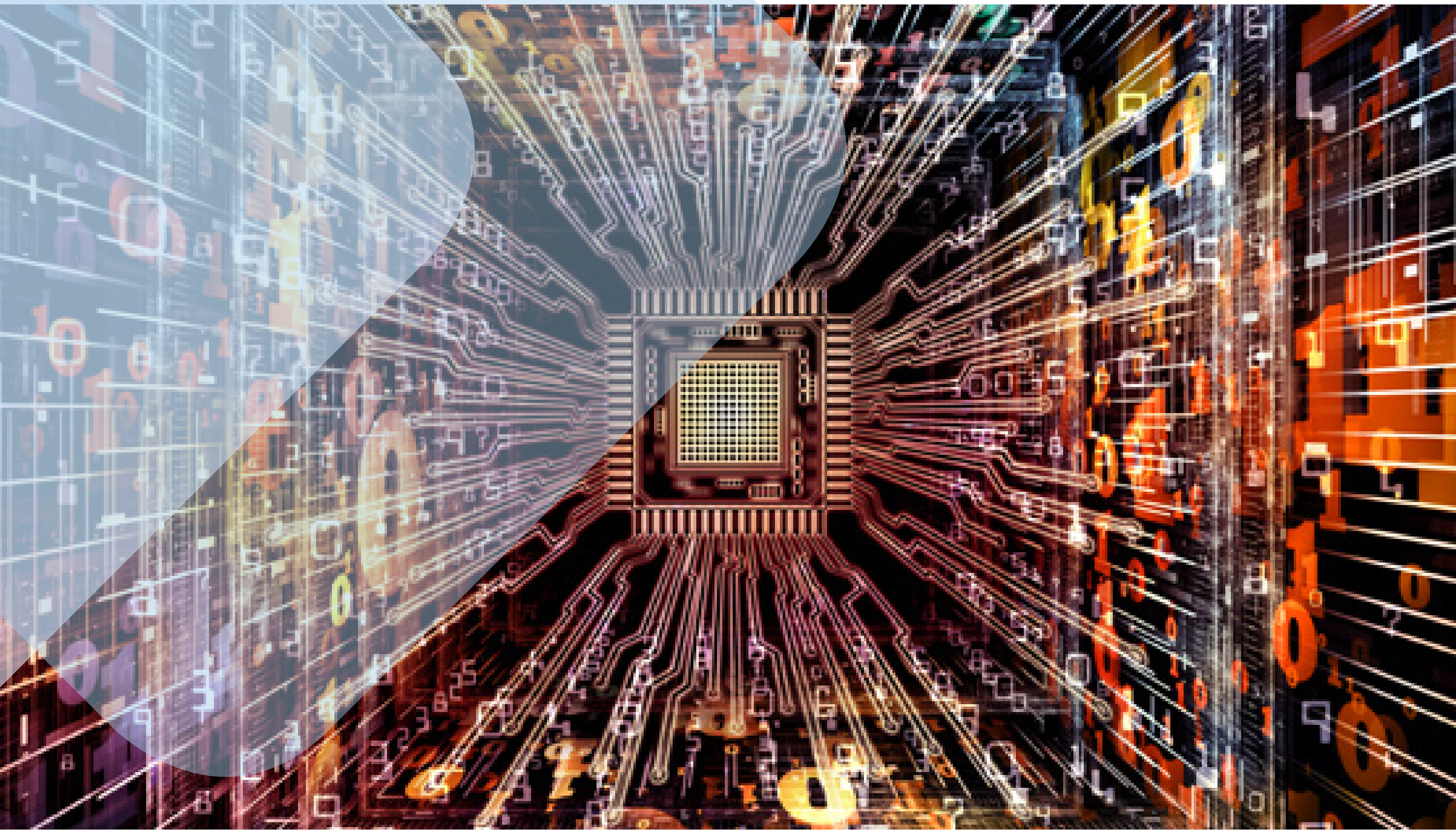
RESEARCH REPORT

Eurofound

Future of manufacturing

Game changing technologies: Exploring the impact on production processes and work



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Game changing technologies: Exploring the impact on production processes and work

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European Foundation for the Improvement of Living and Working Conditions

When citing this report, please use the following wording:
Eurofound (2018), *Game changing technologies: Exploring the impact on production processes and work*
Publications Office of the European Union, Luxembourg.

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Eurofound project: Future of Manufacturing in Europe

Acknowledgements: This overview report is based on five case studies conducted in the framework of the project by Technopolis Group: Gaëtan Coatanroch and Andreas Ligtvoet (Industrial biotechnology); Chiel Scholten (Industrial internet of things); Markus Lindström and Thomas Heimer (Electric vehicles); Joost van Barneveld and Tommy Jansson (Additive manufacturing); and Carlos Hinojona and Xavier Potau (Advanced industrial robotics).

Martijn Poel and Annemieke Biesma (project management and editors at Technopolis Group)

Luxembourg: Publications Office of the European Union

Print	ISBN 978-92-897-1628-4	doi: 10.2806/59825	TJ-01-18-077-EN-C
PDF	ISBN 978-92-897-1629-1	doi: 10.2806/36769	TJ-01-18-077-EN-N

Web: http://eurofound.link/ef18001

The European Foundation for the Improvement of Living and Working Conditions (Eurofound) is a tripartite European Union Agency, whose role is to provide knowledge in the area of social, employment and work-related policies. Eurofound was established in 1975 by Council Regulation (EEC) No. 1365/75 to contribute to the planning and design of better living and working conditions in Europe.

European Foundation for the Improvement of Living and Working Conditions

This is a publication from the Future of Manufacturing in Europe (FOME) project.

FOME is a Pilot Project proposed by the European Parliament and delegated to Eurofound by the European Commission (DG GROW).

More information on the FOME project, including available and forthcoming publications and events and relevant data, can be found on the FOME page of the Eurofound website.

Website: http://eurofound.link/fome

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List of abbreviations

AIR	Advanced industrial robotics
AM	Additive manufacturing
EVs	Electric vehicles
IB	Industrial biotechnology
ICT	information and communications technology
IT	information technology
IIoT	Industrial internet of things
IPR	intellectual property rights
R&D	research and development
SMEs	small and medium enterprises
TRL	Technology Readiness Level

Introduction

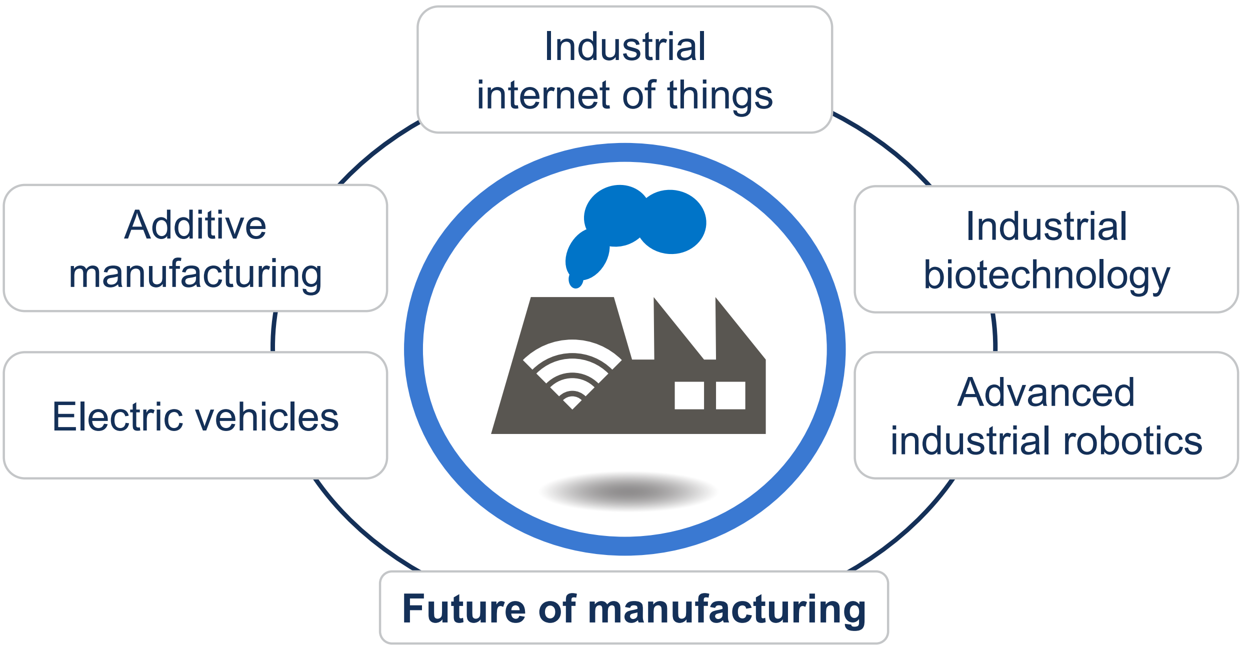
The difference between incremental innovation and disruptive innovation can be seen as the difference between improving a candle by adding a wick that burns more slowly (incremental innovation) and inventing the electric light bulb (disruption) (Christensen, 1997). Technological innovation is permanent and ongoing, but from time to time new discoveries can pave the way for totally new uses and applications.

New technological possibilities and combinations of them can bring disruption not only at a product level, but can also involve the entire process related to its production (Arthur, 2009). This will have consequences for the working conditions of individuals employed on that process and on employment at establishment level, and thereby on the structures that regulate the relationship between the social partners in that particular sector. The extent of the possible impacts of the technologies under consideration in this report, however, could have even wider impacts on the world of work and society in general.

