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Creating Wealth without Labour?

Emerging Contours of a New Techno-Economic Landscape

Wilfried Lütkenhorst

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Abbreviations

AI	artificial intelligence
AIF	Alliance Industrie du Futur
AM	Additive manufacturing
BMBF	German Federal Ministry of Education and Research
BMWi	German Federal Ministry for Economic Affairs and Energy
CNI	Conseil National de l’Industrie
DDI	data-driven innovation
ERP	enterprise resource planning
ESF	European Social Fund
EU	European Union
GDP	gross domestic product
GVC	global value chain
IBA	International Bar Association
ICT	information and communication technology
IIC	Industrial Internet Consortium
IoT	Internet of Things
IT	information technology
MVA	manufacturing value added
OECD	Organisation for Economic Co-operation and Development
OWL	OstwestfalenLippe
PV	photovoltaics
R&D	research and development
RFID	radio frequency identification
RM	rapid prototyping
RP	rapid manufacturing
SCM	supply chain management
SME	small and medium enterprise
UBI	universal basic income
UK	United Kingdom
UN	United Nations
UN-ECOSOC	United Nations Economic and Social Commission
UNCTAD	United Nations Conference for Trade and Development
UNIDO	United Nations Industrial Development Organization
US	United States

Executive summary

This discussion paper reviews the topical debate around the implications of innovative digital technologies for future patterns of competitiveness, employment, equality, the international division of labour and resource efficiency. Within this exceedingly broad subject, the paper focusses on digital production technologies applied in the manufacturing sector and adopts a global economic perspective in a 10- to 15-year time horizon. The leading research questions are: How is the digital revolution likely to impact the future of industrialisation? How will it affect the relative positions of developed and developing countries in global competition? What are the implications for industrial policy? While the industrial policy responses of major industrialised countries take centre stage, also the implications for latecomer industrialisation are considered.

Following an introductory delineation of the paper's objective and boundaries, Section 2 provides a factual account of what can currently be observed in terms of introducing new digital technologies in industrial production processes and products. The technological remit of the paper and the incidence and relevance of applying various technologies are elaborated. This section provides a brief account of how the world of manufacturing is changing, which new digital technologies are driving the process and how various more general enablers are translated into real-world technological innovations. The perspective adopted here is factual and aims at providing a point of departure for the deeper analyses to follow. Particular emphasis is placed on interconnected trends in key technology domains, such as big data, the Internet of Things, additive manufacturing and robotics.

Section 3 frames the digitalisation discourse in the context of the changing nature and sequencing of industrialisation (specifically the debate around premature deindustrialisation), its role in latecomer development, and the increasingly complex and blurred intersection between manufacturing and services (the so-called servicification of manufacturing caused by a growing role of embedded and embodied services as well as new service-based business models). This is followed by a consolidated overview of the implications of the digital revolution for competitiveness, employment, equality and inclusion, the international division of labour, global value chains and resource efficiency. Throughout this section, the prevailing high degree of uncertainty is emphasised. For instance, when it comes to expected employment effects, neither the magnitude nor the cross-country correlation with income levels are undisputed, that is, there is ambiguity as to whether the share of jobs at risk is positively or negatively related to per capita gross domestic product. Similarly, the impact of digitalisation on the future of global value chains – more specifically, the incidence of backshoring industrial production to high-wage countries – is still subject to debate and calls for further research at the level of various industrial sectors.

Section 4 moves towards the policy domain. It contains a case study of the German "Industrie 4.0" strategy and platform, which represents a priority mission-oriented project within the government's High-Tech Strategy 2020. The main policy instruments, institutional support facilities and public–private partnerships are reviewed. Following a briefer comparative look at similar approaches in selected countries as well as the coordination and harmonisation efforts at the level of the European Union, the section derives more general conclusions on the role of industrial policy in steering the digital

revolution in a socially desirable direction, preventing damaging consequences and promoting its positive impact. Special attention is given to the renewed significance of technology foresight exercises for anticipating likely trends in technology development and adoption as well as their impacts on future patterns of competitiveness.

Section 5 provides an outlook on the implications of the digital revolution for the prospects of latecomer industrialisation and the challenges that developing countries in particular are facing. The digital revolution bears the risk of speeding up the process of premature deindustrialisation in developing countries, whereas in parallel, it may also accelerate the transition towards innovative IT service-based jobs as a growth escalator. Much will depend on the relevant time lags between the technological feasibility and the commercial viability of introducing new digital technologies. However, a question mark needs to be placed behind the future replicability of the type of rapid latecomer industrialisation that has been characteristic for many South East and East Asia countries.

In seeking to design responses to the digitalisation challenge (quite similar to acting on the implications of climate change for a decarbonised green economy), policymakers are faced with the manifold challenges of managing transformation under uncertainty and within long time horizons. Moreover, in many cases, the technical and commercial feasibility of new digital technologies have not yet been established, and a distinct negative bias is at work: Whereas the job displacement effects of some new technologies are predictable in general terms (and are often already visible), the new employment opportunities that may be created in the future are hard to discern. This renders it difficult to tell facts from fiction and wishful thinking from dystopian visions. The latter flourish and dominate the discussion. They can only be countered with a sober and balanced stocktaking of both the perils and potentials of new digital technologies. This is precisely what the paper seeks to deliver.

"We are suffering, not from the rheumatics of old age, but from the growing-pains of over-rapid changes, from the painfulness of readjustment between one economic period and another."
(John Maynard Keynes, 1930)

"No one knows fully how all of this will play out."
(Michael Spence, 2014)

1 Introduction: context, framing and boundaries

The fundamental underlying forces of industrial production and competitive integration of world markets have remained essentially unchanged for many years. The last couple of decades have witnessed a steady increase in the globalisation of economic activities, which was only temporarily dented by the post-2008 financial crisis and seems to currently be withstanding also growing protectionist sentiments and policy pressures in some major industrialised economies. At the same time, tectonic changes have taken place in terms of the shifting relative weights of country groupings. Developing countries have recorded a significantly rising share in global production and exports (leading to what Baldwin (2016) has coined the "great convergence"), albeit with significant regional deviations and in large part driven by the uniquely successful and rapid rise of China. However, in a stylised perspective, the basic pathway towards an ever more interconnected economy largely based on global value chains has been rather *evolutionary*, in essence *stable* and to a great extent *predictable*.

This scenario seems to be changing now. There are strong indications of more radical, *path-disrupting* changes shaping future economic development. On the one hand, this originates from climate change trends and the resulting imperative of achieving a fast and deep decarbonisation of future economic growth in accordance with the commitments made in the Paris Agreement. However, unless crises force policy-makers to introduce drastic measures – with the exception of energy system transformation – the disruptive impacts may be felt only one or two decades from now.

On the other hand, there are likely to be fundamental and more immediate implications arising from the digital production revolution in its various manifestations. While the speed and magnitude of incipient technological changes are still subject to intense debate, it is quite likely that the patterns of international specialisation will, to some extent, be redrawn. Technological innovations happening in the advanced countries of the Organisation for Economic Co-operation and Development (OECD) will significantly co-determine the prospects of developing countries in their latecomer industrialisation efforts, which may become seriously jeopardised in the future. The pointed question is being asked whether the conventional manufacturing-driven pathway to prosperity is gradually being closed (Hallward-Driemeier & Nayyar, 2018; UNCTAD [United Nations Conference for Trade and Development], 2017a).

