economic (e.g. inequality negatively affects growth) and social (e.g. inclusive growth) consequences. Future workers will need to be equipped with higher skills, as digital skills in combination with other skills will be increasingly essential to land a production job in the future. This may have direct implications for education policy: does the current education system provide (future) workers with the necessary skills? In addition, how can policies prevent that the ageing of the workforce result in a loss of knowledge for production companies? The economic and social challenges on future labour markets are legion; the success of the next industrial revolution will then also be measured against how well these challenges are addressed.

Tapping into the next industrial revolution requires actions on many levels and in many different areas. In particular, unlocking the potential of emerging and enabling technologies requires policy development along a number of fronts, from commercialisation to regulation and the supply of skills through education. The objective of the OECD work on the 'Next production revolution' in 2015-2016 is to examine and better understand the pathways – both technological and non-technological – of future prospects for growth, innovation and productivity across the economy. The ambition is to better understand the key structural changes both in manufacturing and services that could occur and assess the implications these technological changes and the resulting business dynamics will have for a wide range of policies. The work does not aim to forecast what will happen in the future as this is an impossible task in a world characterised by increasing levels of volatility, uncertainty, and complexity. The aim is rather to formulate robust policy recommendations on how economies can fully benefit from the emerging new opportunities, and prepare for the challenges of the next production revolution.

SELECTED REFERENCES

Boston Consulting Group (2014), The Shifting Economics of Global Manufacturing

Brynjolfsson, E. and A. McAfee (2014), The Second Machine Age: Work, Progress and Prosperity in a Time of Brilliant Technologies, New York

Gartner (2014), Gartner's 2014 Hype Cycle for Emerging Technologies Maps the Journey to Digital Business

Gordon, R.J. (2012), Is US Economic Growth Over? Faltering Innovation Confronts the Six Headwinds, Policy Insights, CEPR.

Kharas, H. (2010), The Emerging Middle Class in Developing Countries, OECD Development Centre Working Papers, No. 285, OECD Publishing

OECD (2009), The BioEconomy to 2030: designing a Policy Agenda, OECD Publishing

OECD (2010), The OECD Innovation Strategy: Getting a Head Start on Tomorrow, OECD Publishing

OECD (2010), The Impacts of Nanotechnology on Companies: Policy Insights from case Studies, OECD Publishing

OECD (2012), Looking to 2060: A Global Vision of Long-Term Growth, Economics Department Policy Note No 15, OECD publishing

OECD (2013a), Interconnected Economies, Benefitting from Global Value Chains, OECD Publishing

OECD (2013b), Supporting Investment in Knowledge Capital, Growth and Innovation, OECD Publishing

OECD (2013c), OECD Science, Technology and Industry Scoreboard 2013, Innovation for Growth, OECD Publishing

OECD (2015a), Manufacturing or services?: That is not the Question, Science, Technology and Innovation Department Policy Note, forthcoming

OECD (2015b), The Digital Economy Outlook, forthcoming

OECD (2015c), Data-Driven Innovation for Growth and Well-Being, forthcoming

OECD (2015d), Innovation Strategy, forthcoming

OECD (2015d), The Future of Productivity, forthcoming

Policy Horizons Canada (2012), Metascan 2: Building Resilience in the Transition to a Digital Economy and a Networked Society, Government of Canada

Policy Horizons Canada (2013), Metascan 3: Emerging Technologies, Government of Canada

UK Government Office for Science (2013), International Approaches To Understanding the Future of Manufacturing, Future of Manufacturing Project, Evidence Paper 26, UK Government

UNIDO (2013), Emerging Trends in Global Manufacturing Industries, Vienna.

For more information visit
www.oecd.org/sti

Or contact Senior Economist
Koen De Backer
Koen.debacker@oecd.org

For more information about the work of the Production Council visit www.evm.dk or contact om1@evm.dk