This overview report presents the findings of five case studies that examined the potential impact of new technologies – the 'game changers' or disruptors – on manufacturing in Europe (Figure 1). The time horizon is 2017 to 2025. The technologies examined are:

- advanced industrial robotics (AIR);
- industrial internet of things (IIoT);
- additive manufacturing (AM);
- electric vehicles (EVs);
- industrial biotechnology (IB).

Figure 1: Game changing technologies in relation to manufacturing



About the case studies

The main purpose of the case studies was to better understand, and allow stakeholders to anticipate and address, the impact of new technologies on production processes and work. As such, the case studies are organised around the following components:

- the **level of maturity and the scope of applicability** of the technologies, in terms of specific subsectors and geographical areas across Europe;
- the (potential) **qualitative impact on the production process,** including the impact on value chains, business models, productivity and output/products;
- the (potential) **qualitative impact on work,** in terms of employment (such as occupations that are emerging or disappearing), tasks (such as changes in physical, social and intellectual tasks), skill types and skill levels, education/training needs and working conditions.

The case studies also explored the **implications for the social partners** in the light of changes brought about by game changing technologies – between companies, industry associations, trade unions, education/training institutions, governments and other stakeholders.

In each case study, technology is the point of departure. However, the analysis acknowledges that technological trajectories are influenced by:

- established players (with vested interests);
- new entrants (notably disruptors);
- path dependencies;
- social partners;
- policy and regulation;
- broader economic, social and environmental developments.

The five case studies were prepared by Technopolis Group on behalf of Eurofound between May 2016 and July 2017.

Methodology

Each of the case studies started with a structured literature review. Because the phenomena studied are quite recent, academic articles were used together with other literature such as reports prepared for policymakers and industry associations, and reports prepared by consultants. The Scopus database and Google Scholar were used to identify articles and reports with keywords, with an emphasis on publications from 2013 to 2016.

Subsequently interviews were held with 30 leading experts, covering the five game changing technologies from a variety of perspectives (industry, research and policy). A detailed questionnaire was used to ensure that the three main parts of the study (technology, production process and work/employment) were covered.

The third and final step consisted of five regional workshops (one for each technology) with companies, researchers, cluster organisations and other stakeholders.

Structure of the report

This report is set out as follows.

Chapter 1 describes the individual game changing technologies, including potential complementarities between them. Barriers that might hinder the uptake of the technologies are identified as well as the drivers likely to make these specific technologies particularly disruptive. Chapter 2 discusses the impact that adoption of these technologies could have on production processes, while Chapter 3 examines their implications for employment and working conditions. Some brief summary conclusions are offered in Chapter 4.

The five case studies are available on the FOME page of the Eurofound website (http://eurofound.link/fome).

1 Description of the technologies

Digital technology is changing manufacturing. Such changes, often placed in the heading of Industry 4.0, together describe a set of technologies that are likely to bring about deep transformations of the production process. Advanced robots, networked machines and artificial intelligence will be combined to generate new products and new ways of making products. This project focused on five possible game changing technologies over a time horizon of 10 years (that is, up to 2025). A brief description of the five technologies is given in Table 1.

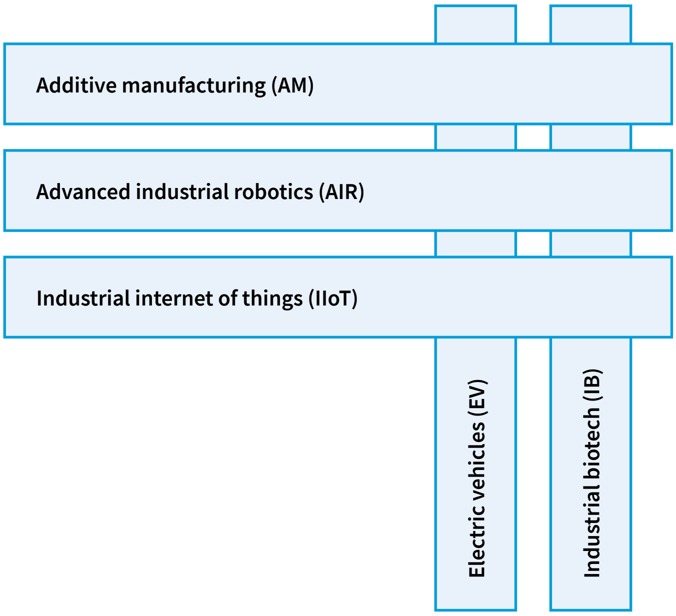
Of the five technologies explored, IIoT, AIR and AM can be applied in many manufacturing industries owing to their versatility and, in many cases, complementarity. Sensors can be deployed along a production line as well as in combination with AM printers, or attached to robots in order to monitor the environment and enable movements. One of the main differences from traditional manufacturing is the possibility of gathering an enormous quantity of digital data about processes, thus linking manufacturing with the digital realm.

Table 1: Description of the five technologies

Name and acronym	Description
Advanced industrial robotics (AIR)	Advanced industrial robotics is the branch of robotics dedicated to the development of robots which, through the use of sensors and high-level and dynamic programming, can perform 'smarter' tasks, that is, tasks requiring more flexibility and accuracy than those of traditional industrial robots – for example, a robot that can handle lettuce without damaging it. The term applies to digitally enabled robots working within industrial environments that are equipped with advanced functionality (for example, sensors detecting potential collisions, and halting or performing a programmed motion with a very limited lag), allowing them to deal with less structured applications and, in many cases, collaborate with humans (instead of being segregated from them).
Additive manufacturing (AM)	Additive manufacturing is a technique using the super-imposition of successive layers to build a product. It is additive in the sense that products and product components are built up rather than cut out of existing materials – subtractive manufacturing. The key prerequisite of the AM process is that products can be digitally modelled before being physically generated. The 'revolution is … the ability to turn data into things and things into data' (Gershenfeld, 2012).
Industrial internet of things (IIoT)	Sensors applied to the manufacturing industry create cyber-physical systems where the information collected from the sensors is fed, through the internet, to computers in order to gather data about the production process and analyse these data with unprecedented granularity. In advanced cyber-physical systems, a whole factory can be digitally mapped and enabled using such sensors.
Electric vehicles (EVs)	Electric vehicles are vehicles for which the main system of propulsion depends on electricity and not on fossil fuel. The vehicle relies on the storage of externally generated energy, generally in the form of rechargeable batteries. The main current example is the battery electric vehicle.
Industrial biotechnology (IB)	Industrial biotechnology is the use of biotechnological science in industrial processes. Modern biotechnology is based on the most recent scientific insights into the specific mechanisms of biological processes within living organisms (for instance, through systems genomics and metabolomics research). These are used to design processes in industry using yeasts, bacteria, fungi and enzymes (biological catalysts that improve reaction processes and that are relatively easy to obtain) to produce biomaterials and biofuels.

EVs and IB, however, are technologies that are changing well-established industries as a result of innovations in battery and biomaterial technologies. They can be considered the two ends of the spectrum when considering the magnitude of the impact on existing workforce and production processes. While EV development is likely to bring about substantial changes in terms of employment and the value chain, IB is unlikely in the short term to have such a significant effect. In theory, the three more 'transversal' technologies (IIoT, AIR and AM) have the potential to be deployed in all manufacturing sectors including, to different degrees, in combination with EVs and IB (Figure 2).

Figure 2: Potential use of the five game changing technologies in combination



Source: *Technopolis Group*

More generally, the adoption of these technologies depends not only on their profitability and cost-efficiency but also on financial, political and technological development factors. The following sections summarise similarities and differences across the technologies, with a focus on investment needs, access to materials, the adoption of standards and the operational maturity of the technology.

Barriers to their adoption

Investment

Although the level of investment necessary for the adoption of each technology varies, it is possible to distinguish between initial investment and incremental investment requirements.

AIR and IB require a substantial initial investment, thus limiting the number of players in these two industries. AIR requires a cash flow sufficient to support the conversion of the production process, the training of the workers in charge of monitoring the robots, and the purchase of this sophisticated equipment. Experts consulted for this study stressed that these high costs are typical of a starting phase and that, like other high-tech goods, the cost of AIR should become more affordable over time.

As EVs are based on a different technology from existing combustion engine vehicles and rely heavily on digital technologies, they are attracting companies specialised in information and communications technology (ICT) such as Apple, Google and Tesla, but which also have the investment capability and relevant technical expertise that can be applied somewhat outside their existing sphere of activity. These companies are looking to expand into the EV market in anticipation of the introduction of driverless vehicles and where they have the competitive advantage of a deep understanding of ICT. In this case, the barriers to entry are high for new competitors but more surmountable for established manufacturers that have decided to switch, such as Toyota, BMW and Volvo.

From the point of view of investment barriers, IIoT and AM are less demanding. These technologies allow changes to the production process to happen incrementally, for example, by installing sensors in one part of the factory for IIoT, or by starting to use AM machines for prototyping only. However, for a full implementation across the entire production process, significant investment would be required.

Access to raw materials and energy sources

These new technologies will require new types – and in some cases an increased quantity – of raw materials. IIoT, AIR and EVs will probably require rare earth materials for their components. AM may also require some input materials that are not commonly available. IB needs a constant stream of biomaterial to feed its processes, and production will depend on circumstances such as seasonal or local availability.