Against this backdrop, the present discussion paper will explore key dimensions of the impact of the digital revolution on the future economic development agenda. More specifically, it will address the effects of digitalisation on key economic, social and environmental objectives and, in particular, the future international division of labour.

Although the industrial policy responses of major industrialised countries will take centre stage, the implications for latecomer industrialisation will also be considered. Such a broad objective obviously calls for a number of qualifications and the setting of precise boundaries. More specifically, the paper will feature the following characteristics and focus areas:

- Within the broader realm of what has been aptly labelled "the next production revolution" (OECD [Organisation for Economic Co-operation and Development], 2017a), the emphasis is on the interconnected *new digital technologies* (robotics, additive manufacturing, the Internet of Things (IoT), big data, etc.), thus excluding the impacts of biotechnology and nanotechnology, which would warrant a separate discussion.
- The overall perspective adopted is on the *economics* of the new digital technologies, as opposed to their technical and engineering dimensions, and their social policy implications (which is briefly touched upon in Section 4.2.3). The emphasis thus is on their impact on productivity, competitiveness, structural change, employment and skills as well as trade and investment patterns within global value chains.
- In sectoral terms, the discussion paper deals primarily with production processes within *manufacturing industries and related services*. Other important areas impacted by digitalisation, such as government and administration, banking, personal communication and also agriculture, are not addressed. By implication, the paper's focus is on the supply side (digital technologies in production) and not on the demand side (digital products in consumption).
- A global lens is adopted that looks at the impact on economic interactions at the country and sector levels (i.e. not firm-level). From this perspective, trends related to *global value chains* (outsourcing vs. reshoring) assume special significance, and the paper will seek to identify the industrial sectors most seriously affected by incipient technological changes.
- Although there is only scant evidence available, an attempt is made to look at the intersection between digitalisation and *resource efficiency*, that is, to explore if and how the digital revolution may create synergies with parallel efforts to achieve a green transformation of economic growth.
- The time frame of the paper covers roughly the *next 10-15 years*, which is a time horizon near enough to allow for a reasonable extrapolation of current evidence, thus avoiding pure speculation.

The discussion paper is organised in the following manner. At the outset, Section 2 provides a factual account of what can be observed in terms of introducing new digital technologies in industrial production processes and products. The technological remit of the paper is delineated, and the incidence and relevance of applying various technologies elaborated.

Section 3 widens the scope from what we actually know to what we can reasonably expect in terms of various impact dimensions. The section starts from the ongoing discourse on the changing nature and sequencing of industrialisation, its role in latecomer development, and the increasingly complex and blurred intersection with services. This is followed by a consolidated overview of the implications of digitalisation for competitiveness, employment, equality and inclusion, the international division of labour and resource efficiency.

Section 4 moves towards the policy domain. It contains a case study of the German "Industrie 4.0" strategy and platform, which represents a priority mission-oriented project within the government's High-Tech Strategy 2020. The main policy instruments, institutional support facilities and public–private partnerships are reviewed. Following a briefer comparative look at similar approaches in selected countries as well as the coordination and harmonisation efforts at the level of the European Union, the section derives more general conclusions on the role of industrial policy in steering the digital revolution in a socially desirable direction, preventing damaging consequences and promoting its positive impacts. Special attention is given to the renewed significance of technology foresight exercises for anticipating likely trends in technology development and adoption as well as their impacts on future patterns of competitiveness.

Section 5 provides an outlook on the implications of the digital revolution for the prospects of latecomer industrialisation and the challenges that developing countries, in particular, are facing.

In general, the current controversial debate on the development impact of pervasive digitalisation is a minefield fraught with ambiguities and speculation. This does not come as a surprise, given that we are witnessing the incipient stages of what most analysts consider to be genuinely disruptive change and, consequently, the possibility of entirely new development trajectories going forward. Similar to acting on the implications of climate change for a decarbonised green economy, policy-makers are faced with the manifold challenges of managing transformation under uncertainty and within long time horizons (Altenburg & Lütkenhorst, 2015). Moreover, in many cases, the technical and commercial feasibility of new digital technologies have not yet been established, and a distinct negative bias is at work: Whereas the job displacement effects of some new technologies are predictable in general terms (and are often already visible), the new employment opportunities that may be created in the future are hard to discern. This renders it difficult to tell facts from fiction and wishful thinking from dystopian visions. The latter flourish and dominate the discussion. They can only be countered with a sober and balanced stocktaking of both the perils and potentials of new digital technologies.

2 Emerging digital technology trends: what we know

2.1 Overall context

The impact of technological change on productivity, competitiveness and international specialisation has always been at the heart of economic theory. More specifically, also the discourse on the implications of new *digital* production technologies is by no means a new concept. Back in the 1980s, there was an intense debate around what at the time was called "micro-electronics" and its role for a new wave of industrial automation technologies in both light and heavy manufacturing industries. Back then, issues such as increasingly jobless growth (Kaplinsky, 1987) and the possible relocation of industrial production from developing to developed economies (Jungnickel, 1988) were as prevalent as they are today. Those were the early days of digitalisation in the guise of computer-aided design, computer-aided manufacturing and computer-integrated manufacturing, which were among the triggers of fundamental changes leading to a new international division of labour. It would be a fascinating subject in itself to trace the main arguments in that debate and demonstrate their structural similarities to the arguments being exchanged today.

What is different today is, of course, the specific technological innovations and advances being made (which are briefly summed up below), and the fact that we are witnessing a confluence of new digital technologies that, in their combined impact, are *transformational* in nature, *cross-cutting and pervasive* in their innovative application across the various sectors of industry, and leading towards a *growing homogeneity* of industrial processes in functions ranging from design all the way to monitoring and control. The new digital technologies thus represent the latest generation of “general purpose technologies” (Jovanovic & Rousseau, 2005), as did steam engines and electricity in earlier industrial revolutions. They generate wide-ranging implications for industrial organisation and human labour, both in terms of employment levels and changing skill requirements. In a nutshell: The combined impact of various digitalisation technologies is highly disruptive. The manner in which industrial companies produce goods and services, compete with each other, engage in global trade and value chains, interact with customers and adopt new business models will be subject to radical change. Many of these changes are already happening; others are visible on the horizon and can be predicted with reasonable likelihood, while much future innovation may surprise even the community of experts.

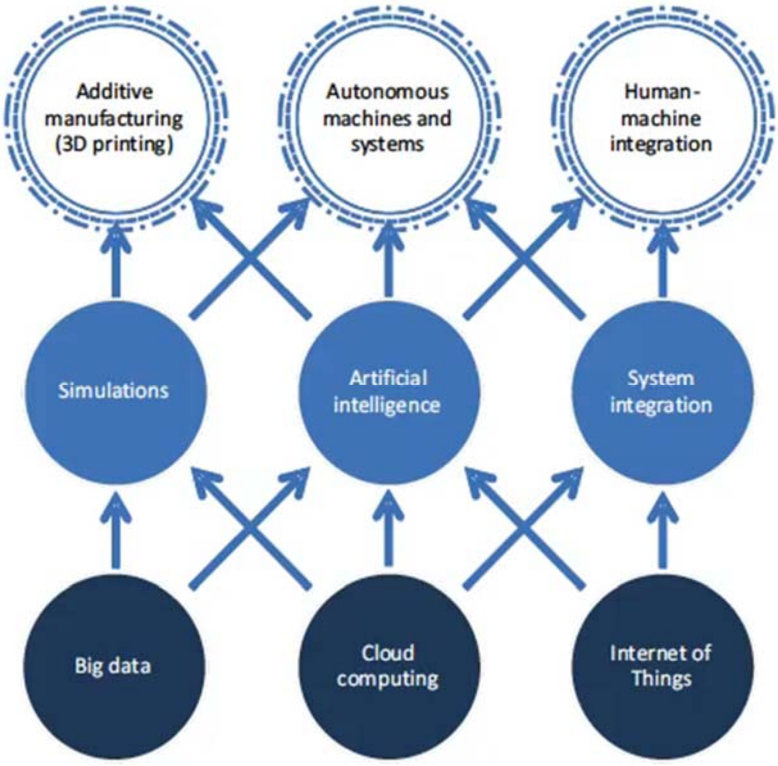
This section provides a brief account of how the world of manufacturing is changing, which new digital technologies are driving the process and how various more general enablers are translated into real-world technological innovations. The perspective adopted here is mostly factual and descriptive. It is aimed at providing a point of departure for the deeper analyses to follow. The difficult task of assessing the likely implications of digitalisation on future employment, skill requirements and patterns of globalisation is addressed in Section 3.

The implications discussed in Section 3 unfold against the backdrop of other mega-trends, such as the planetary challenge of climate change; a rapidly growing and rapidly ageing world population; widening income gaps leading to higher levels of inequality in developed and developing countries alike (OECD, 2011; Ortiz & Cummings, 2011); a global trend towards further urbanisation, which calls for the long-term planning of sustainable agglomeration infrastructures and transport systems (WBGU, 2016); as well as changing consumer preferences of globally growing middle classes leading to new lifestyles, such as those visible in various strands of an emerging sharing economy (Rifkin, 2014), but also implying more resource-intensive consumption patterns in the medium term.

2.2 Digital enablers

Figure 1 presents a highly stylised picture of the interactions between the fundamental enablers of the digital revolution (big data, cloud computing and the Internet of Things) and the main new technologies as applied in industrial processes (additive manufacturing, autonomous machines and systems, and human–machine integration) through which the main productivity-raising effects are generated.[1]

Figure 1: Key digital technologies and enablers of industrial transformation



Source: OECD (2017a, p. 78)

We now take a look at these building blocks one at a time.[2]

Big data

Arguably, the rise of big data can be considered as a central precondition and trigger of the new digital production technologies. In comparison to conventional database software (e.g. enterprise resource planning (ERP) and supply chain management (SCM) systems), big data is defined by the extraordinarily high *volume* of data, the ever increasing *velocity* of data processing (requiring stream processing as opposed to batch processing), the *variety* of data (including complex and unstructured datasets) and the often *hidden value* of data that becomes evident only after deep analysis aimed at identifying patterns and structural

1 A review of 10 major studies published after 2015 confirms that the following fields of technological innovation (in descending order of priority) are considered as being central to the digital revolution: Internet of Things, big data analytics, additive manufacturing, advanced robotics, smart sensors, augmented reality and cloud computing (Cirera et al., 2017, cited in Hallward-Driemeier & Nayyar, 2018, p. 95).

2 Clearly, many different options exist for structuring the subject matter under consideration. However, this discussion paper is not aimed at definitional and typological discussions, which sometimes involve hair-splitting. Unless otherwise specified, the terms "digital manufacturing", "industrial digitalisation", "fourth industrial revolution", "Industry 4.0" and "smart manufacturing" will thus be used broadly interchangeably.

relationships (Tian & Zhao, 2015).[3] The generation and processing of vast amounts of data has allowed for data-driven innovations (DDI) that are based on sensors used to monitor, control and adapt every step of industrial production; led to optimised machine efficiency and production control; and allowed for better integration of suppliers into value chains. It is estimated that the systematic use of DDI at the enterprise level can lead to a 5-10 per cent advantage in labour productivity growth compared to other enterprises (OECD, 2015). However, the evidence so far is scarce, as the use of big data is only gradually making inroads into the whole manufacturing sector (beyond information and communication technologies (ICT) firms as natural "early adopters"). All in all, the pool of digital data is doubling roughly every two years; by 2020, it is expected to reach 44 zettabytes,[4] which would represent a 50-fold increase over 2010 (UBS, 2016, p. 30).

Cloud computing

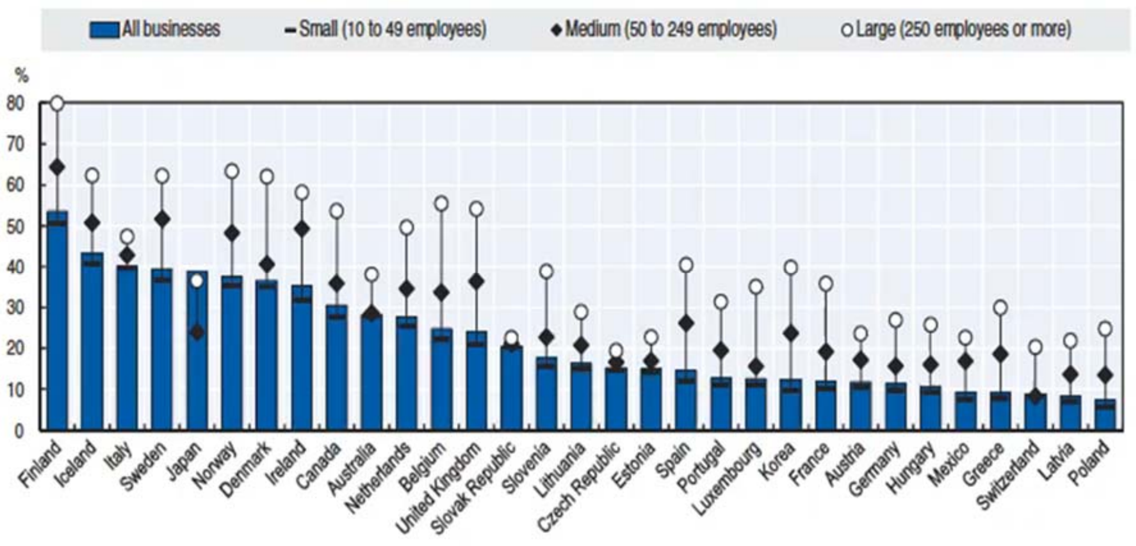
The emergence of cloud computing can, in part, be interpreted as a response to the rise of big data, which has created the need for a technological infrastructure that allows for the storage and processing of large and rapidly growing amounts of data. Cloud computing is characterised by the use of a network of remote, internet-hosted servers. Its key features include *on-demand self-service* with a range of easily accessible devices (including smartphones, laptops, etc.), *pooled data* resources that can be accessed using a multitude of connected customers and a particularly large *elasticity in usage volumes* (UNIDO [United Nations Industrial Development Organization] & Policy Links, 2017). For companies in manufacturing and beyond, cloud computing offers the possibility to keep down the investment costs of a dedicated ICT infrastructure and to increase flexibility in data storage and usage, which typically is subject to changing requirements in the growth cycle of an enterprise. It also allows for the integration of a multitude of information technology (IT) systems, both vertically within a company and horizontally between companies, for example at various stages in a value chain.