Human society has unprecedented access to a range of sources of energy. While advances in renewable energy technologies may facilitate a shift towards less reliance on fossil fuels, energy demand will increase. According to the World Economic Forum (WEF), the global demand for electricity by 2050 will be double that of today (WEF, 2017).

Energy efficiencies in the game changing technologies may offset some of the environmental impacts of increased energy demands. EVs will also benefit the environment through reductions in carbon and other emissions such as particulate matter, nitrogen oxides and carbon monoxide, but concerns remain about the recyclability of the (large) lithium-ion batteries required to run EVs.

Standards

The introduction and spread of new technologies make standardisation necessary in order to ensure quality and reliability. The most prominent standards are those developed by the International Organization for Standardization (ISO). These list requirements and set out specifications, guidelines and characteristics that can be applied consistently to ensure that materials, products, processes and services are fit for purpose.

A need for standards was identified for all five of the studied technologies.

In particular, IIoT adoption will rely on common protocols and standards for security and interoperability. Networks should be secure from external threats, and the various programming languages and platforms that are part of the cyber-physical factory should be able to communicate with each other. For IIoT to become a pervasive technology it will also need to be adopted along the value chain, including by small and medium enterprises (SMEs).

Standards should also be developed by companies manufacturing EVs, especially for the treatment of batteries, which can cause work hazards due to chemical reactions. From the perspective of market expansion, standardisation and interoperability for European motorists, it is necessary to reassure consumers that they will have access to compatible networks of EV supply equipment when they drive from one country to another (IEA, 2013).

For IB, and in particular for biomaterials, uncertainties remain concerning the performance of bio-based products. Manufacturers will therefore demand products that comply with required specifications on safety, durability, elasticity and other quality dimensions.

Drivers

Despite the challenges described above, the reason why these technologies are attractive is that the estimates for market growth are impressive (Table 2), often implying a recoupment of investment within a horizon of 10–15 years. Their adoption has already been shown, in many cases, to be a cost-efficiency booster. An additional driver for EV and IB is the transition from using fossil fuels to biofuels and biomaterials.

Table 2: Estimated potential market size of the five game changing technologies

Technology	Estimates of potential market size
AIR	Impact on global market of between USD 1.9 trillion and USD 6.4 trillion (€1.61 and €5.42 trillion as at 15 December 2017) per year by 2025 (RAS 2020, 2014, p. 9)
AM	Estimates of the global AM industry vary from USD 1.7 billion (€1.44 billion) (Roland Berger, 2013) to as much as a turnover of USD 500 billion (€423 billion) per year (Manyika et al, 2013)
IIoT	Deployment in the automotive industry only: USD 210–740 billion (€170–€626 billion) value by 2025
EV	Electric car stock at global level will be between 9 million and 20 million by 2020 (10% of the market)
IB	The EU market for IB-derived products is expected to increase from €8 billion in 2013 to €50 billion in 2030 (BIO-TIC, 2015)

Operational maturity

To understand the pace of change likely to happen up to 2025, the project examined the Technology Readiness Level (TRL) of each technology both from the perspective of references in literature and from expert interviews and workshops.

TRL is a scale that assesses the level of maturity and applicability of a technology. It goes from level 1, where a technology is in its preliminary phase and only its basic principles have been observed and reported, up to level 9 where the technology is fully implemented and proven in a production environment.

The five game changing technologies are at a relatively mature stage, ranging from testing in relevant environments (TRL5–8) to being fully operational (TRL9). The number of application areas is increasing; Table 3 gives some examples.

Table 3: Current estimated operational maturity of game changing technologies, by sector

Technology	Currently applied in production (TRL9)	Stages up to testing and prototyping (TRL5–8)
AIR	Electronics assembly Automotive parts manufacturing Aerospace	Food preparation industry* Craft and bespoke manufacturing*
AM	Consumer production using plastics	Automotive Aerospace Human prosthetics (hearing aids, dentistry, artificial limbs) Living cells[1] Creative industries such as jewellery, entertainment, fashion and shoes
IIoT	Oil and gas Automotive	Chemicals and chemical products Motor vehicles, trailers and semi-trailers Coke and refined petroleum products Repair and installation of machinery and equipment Other transport equipment Food products Machine manufacturing
EV	Plug-in hybrid electric vehicles	Extended range electric vehicles
IB	Pharmaceutical industry* Energy industry* Chemical industry* Materials industry*	Application of new production processes in the industry

Notes: ** See text below for more details.*

Some of the technologies considered have a broad application across manufacturing sectors so the TRL may vary between them. However, the game changing potential can be distinguished for each of them.

For example, **AIR** is already used in sectors ranging from electronics assembly and automotive parts manufacturing to aerospace. However, the study identified potential game changing effects for:

- the food preparation industry (handling material of different textures and shapes, replacing manual labour in fast turn-around tasks or in tasks where controlled conditions are needed for hygiene purposes);
- craft and bespoke manufacturing where production needs to be closer to the market, or batches customised on demand for the manufacturing of soft products (such as clothing and shoes).

Despite the high level of interest in robotics, the level of uptake of AIR remains low; for example, in the textile industry in northern France only a handful of companies have adopted it. This is because about 75% of the textile companies in this region are not in a position – either financially or in terms of skills – to implement automation for most tasks (Eurofound, 2018a).

The TRL in **AM** can be categorised in different ways, for example, by scale (domestic or mass production) or by material. Operational maturity is high for domestic consumers where the equipment can be bought for a relatively low price – around €500 for a 3D printer – and small batches can be printed at household level. In mass production, AM is starting to have an impact where prototyping and visual design are important, such as in the automotive and aerospace industries. AM can also be categorised in terms of materials used. Printers using plastic are at TRL 7–9 (advanced), while those using metal and ceramics are at TRL 3–7 (low to intermediate). This is because more fine-tuning is necessary to meet quality standards for metal and ceramics. An example quoted in both the literature and by experts is the case of General Electric, which is prototyping components for its energy turbines. Another early adopter is the biomedical industry

1 Living cells is the term used in papers on 3D bioprinting. This relatively new technique could be used in 'regenerative medicine to enable the production of complex tissues and cartilage that would potentially support, repair or augment diseased and damaged areas of the body' (University of Oxford, 2017).

where lightweight and customised design is particularly adapted to the production of human prosthetics (hearing aids, dentistry, artificial limbs). Finally, creative industries such as jewellery, entertainment, fashion and shoes may find the application of AM beneficial thanks to the customisation aspect and the possibility of producing complex shapes.

The capacity to process and store huge amounts of data, combined with the development of 5G networks, has changed the way manufacturing uses sensors. These are not new of course, but their widespread connectedness allows the creation of virtual simulacra of entire factories (WEF, 2015). This will enable granular monitoring of the production process, often via simulations, as well as applications in the field of predictive maintenance dealing, for example, with process failures. **IIoT** is not only applied to machines but also to workers, equipping them with wearables that can monitor both environmental and person-specific variables. The oil and gas and automotive industries have seen the potential of this new technology and, in these two sectors, the TRL is at operational maturity level. IIoT also has wide applicability, according to the literature, in the production of chemicals, motor vehicles, coke and refined petroleum products, the repair and installation of machinery and equipment, other transport equipment, food products and machine manufacturing. The textile sector is another sector that could be transformed. The often-cited case of the Zara[2] stock management system, where each item is tracked from production to retail outlet, is an example of data collection and analysis informing production decisions in real time; Zara's stock is renewed and changed every two weeks.

The level of technological maturity of both **IB** and **EV** is relatively high. Many applications are already proven and commercialised, although specific features apply to each. The TRL of EVs depends on the specific technologies used. Some technologies are only in the development phase (for example, technologies for extended range EVs), while others are already proven and commercialised (for example, plug-in hybrids). For IB, the TRL is mature. IB can be found in the pharmaceutical industry (antibiotics), in the energy industry (biofuels), in the chemical industry (production of amino acids, biosurfactants or biolubricants) and in the materials industry, notably in the production of bioplastics and biopolymers.

Supporting policy initiatives

An important push towards the adoption of **EVs** has been the recent announcements by national governments that they want to ban cars with combustion engines in the long term. In France and the UK, such cars will be banned by 2040 (the Guardian, 2017a). The Netherlands wants only (new) electric cars to be sold by 2025 and Germany is considering a 2030 deadline. Norway already has an EV market share of 29% (IEA, 2017). Sweden is looking at a 2045 horizon and, on the producer side, Volvo Cars has announced its intention to produce only electric or hybrid cars from 2019 onwards. In Italy, the 'retrofit act' Decreto Retrofit D.M. No. 219/2015) makes it easier to convert a fuel-propelled car into an electric car without the burden of a long administrative procedure and without limits on the age of the car. The aim is to tackle the obsolescence of automotive stock and to promote low-carbon solutions.

Similar attention to environmentally friendly measures applies to **IB**, for which initiatives have been put in place to support the competitiveness of bio-based products. One example is the commitment by the European Union to replace up to 20% of greenhouse gas emissions from fossil fuel use in the transport sector in 2008 with biofuels by 2030 (European Commission, 2014, p. 14).

IIoT, **AIR** and **AM** are part of Industry 4.0, of which the German government is one of the main promoters (GTAI, 2014). Visitors to the 2017 Hannover Messe – one of the biggest industrial trade fairs in the world – witnessed the many IIoT and Industry 4.0 solutions that are already available.

Industry 4.0 initiatives are spreading not only in Germany but also across Europe; initiatives by EU Member States aimed at promoting advanced manufacturing techniques are being monitored by the European Commission (European Commission, undated). Table 4 gives details of 10 relevant national strategies operating as of May 2017.

In June 2017, the three national initiatives in France, Germany and Italy agreed on a trilateral cooperation based on three points (Plattform Industrie 4.0 et al, 2017):

- developing common standards;
- engaging SMEs in the adoption of AM, AIR and IIoT;
- developing shared policies to support Industry 4.0.

While these national initiatives seek to promote the adoption of Industry 4.0, the transformation of European industry will also have consequences for its workforce. The matching concept of Work 4.0 (*Arbeit* 4.0) relates to the development of employment and working conditions in smart factories and services. These are discussed in Chapters 2 and 3.

Finally, intellectual property rights (IPR) and cybersecurity will both need to be strengthened to protect valuable business data from theft. For example, (Deloitte, 2015) related to AM design, there are considerations of:

- legal and regulatory implications in terms of IPR on goods, products or models;
- liability implications in case of design or production failures;
- how and at what stage of the product cycle customs duties and value added tax should be levied.

This will require new approaches, especially in the realm of AM and IIoT, where design and process information will be shared within the value chain. Companies need to invest considerably and upfront (with an uncertain return on investment), and may need to make a transition to new business models that are currently not yet fully proven. IPR influences these types of business decision (WEF, 2015).

2 A 'fast fashion' manufacturer (part of the Inditex group) and seller based in Spain.

Table 4: National strategies in 10 EU Member States in relation to Industry 4.0

Country	Title	Budget	Goals
Czech Republic	Průmysl 4.0	No special budget	Maintaining and boosting the competitiveness of the Czech Republic – a group of experts will have an input in industrial policies
France	Alliance pour l'Industrie du Futur	~€10 billion of public funding and industry contributions	>800 loans to companies 3,400 company assessments for modernising production >300 experts identified Involvement of 18 regions
Germany	Plattform Industrie 4.0	€200 million complemented by financial and in-kind contributions from industry	Reducing industry segregation Transforming research agenda into practice Developing reference architecture Launch of platform with 150 members
Italy	Piano Industria 4.0 Cluster (*Cluster Fabbrica Intelligente*; CFI)	Funding public investment of around €20 billion Amortisation of 140% and 250% A 50% tax credit on R&D investments Incentives on investments in start-ups and innovative small businesses Education funds for all levels and PhD scholarships	Stimulate private investments in Industry 4.0 technology drivers Increase private expenditure in R&D and innovation Expand open innovation relationships between mature companies and high-tech start-ups
Netherlands	Smart Industry	Around €25 million for 2014–2017 period with co-financing by industry	14 field laboratories set up by end of 2016 – each field lab has an annual turnover of €250,00 to €4 million
Portugal	Indústria 4.0	€4.5 billion over four years	No specific funding scheme available – a mix of funding instruments will be used (loans, tax aid, private investment) Implemented by private players through an online platform Constant review and adjustments of the measures
Spain	Connected Industry 4.0	€97.5 million for project calls for 2016, €78 million from additional related programmes	Innovation and research programme set up in June 2016 Pilot of enterprise support programme
Sweden	Produktion 2030	€25 million offered by Vinnova for 2013–2018 period and ~€25 million from industry	Funded 30 projects, involving over 150 businesses Set up a PhD school, obtaining 50% industry co-financing for each activity and instrument
UK	HVM Catapult	€164 million in public funds for 2012–2018 For 2015–2016: €79.7 million commercial income; €61.3 million public funding; €62 million collaborative R&D	Value of innovation work represented 123% of the target Every €1 of public funding generated €17

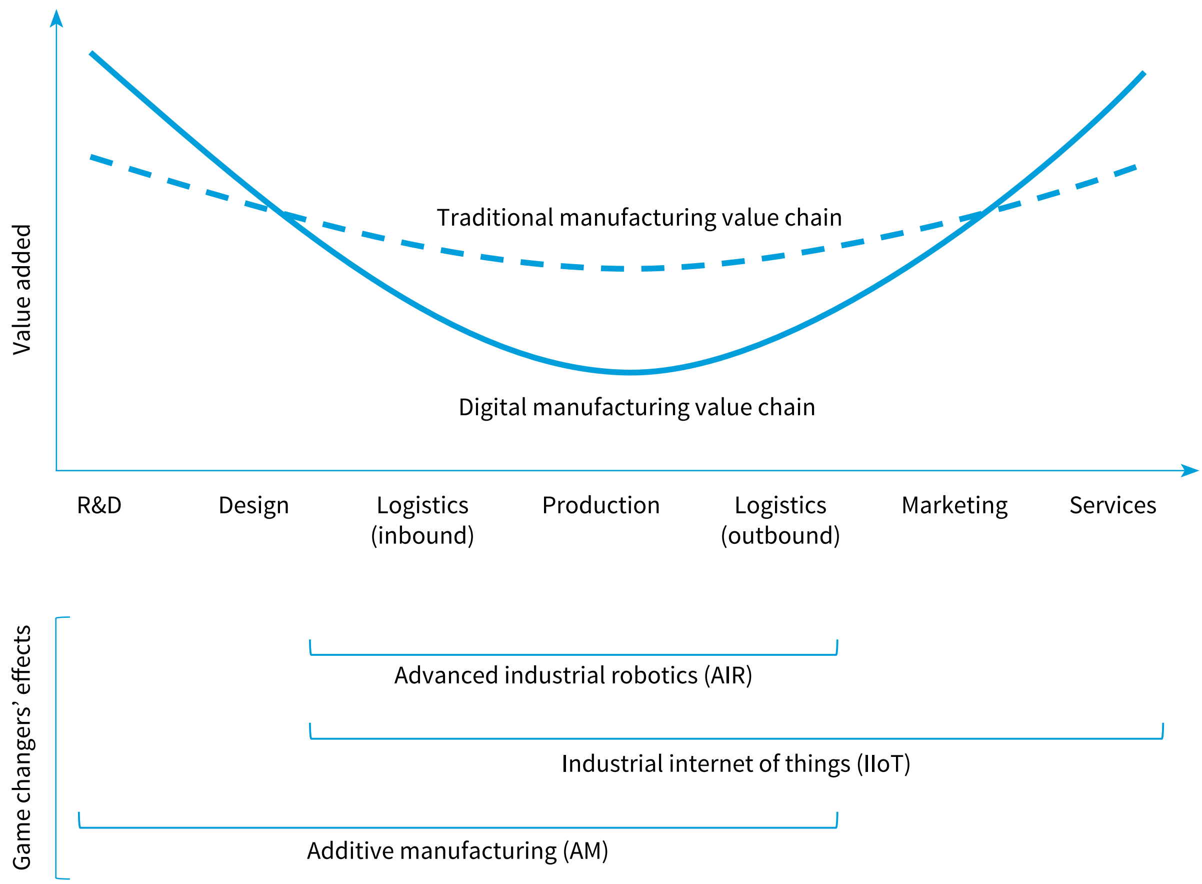
Source: *Digital Transformation Monitor (European Commission, 2017)*

2 Game changing technologies and the production process

Value chain smile curve

In order to discuss the effect of the five game changing technologies on the production process, it is useful to introduce the concept of the value chain smile curve. This refers to a graphical representation of the relative contribution to added value of the different stages of the production process for a product, company or industry – from R&D to distribution and sales. The concept was proposed in the early 1990s by the chairman of the Taiwanese IT company, Acer, who argued that in the personal computing industry the tails at either end of the value chain (R&D and marketing and sales) generate more added value than the middle steps (logistics and production). The idea was generalised to the effect of digital technologies and globalisation on advanced capitalist economies, where the increasing automation and offshoring of the middle steps of the value chain would depress their contribution to value added, thus deepening the 'smile' (Figure 3, top panel).

Figure 3: Value chain smile curve (top panel) and the steps of the value chain where process game changing technologies can have an effect (bottom panel)



Note: *EV and IB do not fit in this representation because they are product rather than process innovations.*
Source: *Authors' own elaboration*

The bottom panel of Figure 3 illustrates what steps of the value chain could be affected by the three game changing process technologies studied.

AIR would mostly affect the intermediate steps of the value chain, that is, production and logistics (both inbound and outbound). AIR would also affect steps of the value chain which, in advanced economies, already have a small relative impact on value added. This in itself implies a limit on the potential benefits and impact of AIR on manufacturing. After all, these intermediate steps have already been automated or offshored to a large extent in European manufacturing. However, some argue that the possibilities of further automation with AIR may increase the profitability of those intermediate steps and justify the return of production and logistics to Europe in some cases (see Box 1 in Chapter 3 for more details).

IIoT would affect all steps of the production process from inbound logistics to sales and services. The autonomous exchange of information and the connectivity of machines, components and products, can significantly increase the efficiency not only of logistics and manufacturing, but also marketing, sales and post-sales services.

Finally, **AM** would affect the first half of the value chain, from R&D to outbound logistics. With AM, the efficiency and flexibility of R&D and design can increase by several orders of magnitude, since it allows direct operation on digital models that are later physically rendered by the technology. Potentially, AM could radically simplify inbound logistics, production and outbound logistics into a single step, that of materialising (3D printing) the digitally designed goods on demand.