The share of manufacturing firms using cloud computing services differs markedly within OECD countries – ranging from more than 50 per cent in Finland to close to 25 per cent in Japan, approximately 20 per cent in the United Kingdom and only some 10 per cent in Germany (OECD, 2017a, p. 85). In most developing countries, company usage rates are at much lower levels due to a combination of internal barriers – such as the lack of knowledge and understanding, financial constraints and security concerns – and external barriers, such as the lack of a reliable IT infrastructure to ensure stable access (Afshari, 2014; UNCTAD, 2013). Furthermore, small and medium-sized enterprises (SMEs) display much lower usage ratios than larger enterprises (Figure 2). Given the relatively low financial barriers of accessing cloud computing, this is likely to be primarily attributable to knowledge gaps and prevailing "conservative" business cultures.

3 On a more philosophical note, the often unstructured generation of big amounts of data with initially unknown specificities of their later use and value possibly implies the emergence of a whole new way of approaching problems, in that the "importance of causation is being challenged by a preponderance of correlations" (Cukier & Mayer-Schoenberger, 2013, p. 39).

4 1 zettabyte = 1,000 petabytes = 1,000 x 1,000 terabytes = 1,000 x 1,000 x 1,000 gigabytes.

Figure 2: OECD countries – percentage of enterprises using cloud computing services in 2014, by size



Source: OECD (2017a, p. 84)

Internet of Things

IoT is still in its infancy and is widely considered to be "the next big thing". Basically, it is about connecting physical objects to the internet through a variety of mechanisms, such as radio-frequency identification, tags, sensors, actuators and/or mobile phones, so that physical things acquire virtual identities that allow for intelligent interfaces within integrated information networks (Atzori, Iera, & Morabito, 2010; Xu, He, & Li, 2014). In conjunction with the analytical power of big data and the storage power of cloud computing, this enables industrial machines to become autonomous and intelligent in terms of being capable of learning and adjusting. The synergies thus created are considered to be no less than "a game changer" (OECD, 2017a, p. 85) for industrial production. Indeed, according to IoT Analytics (2018), 2017 was the first year in which the number of IoT-connected devices (machines, metres, cars, wearables, etc.) surpassed the number of non-IoT connected devices, such as PCs, laptops, tablets and smartphones. It is estimated that by 2020, the number of IoT-connected devices in industry alone will be around 7.6 billion (Crooks, 2017), and that companies globally will spend €250 billion on IoT, with investments in predictive maintenance, self-optimising production and automated inventory management accounting for the lion's share (BCG [Boston Consulting Group], 2017). Such investments are expected not only to reduce production costs (e.g. through eliminating downtime and extending maintenance cycles) but also to lead to quality improvements and shorter response times throughout the entire supply chain. In this context, it is noteworthy that in a European survey of SMEs, 70 per cent of respondents indicated that the main driver of IoT-use indeed was to improve product quality and to introduce new service-based business models (Lueth, Glienke, & Williams, 2017).

2.3 Digital production systems

The three enablers briefly reviewed above (big data, cloud computing, IoT) constitute highly interactive systems. Amplified by the power of simulations, the use of artificial intelligence (AI) and system integration (see Figure 1), they have led to the emergence of fundamentally new digital production technologies, which are described below. Before doing so, it is helpful to take a synoptic look at the key drivers, features and impact areas of digitalised production systems (Table 1).

Table 1: Key drivers of digitalised production systems

Driver	Main feature	Area of impact
Digitalisation of assets	Encoding information and physical objects into binary digits	Computer processing of data and physical assets (additive manufacturing)
Datafication of business processes	Using sensors for monitoring real-world business processes	Enhanced process control, e.g. for preventive maintenance
Communication between physical assets	Connecting objects via IoT	Product/process innovations
Codification and automation of business processes	Applying dedicated software (ERP, SCM, etc.)	Higher levels of process standardisation
Trading of data	Creating intersectoral markets for selling data packages	Creation of new service industries

Source: Compiled by author based on OECD (2017a, pp. 88-93)

Let us now turn to the digital revolution in industrial production processes themselves, where innovative applications have seen rapid growth as a result of the enabling and amplifying forces described above. Again, we will follow the presentation in Figure 1.

Additive manufacturing[5]

Although the origins of additive manufacturing (AM) can be traced back to the end of the last century, it is only now that its various technological manifestations are rapidly diversifying and its industrial applications are entering a phase of exponential growth. Similar to what is happening in the field of renewable energies, AM finds itself on the steep part of the technological learning curve, resulting in falling prices for both the equipment itself and the various materials used. The latter range from metals, plastics and paper to more specialised applications based on, for example, food or even living human cells as well as the blending of different materials. The common characteristic of all AM techniques is the additive layering in producing parts, components and entire products (as opposed to the subtractive manufacturing approach applied in conventional machining), which, in turn, draw on a variety of processes, such as simple two-component adhesives, thermoplastic extrusion or laser sintering. In essence, AM counteracts specialisation. It allows for the integration of previously discrete manufacturing operations into just one process that can be handled by a single skilled worker – which is why Baldwin suggests labeling this approach *"compufacturing"* (Baldwin, 2016, p. 200).

5 Among the alternative terms used to describe this technology are: additive layer manufacturing, layered manufacturing, freeform fabrication or, more colloquially, 3D printing.

At present, the AM industry is gradually transiting from its earlier application focus on rapid prototyping towards genuine rapid manufacturing, that is, towards producing industrial parts – and even entire products – on a larger scale, both in terms of the volume and size of individual pieces. Prime examples include certain medical devices (e.g. dental crowns), high-value lighting goods and complex components used in automotive and aerospace industries (Mellor, Hao, & Zhang, 2014). The benefits to be reaped in AM are widespread and range from design flexibility for customisation to shorter lead and ramp-up times in production, enhanced product performance (e.g. through weight reductions), reduced reliance on complex supply chains and possibly a more efficient use of scarce resources (see Section 3.5 on the environmental impact of digitalisation).

The full-blown development prospects of AM are as yet unclear. It seems though that an earlier belittling of AM as a non-scalable, special-purpose niche technology is giving way to expecting a great potential for AM to morph into a truly transformative, game-changing technology of the future. The global market for AM products and services is estimated to grow from €2 billion in 2012 to €20 billion in 2020 (acatech [National Academy of Science and Engineering], German National Academy of Sciences, Leopoldina, & Union of the German Academies of Sciences and Humanities, 2017). The United Kingdom's Royal Academy of Engineering considers AM "not only a disruptive technology that has the potential to replace many conventional manufacturing processes, but also an enabling technology allowing new business models, new products and new supply chains to flourish" (Royal Academy of Engineering, 2013, p. 3). This rather optimistic assessment has more recently been corroborated by a World Bank estimate that puts the trade disruption potential of AM at a staggering 5-15 per cent range of total global trade flows (Hallward-Driemeier & Nayyar, 2018, p. 137). Likewise, a recent extensive Delphi Survey[6] among 65 experts (Jiang, Kleer, & Piller, 2017) concludes that AM will widely challenge existing business models and market structures. More specifically, industry experts, in particular, consider it likely that the following statements will apply by the year 2030:

- More than 50 per cent of industrial AM capacity is supplied in-house within companies (as opposed to being sourced externally from special AM providers).
- The distribution of more than 25 per cent of final industrial products takes place in the form of selling digital files rather than physical products.
- The sources of competitive advantage have moved significantly from hard manufacturing capabilities towards soft assets in terms of access to customers and networks of designers.
- Across all industries, the market share of AM products exceeds 10 per cent.