Although IB – and especially EV – are product rather than process innovations, this study also identified some specific effects of these technologies in the value chain. The mechanical technology of **EVs** is simpler and requires significantly fewer parts than internal combustion vehicles, which could lead to a simplification of the production process and reduced need for maintenance and aftersales services. With respect to **IB**, significant differences were found compared with traditional chemical industries, such as a higher seasonal variation as a result of the use of biomaterials and a reduction in the optimal production size. This can lead to production organised around smaller units with a larger regional spread.

Figure 3 (above) raises several general issues, particularly as regards the process related technologies. It could well be the case that these advanced manufacturing technologies lead to innovations that become a crucial source of competitive advantage, so that more value added is in fact located in the manufacturing stage of the supply chain. If, in addition, these technologies lead to extreme rationalisation of the workforce, then the reduction in the total wage bill would make the cost of labour much less important for the locational decision of the firm, compared to other costs, such as energy. However, the digital nature of these technologies makes predictions of the geographical location of these activities in both the short and long run is quite uncertain.

The classification of the supply chain into business functions in Figure 3 also raises the possibility that the concept of business functions may become much less distinct and analytically relevant with these new technologies. For example, AM may merge design and manufacture, with inward logistics becoming if not almost negligible then at least much simplified. Moreover, several of these technologies, not least the IIoT, blurs the classic distinction between manufacturing and services.

Main effects

Digitisation

The first and perhaps most important effect of the studied technologies is the crucial importance (centrality) of digital information in the production process. This should be no surprise, since all of the technologies studied in this project are part of a broader trend of the digitalisation of economic processes, which are as a result of the increasing diffusion and widespread application of digital technologies to different types of economic activity (Fernández-Macías, 2017).

The three process technologies studied here (AIR, IIoT, AM) all rely directly on the key inventions of the digital revolution that have been around for decades, such as the microprocessor and the internet. EV and IB are not strictly part of that family of technologies (the basic design of EVs goes back to the early 20th century and IB is rooted in microbiology and fermentation techniques from the 19th century), but their current development would have been impossible without digital technologies.

Although all the game changing technologies studied here involve an increasing centrality of digital information, they do so in different ways.

The main difference between **AIR** and traditional industrial robots is that the former can autonomously process information from their environment and interact with it, thanks to sophisticated sensors and algorithmic control mechanisms. This gives them much more flexibility and allows them to carry out tasks completely beyond the reach of traditional mechanical robots. AIR both needs and generates vast amounts of digital information and digital processing to operate, and the information generated and processed is likely to be fed into the central information systems of the production process of which they are part.

IIoT is directly and explicitly an information encoding, communicating and processing technology. By attaching interconnected sensors to potentially all objects within the production process, IIoT transforms the productive process into a system that is both physical and digital (that is, cyber-physical). As well as generating a detailed virtual model of the entire production process that can be optimised with the superior processing power of digital technologies, the technology makes the objects themselves digital devices that can interact and be algorithmically controlled.

AM makes the design and testing of products a digital process, to a large extent, since it allows complex digital models to be directly materialised in a single step of 3D printing. As previously mentioned, AM could radically simplify almost the entire manufacturing process, transforming it into a sequence of processing, communicating and storing digital information (the 3D models of manufactured goods), with a single final step of physical rendering.

This increasing centrality of information in the manufacturing process can have wide-ranging socioeconomic implications. It requires a type of skill and know-how that is very different from that of traditional manufacturing. In general, it increases the importance of ICT. In the cases studied in this project, it was often found that this can also be associated with the arrival of new players, partly because of a lack of ICT skills and know-how in traditional manufacturing, and partly because of the very large investment needed for a full renewal of processes and players.

For instance, the introduction of AIR and IIoT is often subcontracted to specialist companies from the ICT sector, which sometimes even provide the machines (robots, sensors) and people (experts) necessary within some kind of leasing or subcontracting agreement. This may be typical of the early adoption of promising but still immature technologies (experimenting with external contractors seems more sensible than making massive investment if there is still uncertainty about the benefits of the technology), but it can also lead to a creeping colonisation of ICT companies into traditional manufacturing. If information becomes central in manufacturing, and if it is in fact controlled by external ICT contractors operating the robotic and cyber-physical systems of factories, traditional manufacturers may become increasingly dependent on those ICT contractors.

Mass customisation

The second important effect of the technologies studied is that they open up the possibility of mass customisation. In the past, such a statement would have seemed contradictory. Mass production is generally understood as the opposite of customised production; the latter is expensive (per unit), flexible and only suitable for small quantities, while the former is cheap (per unit), rigid and enormously scalable. According to the interviews carried out for this project, the three process technologies studied have the potential of removing this contradiction, thus facilitating a production process that is both cheap, flexible and highly scalable.

The key lies again in the possibilities afforded by digital technologies. In Fordist mass production, the entire production process was centrally arranged and controlled, with both human workers and machines reduced to cogs in the machine. Production workers tended to be relatively low skilled and have low levels of autonomy (as simple operators), while machines and robots generally served a single particular purpose for which they were specifically designed. As a result, changing the process was very difficult and costly, since it required a complete rearrangement of the entire system. The three process technologies studied here can change this in different ways.

First, in contrast to traditional robots, **AIR** are algorithmically controlled, general purpose machines that can be easily reprogrammed to carry out different tasks in production. Indeed, with artificial intelligence, they would be able to interact and respond autonomously to changes in their environment. This obviously increases the flexibility of the production process. However, this flexibility does not necessarily come at the expense of standardisation. Although they can be easily reprogrammed and redeployed for different customised outputs, AIR are still robots that behave according to predefined rules and thus their output will be standardised and consistent. This is crucial for mass customisation to be economically successful.

Second, by interconnecting all objects of the production process under centralised and (partly) algorithmic supervision, **IIoT** systems also increase the flexibility of the process. In the same way that digital robots are inherently more flexible than mechanical ones, cyber-physical production systems are inherently more flexible than traditional ones. Real-time centralised control and interconnectivity not only allow a much faster reaction to problems, but also a relatively fast reprogramming of production in response to changes in demand or other factors.

Finally, the contribution of **AM** to mass customisation is even more obvious. AM collapses the entire physical production process to a single and simple step, the 3D printing of the digital model, with remarkably little restriction in terms of the physical configuration of the resulting object. The digital object can be easily reconfigured as desired, and the printed objects can have a consistent quality even if they are different – provided the rendering process and materials used are the same.

Of course, the materialisation of these possibilities for mass customisation depends ultimately on the relative costs of these digital technologies compared with the equivalent Fordist methods and tools. At present, these remain high and therefore such technologies should still be considered experimental or very specialised. However, the potential of mass customisation is embedded in these technologies, and as they mature and their costs decrease (which seems likely since they are also affected by Moore's Law, being at the heart of digital technologies), these possibilities are likely to kick in.

A final point with respect to mass customisation concerns the role of labour input in digitised factories. As discussed in Chapter 3, all the technologies studied in this project require more skilled labour input and less unskilled labour input. Requiring skilled workers that understand and operate digital processes rather than physical operators performing repetitive tasks is yet another way in which these new technologies are inherently more flexible than those of traditional Fordist mass production.

Servitisation

The third important potential effect on the production process of the studied game changing technologies is the servitisation of manufacturing. The concept of servitisation refers to the increasing importance of services attached to the product in the added value of manufacturing companies. Those services can be anything from maintenance to unrelated additional services.

The most direct and clear contributor to the servitisation of manufacturing is **IIoT**. The connected digital devices embedded in products thanks to this technology allow companies to maintain a line of communication and even control (through data and algorithms) of the product after the sale. This facilitates the provision of aftersales services – data driven or not – such as predictive maintenance and 'updates' that improve or even add functionality to the product, or additional services of any kind.

One aspect of this servitisation trend is that it can have a negative effect on the existing constellation of service providers around industrial products such as cars or household appliances. The reason is that servitisation enabled by IIoT makes it easier to internalise maintenance and services by the producers, thus eliminating the business of independent service providers. A car that is permanently connected to the manufacturer which can remotely and wirelessly control the functioning of its internal algorithms is much less likely to be maintained by a small independent workshop.

However, the same trend can have positive implications for the environment. If products are a platform for long-term services, manufacturers have an incentive to make them more robust and enduring. In an economy driven by demand for mass-produced goods, it is in the interests of manufacturers to generate disposable goods with a short renewal cycle in order to sustain an ever-expanding production. But for a servitised manufacturer, the ideal product is a long-lasting one that can make for sustained service relationships with the client.

It could be argued that **AM** can also contribute to the servitisation of manufacturing, but in a very different way. As mentioned previously, AM could make the physical production process almost disappear, and in any case become secondary to the digital design of the goods to be 3D printed. In a (obviously hypothetical) future in which manufacturing is 3D printed, the most important step for value creation would be the design of digital models, an activity that would today be classified as part of the service sector rather than the manufacturing sector.

The relationship between **AIR** and servitisation is more tenuous, but also important. First of all, it contributes to it by further deepening the smile curve (reducing the value added of core manufacturing activities, which necessarily increases the relative importance of services). That is, after all, the main driver of servitisation: the need to generate new profit opportunities for products whose mere manufacture have a declining profitability. However, the technology studies also identified a trend towards the subcontracting or leasing of AIR by manufacturing companies that can contribute to a different type of servitisation of manufacturing. The core activities of manufacturing (logistics and production) could in practice become an externally provided service. In other words, specialised manufacturing services could take over the manufacturing sector. These manufacturing services might, for instance, be provided by upstream manufacturers of production systems.

In any case, what all these trends have in common is the erosion of manufacturing as traditionally understood and its replacement by a different type of economic activity, with some attributes of services.

Increased resource efficiency

The fourth important effect on the production process of the studied game changing technologies is the increase in resource efficiency. This is also related to the use of digital technologies. Much richer information on every step and aspect of the process and the increased precision of algorithmic control enable a more efficient use of materials and energy in production.

Several aspects of this increased efficiency have been mentioned already. **AIR** can reduce errors and increase the precision of production operations. **IIoT** increases the knowledge available on the conditions of the products and materials throughout the production process and beyond, facilitating enduring products with a more efficient maintenance. **AM** can significantly reduce manufacturing waste by using just the amount of material needed in the additive layer-by-layer product creation.

This fourth effect obviously has very big environmental benefits, and was identified by several of those interviewed as a potential driver for the adoption of these technologies in Europe in the future in the context of growing environmental concerns and policies.

Synergies between technologies

A final point to add with respect to the effect of the studied technologies on the production process is the very strong synergies that exist between them. The combination of two or more of these technologies can multiply their positive effects on the production process, while utilisation of any of these technologies makes the utilisation of the others more likely. These synergies are explained by the fact that all the technologies studied are part of the same broad family of digital technologies and share some key underlying principles, making them easy to combine.

AIR and **IIoT** are different technologies with different purposes, but both require and produce a large amount of digital information on the production process, and ultimately rely on digital algorithms to process and manage industrial processes. IIoT and **AM** can be considered as two sides of the same coin – the digitisation of production processes – since IIoT collects, encodes and processes digital information on the physical process, while AM transforms digital models into physical products. The three technologies together constitute core elements of a cyber-physical model of the manufacturing process, which is one of the possible futures of European manufacturing.

The two technologies that are a mix of product and process innovation (EV and IB) are also strongly linked to the digitalisation of manufacturing and thus have strong synergies with the three process technologies, although in different ways.

EV is a new technology for the car industry. It has among its key supporters and promoters well-known companies and industrialists from the ICT sector, and it is likely to be a catalyst for the adoption of new technologies in production. Being radically new, EV requires the setting up of new factories and processes. This reduces the inertia caused by existing installations and practices, and stimulates experimentation with new tools and methods. Some of the brand-new producers of EVs therefore provide the best example of several of the effects mentioned above (that is, information centrality, mass customisation, servitisation and increased resource efficiency). As such, these new entrants force established car manufacturers to innovate more quickly, and stimulate new and established companies to deploy EV charging stations.

It is a very different story for **IB**, though there are strong connections with digitalisation as IB uses very high-tech equipment that relies on digital technologies similar to the ones that underlie AIR, IIoT and AM. These connections can be summarised as follows.

- Its main source of value is knowledge, with intellectual property playing a central role.
- It involves a renewal of equipment that can trigger experimentation with new process technologies.
- The health risks associated with IB can be minimised by using AIR instead of human operators.
- The development of IB is strongly driven by environmental concerns that can also be advanced by the adoption of the three process technologies discussed here.

3 Impacts of game changing technologies on work and employment

Introduction

This chapter summarises the findings of the five case studies that form the basis of this overview report on the likely or potential impacts of the identified game changing technologies on working and employment conditions in the European manufacturing sectors. The main elements covered are:

- the likely impacts on manufacturing labour demand;
- the shifts in the task content and occupational profiles of manufacturing employment;
- the consequences of the game changing technologies for the work environment and working conditions.

It is important at the outset to emphasise that the five game changing technologies are quite disparate intrinsically in the technical details of what makes them innovative. For example, EVs rely on huge advances in the chemical processes that allow the storage and transmission of electric power in new generation batteries. AIR relies on a combination of sensor technologies and advances in data processing and storage – all linked, increasingly, by self-learning – and dynamically improving machine algorithms (artificial intelligence).

As such, the impacts of the different game changing technologies (for example, on employment headcount) will inevitably be different, weighing more heavily in some sectors than in others. The timing of their impacts will also differ based on different rates of adoption, which in turn depend on various factors, including the permeability of existing industrial infrastructure to applications of the emerging technologies.

EV production is already taking place – in some cases in plants already producing vehicles using combustion engines[3] – and most traditional car manufacturers are committed to the EV transition. IIoT, however, is potentially more pervasive in its cross-industry impacts, though it is also likely to be slower to be adopted precisely because its underlying technological model – networked objects or components communicating with each other – represents such a radical departure from traditional manufacturing processes.

Employment impacts

The most predictable impact of new technology is job loss when machines replace labour. This job loss has knock-on effects throughout the economy due to the loss of purchasing power of the dismissed workers. However, it also implies job creation elsewhere in the economy. Firstly, it leads to an increase in the demand for such technology leading to an increase in the demand for labour in technology supply firms.

New technology is introduced to increase productivity. Higher productivity can lead to a lower price, and so to an increase in demand for the firm's product. Particularly in a global context, an increase in market share can be highly significant and may offset the job loss resulting from the introduction of the labour-saving technology in the directly affected firms. Moreover, lower prices increase the real income of consumers which may be spent on other products and services and thereby lead to job creation elsewhere in the economy. Aggregate demand will also increase to the extent that productivity gains lead to an increase in wages. Thus the distribution of productivity gains is crucial. Job creation knock-on effects occur if the productivity gains lead to lower prices or lower wages. They do not materialise if all the gains are retained as profits.

In addition, the new technology may give rise to completely new products and services. It is extremely difficult to predict the nature of these products and services and so also what type and how many jobs will be created. However, the employment effects will depend upon the amount of consumer demand these products and services generate and the total wage bill required to produce this demand – the hours of employment times the wage rate.

This is a highly stylised account of the employment impact of new technology. It does, however, set out the most important potential channels of job creation and destruction resulting from technological change. Crucial for the net outcome is the extent to which productivity increases are kept as profits or whether they lead to lower prices or higher wages and the extent to which demand is created by a significant fall in prices, and the emergence of new demand for new products.

3 Despite being the largest and most iconic contemporary production unit in the US, Tesla's Gigafactory 1 in Nevada is devoted exclusively to the production of EVs.

The impact on jobs through direct labour saving by game changing technologies are likely to be most negative for the traditional manufacturing job profile – that of the non- or semi-skilled, blue-collar, production line worker. This is not a very daring prediction. Employment in this type of manufacturing job has been shrinking for many years in developed economies, and in a context of declining absolute and relative manufacturing headcount, these production line jobs have been declining the fastest of all.

The reasons for the ongoing decline have been both trade and technology based. However, both explanations have a common basis, that is, the easy replicability and displaceability of mechanical, predictable work processes. To date, the consensus is that technology, rather than trade, has been the dominant vector of manufacturing job loss.[4] This is likely to intensify, as at least three of the game changing technologies considered (IIoT, AIR, AM) explicitly involve the further replacement of human labour input by technology.

Such negative employment impacts will be recorded at sectoral level in those manufacturing sectors most affected by the new technologies (for example, vehicle, machinery and consumer goods manufacture). However, as noted above, there can be compensatory positive employment growth in the new and emerging occupational profiles associated with the game changers – often within the same sectors – and potentially including some employment growth associated with the reshoring of activities previously offshored from Europe to locations with lower production costs (see Box 1).

Box 1: Game changing technologies and the reshoring of manufacturing to Europe

Globalisation and increases in production costs have driven many companies in past decades to offshore their production activities. However, as costs have increased in developing countries and with concerns related to supply chain disruptions and product quality, reshoring production has picked up, especially in manufacturing industries. The reshoring of productive capacities' can be defined as 'the relocation of previously offshored value chain activities back to the EU'.

According to the 150 reshoring cases identified to date in the European Reshoring Monitor (another FOME project initiative with an open access on-line database), the most common reasons for reshoring are:

- quality and pricing issues;
- proximity to consumers;
- value chain restructuring to shorten delivery times.

These factors correspond to previous literature on reshoring (see, for example, Ellram et al, 2013; Uluskan et al, 2017). Game changing technologies are mentioned only in a few cases such as Hunton Fiber, a Norwegian producer of wood fibre products, which reshored its production back to Norway as a result of AIR and automation. Another good example is Welltec, a provider of well service solutions for oil and gas companies. Because investments in robotics and automation reduced its production costs, it was possible for Welltec to bring its production back to Denmark.

One of the main findings thus far is that where production returns from developing to developed countries, the number employed in the reshored facilities is significantly less. One topical example is the Adidas 'speed factory' in Ansbach, Germany, which produces many hundreds of thousands of pairs of running shoes each year but with a staff of only 160 (Financial Times, 2016). Production at Ansbach relies heavily on two of the five game changing technologies – AM and AIR. The advantages to the company of reshoring this production are not just reduced labour costs. The fact that each product is produced entirely in situ means that much of the cost and complexity of extended supply chains has been eliminated. Production also takes place closer to designers and marketers, as well as end customers, facilitating shorter design–production cycles and a more rapid response to new consumer trends, including that for tailored designs.

Other clothing companies are also reshoring their production back to Europe: for example, Mango, the Spanish clothing manufacturer, has reshored its factories in Asia to Italy, Spain and Turkey. Although the reshoring of textile manufacturing has attracted considerable attention in the media, some industry experts are sceptical about the large-scale reshoring occurring in textile manufacturing, especially as the fastest growing consumer markets are in Asia and Africa (Abnett, 2016; Financial Times, 2017).