Unless this assessment turns out to be overly optimistic (a bias that may easily occur in a community of like-minded experts), it would imply that – in and by itself – AM has a considerable potential to transform industrial production, products and markets in most fundamental ways. However, there are also many voices calling for greater caution and pointing to significant challenges to be met in fields such as standardisation, quality control, product liability and intellectual property, in particular when parts and components generated

6 The Delphi approach is an interactive forecasting method based on expert judgement that can be either quantitative or qualitative. It is one of many methods used in technology forecasting exercises. Regarding the general issue of using technology foresight approaches for assessing the likely trends and prospects of digital technologies, see Section 4.2.1.

under AM conditions are integrated into final products through direct customer interfaces. These and other concerns have led a German research consortium to conclude that AM (while continuously maturing) is still in its infancy and will, in the foreseeable future, "not revolutionize industrial production" (acatech et al., 2017, p. 7). The final jury is still out.

Autonomous machines and systems

In terms of applications in manufacturing, autonomous or semi-autonomous machines (commonly referred to as robots) are at the heart of the digitalisation of industrial production. From the early days of robotics, when industrial robots were just able to perform predefined (i.e. programmed) tasks in highly circumscribed environments, we have come a long way to today's highly flexible robots, which are capable of adjusting and learning within information feedback loops. At the same time, quantum leaps have been made in terms of advanced sensing and enhanced cognitive capabilities, materials-handling abilities, voice and pattern recognition, more refined levels of dexterity and multi-functionality of operations carried out.[7]

Apparently, Moore's Law (predicting a doubling of the number of transistors in dense integrated circuits every two years) is applicable also beyond the narrow realm of integrated circuits; if anything, the capabilities of robots are expanding even faster. There is evidence that many digital devices, processing speeds, memory capacities, sensor density and accuracy, and even the number of pixels are linked to Moore's Law. In one stunning example of a particularly complex production planning challenge, it was shown that within 20 years, as a combined result of computer hardware and algorithm improvements, the time needed to solve the problem was reduced from 82 years to just one minute (Ford, 2015, p. 71). Metaphorically speaking, the power of digitalisation is now entering the second half of the chessboard,[8] in which the numbers generated exceed the limits of human imagination (McAfee & Brynjolfsson, 2014).

At present, the debate around autonomous devices is dominated by trends in the mobility and transport sectors. These trends range from semi-autonomous driving in private cars to driverless public mobility solutions currently being piloted in many urban agglomerations. Particularly in the context of sustainable urbanisation, there is a growing convergence of electrically powered vehicles with automated driving and internet-based mobility services – reinforced by a variety of concerns related to reducing negative climate impacts, pollution, congestion and costs while increasing road safety and public health (KPMG, 2017).

However, this focus on new forms of mobility must not eclipse the silent revolution taking place in robotics use in manufacturing operations at the shop floor level. Indeed, the installation of industrial robots has seen dramatic growth in recent years and is poised to continue growing at exponential rates in the future. Among the main determinants are both supply-side factors, such as cost reductions and the substitution of scarce skills, and

7 For instance, in the Tesla automotive factory, one and the same robot is capable of welding, riveting, bonding and installing a component (Markoff, 2012).

8 This metaphor goes back to an ancient Indian story in which grains of rice are piled on a chessboard starting with just one and doubling the number of grains on each successive of the 64 squares. The full effect of the exponential growth thus generated kicks in only on the second half of the chessboard, resulting in a staggering total number of 2^{64-1}.

demand-side factors, such as increasing expectations concerning product quality, speed of delivery and, above all, customisation.

Let us take a look at the most recent statistical evidence of industrial robot use (data listed below are drawn or calculated from International Federation of Robotics, 2017):

- In 2016, the global stock of industrial robots was 1.8 million (a 12 per cent increase over 2015) and projected to grow to approximately 3 million by 2020. Annual sales reached a new peak of more than 294,000 in 2016.
- In sectoral terms, two-thirds of robot use are accounted for by the automotive and electrical/electronics industries, with the latter displaying much stronger growth.
- The regional breakdown sees just five countries (China, South Korea, Japan, the United States and Germany) accounting for three-quarters of total industrial robot sales in 2016. China alone absorbed 30 per cent, and its share is forecast to grow to some 40 per cent by 2020. It is noteworthy that, to date, Latin America is hardly on the map of industrial robotics: Although Brazil's purchases of 1,207 industrial robots were equal to just 0.4 per cent of global sales, all other South American countries together generated a meagre 0.14 per cent.
- When looking at robot density in the manufacturing industry, South Korea is leading by far (631 robots per 10,000 employees in 2016), followed by Singapore (488) and Germany (306). Here again, the strongest dynamism can be found in China, where robot density almost tripled – from 25 in 2013 to 68 in 2016.
- In qualitative terms, there is a clear trend towards the use of collaborative robots (see the section on human–machine interaction below), lightweight robots and generally robots that are increasingly easy to install, programme and operate, so technical conditions seem to be improving for a stronger uptake of robots, also in SMEs.

These statistical data could be complemented with rich anecdotal evidence from countless business cases. Here, just one illustrative case from the consumer electronics industry may suffice. In the early 2010s, the Dutch company Philips established a new manufacturing plant producing electric shavers. Located in the Netherlands and using approximately 130 industrial robots, the number of workers is 10 times smaller than in the company's sister plant in Zhuhai, China (Markoff, 2012). While this ratio is strikingly high, it is not totally out of line with more general research results. For the US economy as a whole, it is estimated that with each additional industrial robot, employment is reduced by three to six workers (Acemoglu & Restrepo, 2017). (For a more detailed and differentiated treatment of the employment effects of digitalisation, see Section 3.2 below.)

Human–machine interaction

In Figure 1 above, the OECD uses the term "human–machine integration", which can easily lead into highly speculative future scenarios of machine–mind integration brought about by advances in biochemistry, nanotechnology and virtual reality. In contrast, this discussion paper just talks about "human–machine interaction", which is more tangible and realistic in the immediate future.

The range of activities that robots are capable of performing in the immediate future will expand rapidly, yet remain limited. On the one hand, even with artificial intelligence capabilities increasing fast, the realm of ideas, innovation, creativity and risk-taking is still predominantly the domain of the human mind. On the other hand, there are simple manufacturing operations (e.g. working with soft, shape-changing materials such as textiles) that cannot be easily digitalised.

However, robots are rapidly encroaching on terrain previously considered the preserve of human activity. This trend is reinforced by various new forms of human–machine interaction, which are piloted, above all, in the automotive industry. In the final assembly of cars, the boundaries for robot activities are being pushed even into safety-critical operations within moving environments, such as conveyor belts. Interactive workflows (based on collaborative robots, or "cobots") are now feasible, in which workers are training robots on the spot. Experimental research is seeking to improve robot planning capabilities and "human–robot team fluency" (Unhelkar & Shah, 2015, p. 240). Whether this will ultimately lead to the replacement of workers – or just to more flexible and efficient forms of organising work – remains an open question (Knight, 2014).[9]

3 Impact dimensions: what may happen

The preceding section has provided a synopsis of the key technological trends that characterise the digital production revolution. This has set the stage to now looking at the key impact dimensions, both generally and more specifically, regarding the challenges that developing countries will be facing. Before addressing the key conduits through which new digital technologies will change the global economic landscape, Section 3.1 adopts a broader perspective and places the discussion against the background of recent aspects in the debate around the future of industrialisation. The following sections (3.2 and 3.3) will address the core economic impact dimensions first (employment, skills, productivity, value chains) before Section 3.4 moves on to aspects of inclusive development (inequality, role of SMEs), and Section 3.5 addresses environmental repercussions (natural and energy resource efficiency). Thus, the distinct impacts of the digital revolution on the three pillars of sustainable development provide the overarching perspective.