When estimating the employment effects of such reshorings, the significance of associated employment that may be created in upstream sectors (for example, materials and chemicals) as well as in downstream sectors (for example, legal and accounting) should not be overlooked. Such 'multiplier' effects are typically very strong in manufacturing. Even if the reshorings inspired by game changing technologies result only in modest direct transfers of employment back to the EU, as appears most probable, there is likely to be a second-order employment boost in other sectors.

4 Recent research (for example, Acemoglu et al, 2016) that revisited the impacts of Chinese trade on US manufacturing employment has tended to assign greater influence to trade opening than was previously the case.

Shifts in skill and occupational profile demand

As traditional manufacturing jobs have declined in recent years, higher skilled profiles (engineers and other professionals) have posted significant manufacturing employment gains at aggregate EU level. This skill upgrading of manufacturing employment will intensify with the deployment of the five game changing technologies, as will the requirement for multidisciplinary skills such as bioinformatics and managers with advanced data analysis/statistical competences. According to the experts interviewed for the project, training or professional development was the dimension of working conditions most affected by the game changing technologies studied.

The principal new labour demands identified by the project are for higher skilled workers. Sometimes the demand is for those with a more traditional engineering profile – process engineers, quality control, and chemical, electronic, mechanical or mechatronic engineers. However, it is also for newer skillsets – notably those of designers, industrial data scientists, ‘big data’ statisticians/mathematicians and data security analysts – to take account of the increasing data-intensiveness of production processes.

The centrality of data and information in production is at the heart of the paradigm change that the game changing technologies embody. Once a component can be modelled digitally, its physical manifestation becomes secondary or incidental to its virtual representation, captured in bits and bytes. There is a rapidly growing demand for ‘symbolic analysts’ capable of processing and interpreting the large amounts of data that will be involved in designing and producing things.

Ultimately, the most desirable profile is likely to include some combination of engineering and IT skills. Large companies such as General Electric are increasingly making IT skills training, including basic coding, mandatory for all new employees ‘from top floor to work floor’ (Eurofound, 2018c). The centrality of information processing and computer logic means that even more far-reaching reforms to educational curricula are envisaged, including programming skills tuition for primary school students using products such as Raspberry Pi.[5]

While there appears to be a consensus that training structures have a long way to go before they provide the right mix of skills for the new generation manufacturers, there are some examples of active collaboration between university engineering PhD programmes and local industry. With funding from the European Social Fund, the General Confederation of Italian Industry (Confindustria) in Emilia-Romagna is working with the Universities of Bologna, Modena and Reggio Emilia to facilitate industry placements for post-graduate engineering students in an industrial doctorate programme. These placements are intended in part to create a better balance between theory and practice, as existing PhD programmes are often considered over-theoretical and ill-adapted to the needs of industry. In addition, greater emphasis on in-house training, mentoring and skill transfer will reflect the rapidity of advances in knowledge and new technologies; a greater share of professional knowledge will probably be acquired outside formal educational channels and on-the-job training. Online learning (massive open online courses, MOOCs) will play an important role here, as well as innovative manufacturers that are themselves becoming an important provider of training (for example, companies supplying AIR systems). Indeed, it is the case that more basic research is being pioneered not at universities but within large companies. Recent developments in artificial intelligence are, to a significant extent, happening in companies such as Google, Amazon and Apple. This is partly related to the unparalleled amount of data exclusively available to these companies

In addition to specific, generally high-skilled occupational profiles, non-technical skills are becoming increasingly relevant in new generation manufacturing. Social and communication skills will become more important as many of the game changing technologies straddle different, quite specialised technical domains and will necessitate interdisciplinary collaboration between team members and departments, as well as external service providers. As emphasised in Eurofound (2018c), ‘clear communication becomes even more important in complex environments’. The capacity to work in teams will therefore be essential, as will adaptiveness as individual specialists will be contributing to many different project teams.

Other skills frequently cited include independent decision-making and creativity. Decentralised production processes may require rapid intervention in cases of dysfunction or production ‘exceptions’. This is likely to require not only extensive knowledge of technical processes but also leadership skills and problem-solving capacity, as well as other temperamental attributes (‘grace under pressure’).

There will be keen competition among employers in each of the game changer domains for workers who combine the different technical skillsets and competences indicated above. Already, one of the main bottlenecks in manufacturing is a shortage of graduates in science, technology, engineering and mathematics (STEM). The ideal occupational profile will increasingly be some combination of each of the four prongs of the STEM acronym, especially given the emerging demands for statistical and data processing tasks. In practice, the combination of such advanced skillsets – as well as the indicated soft skills – in any one individual becomes less likely as the individual subjects become increasingly specialised. Projects will, out of necessity, be team-based.

Game changing technology companies may prove attractive for job-seekers, given their promise of a stimulating work environment focused on innovation, new knowledge and new products. The fact that game changer start-ups share many of the characteristics of digital IT start-ups – including remuneration tied in part to company growth via share options – could also be an advantage in attracting staff. However, at least one of the case studies draws attention to work intensification and related psychosocial risks (for example, stress and unsocial hours) as a possible corollary

5 www.raspberrypi.org

in tech start-ups. A number of large and fast-growing technology companies have suffered negative media coverage for these reasons, including Amazon, Uber and Tesla (the Guardian, 2016; the Guardian, 2017b).

Remote telework and telerobotics may offer one way of solving potential skill bottlenecks as they can enable individuals and companies in third countries to provide services largely provided locally. One example in which this is already happening is telesurgery, but this could easily also manifest itself in most of the game changing technologies. For example, the work of an industrial data scientist is screen-based and computer-intensive, and as such largely location-independent. Labour cost arbitrage – especially for the higher level professional skills – may make this especially attractive in high-cost locations such as the US and the EU. This could result in a further phase of what Harvard economist Richard Freeman has referred to as 'global doubling'. This was the effective doubling of the global workforce available to multinational employers following the collapse of Soviet state socialism and the integration of India and China in global trade from the 1980s onwards (Freeman, 2007).

In a new phase, the driver would be technology rather than politics (Baldwin, 2016). Rather than production being offshored, individual jobs or tasks would be offshored. Vectors of resistance to such a development include the requirements of occupational licensing (generally organised at national level), which restrict certain trades or activities to those possessing relevant formal qualifications. In addition, there will be resistance from unions and worker representatives defending member interests.

The importance of multidisciplinary teamwork and communication in many of the game changing technologies may also be a powerful factor against the physical dispersion of individual roles, especially given the extent to which time lags, time zone differences or any operational imperfections in the virtualised workplace persist. However, these are likely to be eliminated in the medium term, as technical advances make real-time virtualisation more or less 'seamless'.

Likely occupational labour demand shifts along the lines described by the value chain smile curve (see Chapter 2) are summarised in Eurofound (2018b, 2018c). There would be fewer jobs involved directly in production, but more jobs in the processes before and after manufacturing, notably in design and R&D (before) and in marketing, sales, leasing, remote maintenance and post-sales technical support (after). The increasingly core function of data collation and analysis would bind together each of these before and after functions.

Potential impacts on working conditions

Regarding the prospects for working conditions in advanced manufacturing, the case studies draw attention to the diminution of some traditional industrial risks – a potentially positive impact – but also to new and emerging risks. These tend to depend on the specific game changing technology.

Health and safety

For 3D printing technologies (**AM**), the incorporation of the entire production process in one printer lessens the dangers from moving mechanical parts. However, the presence of high voltage arcs and high temperature printer nozzles, as well as the toxicity of small particles of material, all represent significant new sources of physical risk.

For **IIoT** applications, a McKinsey study estimates that insurance costs may be reduced by 10%–20% 'by preventing accidents and injuries with sensors and tags on employees and equipment' (McKinsey Global Institute, 2015). More generally, robots will increasingly take over hazardous jobs previously performed by humans, including the handling of hazardous materials or operating in dangerous environments (for example, underwater welding).

In **AIR** developments to date, there has been a trend to clearly demarcate and separate human and robot spaces in order to avoid industrial accidents. In their current phase of development, deployed industrial robots still tend to be largely preprogrammed and only partially sensitive to changing ambient circumstances, including the presence of human workers. With the rapid developments in artificial intelligence, these shortcomings will increasingly be addressed. However, protection to date has not always proved successful. For instance, there may still be the requirement for repair or maintenance personnel to enter caged robot enclosures. Two reported incidents occurred in auto sector plants in 2015 – one in the US and one in Germany (McAlone, 2015) – in which unforeseen robot–human interactions resulted in the deaths of workers. The first industrial robot-related death occurred back in 1979.

While such incidents have been characterised as 'rogue robot-related deaths', in practice they arise largely as a result of human error in the installation, programming or supervision of pre-programmed machines. In a longer term perspective, the prospect of artificially intelligent, self-learning robots with enhanced sensors and real-time decision-making capacity raises the potential for truly rogue robots. These could actively subvert the wishes of human supervisors or contain algorithms covertly altered by a hostile human agency with similar outcomes. One well-known game changing pioneer, Elon Musk, the CEO of Tesla, has been vocal about the potential threats posed by artificial intelligence especially in potential military applications, and has campaigned to have robotic weapon systems development banned. In a widely reported speech at the National Governors Association meeting held at Providence, Rhode Island in July 2017, Musk claimed that such 'killer robot' systems pose a 'fundamental risk to the existence of civilisation'.

There is good reason to suspect that analogous risks also apply to industrial robotics applications. Such disruptive possibilities highlight the high priority attached to the training and recruitment of data security experts, especially in IIoT and AIR applications. This is all the more pressing as weak digital security is a common vulnerability of all network data systems. To date, security considerations have tended to be secondary to the imperatives of product rollout (for example, in personal computer operating systems and software).