3.1 Industrialisation and development: past and future trends

New technologies and structural change

The history of economic development can be viewed from many different angles. Arguably, for those areas of economics dealing with growth and development, the concept of structural change has always been at centre stage. How the composition of economic sectors changes and diversifies over time is crucial for productivity growth, and hence long-term economic

9 Another new element of human–machine interaction is based on the rapidly spreading commercial use of drones. From monitoring operations on construction sites (e.g. offshore oil rigs) and in large-scale commercialised agriculture to assessing on-site damage scenarios for insurance companies, drones are gradually replacing human labour frequently exposed to hazardous conditions (McAfee & Brynjolfsson, 2017, pp. 99-100).

dynamism. In turn, this is greatly influenced by the availability and commercial application of different production technologies, which over time have been the drivers of successive industrial revolutions. Seminal studies have addressed this question in either historical or analytical approaches, most notably among them the Clark (1940) and Lewis (1955) models, with their emphasis on what Polanyi (1944) famously labelled the "great transformation" from agrarian to industrial societies. In general, structural change is uniquely considered

> as a central feature of the process of development and an essential element in accounting for the rate and pattern of growth. It can retard growth if its pace is too slow or its direction inefficient, but it can contribute to growth if it improves the allocation of resources. (Syrquin, 2007, p. 4)

As Ranis underlines, in the discourse on economic growth during the early decades of development economics, "industrialization was viewed as equivalent to development" (Ranis, 2004, p. 6).[10] More recently, the transition to highly differentiated manufacturing sectors as a source of rapidly growing intra-industry trade (initially demonstrated by Chenery, 1960) has become a dominant theme, followed by evidence of a general trend towards service-dominated, post-industrial economies (see the discussion below on the "servicification" of manufacturing).

The importance of structural change caused by, and related to, the relative growth of different manufacturing industries and technologies can thus hardly be overstated. This warrants a closer look at how the industrial pathway to economic development has evolved in the past, and whether this can be expected to also hold for the future. The stylised picture of successful latecomer industrialisation starts out from labour-intensive, low-skill export manufacturing, often based on foreign investment (typically in textiles and clothing industries), which then moves on to more sophisticated sectors, such as consumer electronics, accompanied by a continuous upgrading process. More advanced skills and capabilities are developed as the mastery of technologies increases, gradually leading to the build-up of a domestic manufacturing base that goes beyond supplying just simple parts and components. This upgrading process is accompanied by rising wage levels that, in turn, erode the competitiveness in simple low-wage activities, thereby making room for other low-income countries to start their industrialisation drive. The prototypical example for this pattern has been East Asia, with its "flying geese" dynamics, which can explain

> how an individual industry upgrades its processes as it goes through a cycle of importing, then producing, and finally exporting; how a variety of industries diversify and upgrade from simple to more sophisticated technologies; and how a latecomer in the development process can benefit from the graduation of industries in a more advanced, dynamically growing economy with similar features. (Lin, 2012, p. 222)

Today, some observers consider the impact of the new digital technologies as being so dramatic that the geese may not fly anymore. The real possibility is raised of China being "one of the last countries to ride the wave of industrialization to prosperity" (Chandy, 2016, p. 14) as a result of both new "digital" cost advantages in mature economies and the trend

10 To date, this assessment has not changed. The latest World Bank report on the future of manufacturing asserts that "industrialization has been synonymous with development because most high-income countries […] achieved that level of prosperity through manufacturing export-led strategies […] some of the biggest development gains in history have been associated with industrialization" (Hallward-Driemeier & Nayyar, 2018, pp. 9-10).

towards a higher importance of industrial services (see below). If this were true, then the wealth aspirations and hopes of developing countries, which are greatly pinned on benefiting from continued industrial productivity gains, would be severely dimmed. What then are the general prospects of industrialisation going forward? How is this process expected to change in relevance, sequencing and sectoral composition? What is happening at the intersection between manufacturing and services?

Premature deindustrialisation

Recently, this debate has been decisively influenced by Rodrik's econometric findings of a phenomenon he labels "premature deindustrialization" (Rodrik, 2015). As this hypothesis has become a central reference point also for the debate around the long-term economic implications of digital technologies, it is helpful to briefly recap its essence.

In a nutshell, Rodrik has demonstrated that the long-term trend towards deindustrialisation – measured in terms of employment and manufacturing value added (MVA) shares in gross domestic product (GDP) – which has been the general pattern observed in developed countries, is even more pronounced in the case of low-income and middle-income developing countries.[11] In their post-1990 development trajectory, the peak GDP shares of manufacturing employment and value-added are both lower than for developed countries and, moreover, occur at lower per capita income levels. In other words: Deindustrialisation kicks in at earlier points in time and, in this sense, can be considered as premature.

Not surprisingly, significant regional differences can be observed. The manufacturing performance over time is strongest in Asia, whereas "the region that has done the worst is Latin America" (Rodrik, 2015, p. 11). Rodrik also highlights the important role that manufacturing has played in historical development processes. In economic terms, these include the role of manufacturing for technological dynamism and productivity growth, the absorption of mostly unskilled labour in incipient development stages and the tradability of manufactures. In broader political economy terms, he alludes to the historic importance of industrialisation in "creating modern states and democratic politics" (Rodrik, 2015, p. 25) and sees a great risk of the "quintessential escalator for developing economies" (Rodrik, 2015, p. 3) slowing down, or even coming to a halt.[12]

The metaphor of a growth escalator is also employed by Ghani and O'Connell (2014), who argue that the services sector could assume this role in low-income countries – not necessarily replacing, but complementing manufacturing industries. This is an interesting proposition that leads us straight into the rapidly changing relationship between industry and services. In particular, the new digital technologies are contributing to a further blurring

11 This broadly tallies with the observation that, even in half of the fast-growing countries with rising shares in *global* MVA, the sector's share is declining in their *domestic* economy (Hallward-Driemeier & Nayyar, 2018, p. 52).

12 Haraguchi, Cheng and Smeets (2017) argue that the premature deindustrialisation to be observed in many developing economies may not be the result of a decreasing relevance of manufacturing, but rather the consequence of a growing concentration of manufacturing in just a few countries. China, with its continued high GDP share of manufacturing, clearly is a case in point. For other countries, in-depth analyses would be required to prove the validity of this point.

of the dividing line between both sectors.[13] At the intersection of manufacturing and services, a number of different phenomena need to be separated. Although these tend to happen simultaneously and are highly interconnected, they call for analytical distinctions.

The servicification of manufacturing

Over time the service content of manufactured products has risen strongly. This fact has been referred to as the servicification of manufacturing. What are the main trends to be observed? A conceptual distinction needs to be made between embodied services, new service-based business models and embedded services.

Embodied services

First, there is a whole range of *embodied services*, which in and by itself is not a new element. Manufacturing was never possible without relying on a whole range of specialised services in areas such as legal support, banking, insurance, transport, etc., which were bought by industrial companies and thereby contained in the final value of products. In recent years, however, a pronounced trend towards a further outsourcing of services can be observed. Industrial companies seeking to focus on their core manufacturing competences source out service operations that traditionally have been provided in-house. Frequently, this is the case with regard to ICT-related activities, for example developing software or maintaining databases. Although the nature of activities carried out remains essentially unchanged, they move from the industrial to the services sector and, as a result, create the statistical artefact of a higher GDP share of services. The curious effect is thus generated that countries with a high preponderance of large, vertically integrated companies tend to display relatively higher GDP shares of manufacturing.

The empirical evidence on outsourced embodied services is strong and points to their significant and growing role. According to World Bank calculations, for major low-income and middle-income economies, the contracting out of services from manufacturing companies accounted for approximately 10 per cent of the annual growth of services value added in the 2000-2014 period. At the same time, in 2011 gross manufactured exports derived 35 per cent of their global value (and even a staggering 40 per cent in the EU countries) from embodied services (Hallward-Driemeier & Nayyar, 2018, pp. 60 and 146-147). This is mirrored by the fact that, between 1980 and 2008, the share of services in global trade almost doubled, that is, inputs from service industries contributed increasingly to the value of manufactures (World Bank et al., 2017).

New service-based business models

A second trend is the adoption of business models that essentially rely on the selling of manufactured goods as services, that is, on the conversion of products into time-bound user services. This is not entirely new and had already started developing some 15 years ago in the field of industrial chemicals, for example. Although traditionally companies used to sell

13 Again, it is intriguing to note that this argument already appeared in the 1980s debate on automation and micro-electronics. For instance, the United Nations Conference on Trade and Development stressed that "information technologies have created a symbiosis between development in the manufacturing and the services sectors" (UNCTAD, 1988, p. 257).

bulk quantities of chemicals to end-users, chemical leasing provides an alternative solution, through which users only pay for the services rendered by the chemicals (e.g. volume of water treated, number of parts painted, lengths of pipes cleaned, etc.) and not for the volume of chemicals consumed. Real-world examples range from water purification in Colombia to the painting of washing machines in Egypt or newspaper printing in Sri Lanka (UNIDO, 2011).[14]

This trend towards industrial companies charging usage-based fees (based on customised pay-as-you-go services) is strongly intensified by the digital manufacturing transformation, which allows for companies to carry out detailed, real-time monitoring of the volume, time, modalities and efficiency of product use. This, in turn, enables manufacturers to provide sensor-based services aimed at optimising product use (OECD, 2017a, p. 75).[15]

Embedded services

Although the dividing line between embodied services and embedded services can itself be blurred, the former relate primarily to services bought by producing companies and contained in final goods, whereas the latter cover services that are delivered to customers and often bundled within broader packages: "Manufacturing firms increasingly bundle advertising, warranties, and after-sales care with physical goods to foster brand loyalty, derive strategic benefits […] and exploit additional sources of revenue" (Hallward-Driemeier & Nayyar, 2018, p. 147). Here again, providing after-sales services aimed at ensuring reliability and efficiency of product use (from maintenance and repair to full-fledged management consultancy) is greatly facilitated by the new digital technologies and the continuous data flows they generate.

Consequently, the share of the total value generated at pre- and post-production stages is becoming even more important than it used to be within global and regional value chains. Put differently: The "smile curve" of value generation in global value chains (GVCs) is being compressed (Figure 3). In light of the predominant involvement of developing-country firms at the low-cost assembly and processing stages, this is likely to impede their chances of getting inserted into GVCs and, when successful, further squeeze their profit margins.

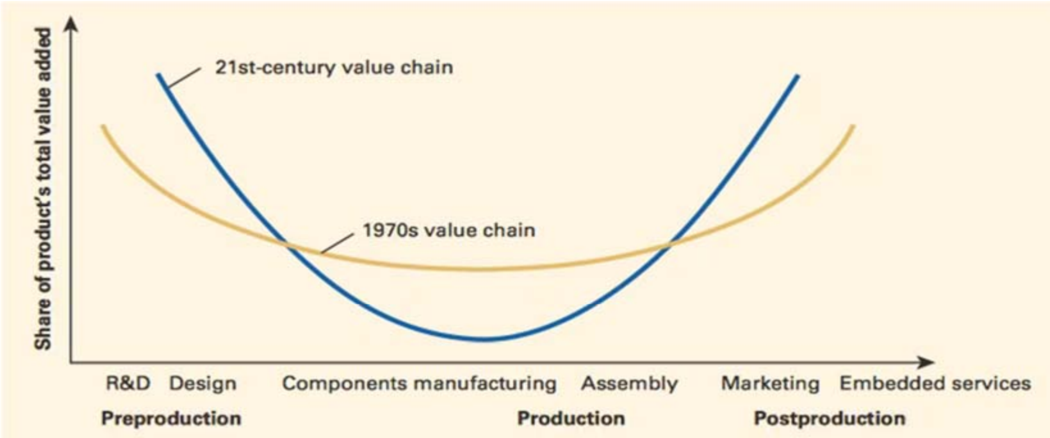
In conclusion, the landscape of globalisation is becoming much more complex. Industrial production itself is being transformed by new digital technologies, the technological bar for market entry is being raised – in particular for low-income and middle-income countries – and the separation between manufacturing and services in both production and trade is becoming outdated (if not meaningless), at least for advanced economies (Lodefalk, 2016). Gone are the times when manufacturing was all about forging and welding, drilling and boring, stitching and sewing, whereas services were considered as lacking the economies of scale, tradability and productivity-enhancing innovations unique to industrial processing. A fresh and sober look needs to be taken at the new industrial realities. What is the most likely scenario for latecomer industrialisation in the years ahead? Will the new digital technologies

14 By decoupling the payment from the consumption of chemicals, chemical leasing offers strong incentives for more efficient chemicals management. This results in both environmental advantages and economic benefits for both suppliers and users of chemicals.

15 For instance, largely based on its own Predix data platform (hosting software to manage clusters of wind turbines or locomotives fleets), General Electric wants to be among the world's top 10 software companies by 2020 (The Economist, 2016).

usher in an even more pronounced phase – an "augmented reality" – of premature deindustrialisation, helping today's developing economies turn "into service economies without having gone through a proper experience of industrialization" (Rodrik, 2015, p. 2)? In other words: Is it realistic to assume that high-value services can be a basis for economic development without reliance on a highly automated core of manufacturing – which would invalidate the conventional argument of manufacturing being the key driver of productivity increases? Moreover, what are the relevant timelines? Will conventional industrial-upgrading strategies still have a window of opportunity in the short to medium term?

Figure 3: Value added of services in manufacturing, 1970s versus 21st century



Note: Figure adapts the "smile curve" depiction of how value added changes across different stages of bringing a manufactured product to market, as first proposed circa 1992 by Acer Inc. founder Stan Shih; for a more detailed discussion, see Baldwin (2012). R&D = research and development. "Embedded services" refers to services delivered through the manufactured good (for example, apps on a mobile phone).

Source: Hallward-Driemeier and Nayyar (2018, p. 16)

To approach these questions, the following Section 3.2 takes a deeper look at the impacts and repercussions of emerging digital production technologies, in particular with regard to employment, productivity and skills.

3.2 Impact on employment and skills

The "productivity paradox"

Before turning to the central issue of employment effects, a few words are in order on the relationship between digital technologies and productivity gains in terms of total factor productivity. It seems that Solow's famous dictum three decades ago about the computer age being visible "everywhere except in the productivity statistics" (Solow, 1987, p. 36) is still valid and applicable. Productivity growth has seen a secular decline over the last couple of decades, which, if anything, has further accelerated in recent years (Acemoglu, Autor, Dorn, Hanson, & Price, 2014; World Bank, 2016). Attempts have been made to explain this "productivity paradox" by using a number of arguments – ranging from a negative measurement bias that fails to capture the many new user benefits and quality features of innovative products, to slow diffusion processes and even mismanagement of information technology in real-world applications (Brynjolfsson, 1993). Be that as it may, rising productivity levels have remained elusive to date, and the alleged productivity-increasing impact of digital technologies still enjoys the benefit of the doubt.[16] What is beginning to be felt though are the daunting implications for the role of labour in the factories of the future.