More generally, there is a need to invest in the safety of processes in situations where robots cooperate with human workers. Eurofound (2018a) refers, for example, to emergency break buttons and improved visual and auditory sensors, as well as natural language systems that allow workers to interact directly with and give instructions to robots that can be processed in real time. The development of 'cobots' – smaller robots designed to co-work with humans, increasingly endowed with artificial intelligence – implies an ongoing desegregration of robots and human workers. EU research projects such as the Horizon 2020 project, Inclusive,[6] is investigating the implications for manufacturing work of these advances in the design of human–machine interfaces.

There are also more mundane concerns about the job quality implications of the virtualisation of work. One concerns the psychological effects of the machine control of work processes. The increasingly secondary role of human intervention – confined to tasks such as supervising robots or machines or exception handling – may result in workers experiencing a loss of control and a sense of alienation from their work, feeling that they are increasingly becoming appendages to a machine. With technical advances, the algorithms become self-improving and smarter, potentially eliminating swathes of better quality, higher paid jobs. At the same time, lower production line employee levels may weaken the social context of work. The capacity of work to forge a positive social identity – at individual and collective levels – as well as personal self-worth and meaningfulness, may be jeopardised as algorithms supplant human agency.

Personal data protection

One important and potentially negative job quality dimension of the game changing technologies relates to personal data privacy. This is referred to explicitly in three of the five case studies.

The digitisation of production processes is the fundamental basis of IIoT, AIR and AM, although it is also important in both the IB and EV domains. This means that all production processes involve large amounts of data processing, including data about individual workers. This can amount to a form of 'digital panopticon' in which an individual's rate of work, rate of task completion, work presence and absence, and potentially even physical measurements such as heart rate and blood pressure, are capable of being actively monitored by employers.

The negative implications of such surveillance for working conditions have already been signalled in the highly automated warehouses or fulfilment centres operated by the online retailer, Amazon. 'Picker's' handheld scanners are used ostensibly to record task completion and to coordinate work organisation. They may also be used to monitor individual performance (miles walked, objects delivered or packed) in relation to production targets as well as toilet breaks. They can also provide data for potential disciplinary actions. While tracking technologies (for example, wearable sensors monitoring air quality or physical indicators) could be deployed to benign effect by responsible employers, concern remains that any existing power asymmetries in the employer–worker relationship are likely to be exacerbated by the wealth of additional data about individual worker performance that the new technologies allow to be generated.

Working time arrangements

In principle, the game changing technologies offer more scope for remote working – including teleworking – and flexible working time arrangements. The digitisation of work processes and the use of remote sensors and virtual screen interfaces mean that more work is theoretically location-independent. In practice, interviewees for this project considered it more likely that greater automation may result in reductions of flexibility (Eurofound, 2018a). Production – especially in AIR applications – is likely to be carried out in single production facilities. Given the capital investment involved, these are likely to operate around the clock, 24/7. A small complement of specialised staff may serve as a constraint on scheduling flexibility, while overnight orders or machine failure may necessitate a constant staff presence or on-call availability. In this way, game changing technologies are likely to quicken the erosion of traditional and predictable working time schedules.

Implications for social dialogue

The implications of the game changing technologies for social dialogue and formal employer–worker relationships have so far received only limited attention from academics and the social partners. In part, this relates to a lack of clarity about how the game changing technologies will affect workplaces. They are all emerging technologies, with many unforeseeable implications for workplace relations. One noted exception is Germany, where the Industry 4.0 debate has engaged all sides of industry in a discussion about how the strong national manufacturing sector will absorb these changes. It has also spawned a multistakeholder reflection (Work 4.0) on how the new manufacturing will affect work.

Trade unions tend to be more cautious about the implications of change. One reason for this is that the companies championing the new technologies have proven less amenable to collective representation. Unionisation is very low in many high-tech companies. These companies also tend to have comparatively few employees in relation to market capitalisation. Automation via AIR or IIoT tends to be viewed with concern by trade unions, given their potential to displace members' jobs. In addition, to the extent that all of the game changing technologies affect labour demand, they tend to favour higher occupational profiles – where the level of worker representation in the private sector has tended to be lower – while jeopardising the types of blue-collar production jobs that traditionally have been highly unionised.

6 www.inclusive-project.eu/vision

Another concern on the part of trade unions is the capacity of digital technologies to drive surveillance and monitoring of workers. This is considered a risk in terms of making work intensification and privacy breaches easier.

While much of the labour market impacts of technological change are uncertain and somewhat speculative, it is reasonably safe to assume that it will lead to significant structural change in the economy and changes in the organisation of work within the workplace. Thus the most immediate and predictable issued to be faced with social dialogue is the anticipation and management of this change. This is the main challenge facing the institutions and regulation of social dialogue.

4 Conclusions

This study examined five game changing technologies: Advanced industrial robotics (AIR); Additive manufacturing (AM); Industrial internet of things (IIoT); Electric vehicles (EVs); and Industrial biotechnology (IB).

A number of (tentative) conclusions can be derived from this analysis of the likely impacts of game changing technologies on production and employment in the manufacturing sector in Europe up to 2025.

Perhaps most importantly, production processes will become **increasingly digital and less mechanical**. All the game changing technologies studied rely on a huge expansion of data flows and requirements for data manipulation and analysis. Digitisation is expanding possibilities to:

- design and test products or processes virtually (simulation);
- repair industrial apparatus remotely;
- automate constant fine-tuning of processes.

These changes are likely to accentuate an existing trend which has seen **value added in manufacturing expand at either end of the product lifecycle** – initial design and R&D at one end, and marketing and post-sales service at the other – and away from the physical mass production process itself.

They also imply a further shift in employment demand in manufacturing away from traditional production line work to increasingly **higher skilled profiles**, including specialisations such as industrial data scientists, encryption experts and network security analysts. Demand for the combination of engineering and data/statistical skills in particular will grow strongly. The specialist nature of many of the game changing technologies will, however, increase the importance of project or teamwork, as well as good management, implying a growing need for 'soft' communication.

Competitiveness in manufacturing will probably be based less on the cost of the labour force and more on the capacity to automate and control production processes (IIoT, AIR, AM; although also relevant for IB and EV). This sets the scene for some reshoring to Europe of production previously offshored on labour cost grounds, although the direct employment benefits from such reshoring is likely to be modest. The impact on employment levels is uncertain: technology will replace considerable labour, however, as reflected in previous experiences of significant technological innovation, the net effect can be positive. The job creation potential is highly related to the distributional outcomes of the productivity gains and the demand generated for the new products and services.

The data-intensive nature of production entails new sets of risks at both company and individual employee level. For companies, managing data – and in particular **data security vulnerabilities** – will become much more important (and potentially business-threatening if not managed correctly). Meanwhile, expanded data flows on individual employee performance raise the spectre of **intrusive monitoring**, surveillance and privacy breaches – a concern noted by worker representatives.

Potentially, many of the game changing technologies will have positive benefits in terms of the working environment (for example, more automation of 'dirty' processes) and environmental benefits in terms of material efficiency and reduced emissions. In a context of global environmental and energy sourcing challenges, this will provide an additional impetus to invest in such technologies (including public investment), most obviously in the case of EVs.

Sectors that are currently at the forefront in terms of the adoption of the game changing technologies studied tend to be highly capitalised and already technology-rich. However, applications are increasingly being identified in comparatively low-tech sectors including clothing and food manufacture. The challenge remains to broaden the potential benefits across value chains, including to SMEs. The adoption and observance of **industry standards and protocols** will be essential to ensure interoperability across production units, whatever their size.

Box 2: A tentative prognosis

Most of this overview report refers to the potential effects of technologies that are not mature or widely adopted, assessed on the basis of discussions with experts, innovators and other players. But what is the actual prognosis for the uptake of these technologies in the near future, over a period of 10 years?

The interviews carried out for this project provide a more cautious assessment of the potential uptake of the studied technologies in the near future in Europe than what is often suggested in the abundant literature on this issue. This assessment can be summarised in the following points.

- The technologies studied will probably have a significant development for some specific applications such as: AM for prototyping, testing and design; IIoT for logistics and some types of service/maintenance provision; and AIR for core production activities in some types of high value added manufacturing.
- A more generalised implementation of the studied technologies is likely to be observed in the next 10 years only in some very specific (leading) companies, probably aided by radical product innovation. Some leaders of

EV production provide early examples of cyber-physical systems with an extended application of the studied technologies.

- A massive diffusion of these technologies throughout the manufacturing sector (including SMEs) is unlikely to be observed over the next 10 years. Instead, a more gradual and uneven implementation can be expected depending on factors such as the perceived technological maturity and relative costs, and the availability of the necessary skills and know-how in specific sectors and companies.

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This overview report summarises the findings of five case studies on the likely impact of game changing technologies on production and employment in the manufacturing sector in Europe up to 2025: advanced industrial robotics; industrial internet of things; additive manufacturing; electric vehicles; and industrial biotechnology. The adoption of these new technological possibilities will not only have consequences for the production process, but also for the working conditions of those employed on the process and on employment demands at company level. The report highlights the increase in digitisation, the greater demand for highly skilled workers, the expansion of value added to both ends of the product cycle, the even greater importance of data security, the possible reshoring of some production back to Europe, and the need to develop and observe industry standards and protocols.

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