Conceptual issues

In the current debate around digital technologies, their short- and long-term consequences for employment take centre stage. This aspect thus deserves special attention. At the outset, conceptual clarity is of the essence. Table 2 presents a synopsis of the key dimensions to be considered in assessing the repercussions of a digitalised industrial landscape and the danger of a new breed of technological unemployment. The table forms the basis for the considerations that follow.

Table 2: Employment effects of digital technologies – a qualitative synopsis
Destruction of jobs
Technological aspects
– projections based on the automatability of entire occupations (Frey & Osborne, 2013) – projections based on the automatability of specific tasks (Arntz, Gregory, & Zierahn, 2016; Autor, 2015) – projections factoring in the potential for task-specific, human–machine interaction
Economic effects
– determining the commercial viability of automation in terms of positive returns on investment (UNCTAD, 2017a)
Societal aspects
– considering social, legal and ethical hurdles (OECD, 2017a, chap. 8)
Creation of jobs
Direct short term
– direct complementary employment opportunities originating from new digital technologies – jobs created by the manufacturing of new digital technologies
Indirect at company level
– higher levels of productivity leading to new investments and the entering of new markets
Indirect at sector level
- higher levels of competitiveness leading to competitive advantages in global markets
Source: Author

At the most fundamental level, one needs to distinguish between the loss of existing jobs following from introducing new technologies and the generation of new jobs as a consequence. This is often referred to as the destruction effect on the one hand, and the capitalisation effect on the other hand, or alternatively, as the displacement effect and the productivity effect. Bringing it even closer to the original Schumpeterian terminology,

16 In recent research commissioned by the Technology CEO Council (i.e. an interested party), it is underlined that, in digital industries themselves, there has been significant productivity growth over the last 15 years compared to sluggish productivity growth in other physical industries (Mandel & Swanson, 2017). But even so, this would seem to indicate that in actually applying new digital technologies in manufacturing production processes, serious shortcomings still prevail.

Table 2 simply refers to the destruction and creation of jobs. Whereas the negative destruction effect can be quantified and projected at the level of specific technologies and industrial sectors (albeit with considerable controversy), the positive effect of creating new jobs is much more in the realm of speculation, as the nature and scale of entirely new industries cannot be easily appreciated and predicted. Hence, in assessing the employment impacts of new digital technologies, there often is a built-in assessment bias working in favour of pessimistic employment scenarios.

Moving down the rows of Table 2, we start from the maximum level of possible job destruction to successively more limited levels of job destruction. Let us first consider the nature of these effects in qualitative terms before addressing the findings of some recent quantitative studies.

- Methodologies that assume the wholesale replacement of entire occupations by new digital technologies result in exceedingly high estimates of job losses. For example, in some studies, it might be assumed that a welding robot substitutes a human welder, or expert software replaces the work of an accountant, a real estate agent or even a legal or financial analyst.
- Following a different, more sophisticated methodology, task-based approaches disaggregate an occupation into a set of specific tasks to be performed. As some tasks may be easily substitutable while others are not, the resulting predictions on employment losses tend to be significantly lower.
- In a further iteration, the task-based approach also allows for scenarios in which machines (robots) and human labour can split up tasks as appropriate and interact within the same workplace, thus enhancing flexibility options (e.g. as in the case of automotive industries, where robot–worker interaction is rapidly expanding). This further reduces the potential loss of jobs by creating semi-automated workplaces.
- The above approaches all stay in the realm of the strictly *technological* automatability of jobs. However, an *economic* calculus also needs to be factored in. Whether or not technological options are realised, depends on a range of economic determinants, above all the relative prices of capital and labour as well as the resulting profit expectations. Only a fraction of what is technologically feasible will also be economically viable.
- Obviously, a number of qualitative societal dimensions need to be considered as well. Disruptive new technologies often lead to forces of resistance originating from ethical concerns (more frequently related to biotechnologies than to digital technologies), legal regulatory requirements (e.g. in the case of autonomous driving) or an explicit preference for human interaction (e.g. in human care and health services). To the extent that such concerns prevail, job losses will be limited further.

The job creation elements of Table 2 are largely self-explanatory. In the short term, new jobs are being created in direct complementarity with new digital technologies (e.g. the evident, yet largely unanticipated surge of employment in delivery services stemming from online trade) and through the very production of new machines, be they industrial robots or 3D printers. In the long term, productivity gains may create new markets and translate into competitive advantages at the global level. In this case, productivity gains induced by automation could lead to higher demand in export markets, as exemplified by the automotive industries in Germany and Mexico (UNCTAD, 2017a, p. 55). Whether or not new export markets are actually conquered by a country, obviously depends on its relative position within the global competitive race, which, in turn, is co-determined by institutional support capacities and policy interventions (see Section 4).

Moreover, fundamental changes in future employment levels and patterns may originate from modified lifestyles and their translation into new consumption patterns. Higher productivity in manufacturing may trigger higher demand for services within a leisure society focussed on personal health and well-being. Whether or not this will actually happen, depends critically on policy responses to digitalisation (see Section 4).

Quantitative evidence

The conceptual reflections above have set the stage to review the most influential recent quantitative studies of employment effects. A widely cited (although never published) study was presented by Frey and Osborne (2013) assessing the scale and structure of the jobs at risk of falling victim to new digital technologies.[17] The study puts forward projections of job susceptibility to computerisation according to an occupation-based typology (routine and non-routine, manual and cognitive, with a total of 702 occupations) developed by Autor, Levy and Murnane (2003), which is complemented by expert judgement. Unlike Autor et al. (2003), the Frey and Osborne study addresses exclusively the *technological* substitutability of jobs and does not consider any economic factors. It also assumes that entire occupations (and not just specific tasks) can be computerised. Based on this approach, it is concluded that, for instance, in the case of the United States, 47 per cent of occupations are at high risk of being replaced over the next 10-20 years. Among the most seriously affected fields are manual industrial production jobs but also increasingly routine service jobs based on standard operating procedures lending themselves to automation. Furthermore, Frey and Osborne predict a "truncation in the current trend towards labour market polarisation, with computerisation being principally confined to low-skill and low-wage occupations" (Frey & Osborne, 2013, p. 45).

When moving from an occupation-based to a task-based methodology[18] (which still looks at *technological* replacement potentials only), the projections of jobs at high risk of automation change by orders of magnitude. Compared to 47 per cent in the Frey and Osborne study, Bonin, Gregory and Zierahn (2015) see just 9 per cent of US jobs in the high-risk category. In the case of Germany, applying the Frey and Osborne approach yields a 42 per cent figure, compared to 12 per cent when disaggregating occupations into sets of tasks. For 21 OECD countries, the latter methodology results in an average share of jobs at high risk of automation of 9 per cent, whereas for many other jobs, significant changes in the task profiles are anticipated (Arntz et al., 2016). Not to be misunderstood: Having approximately one-tenth of its labour force at high technological risk of being replaced by

17 In the relevant literature, the terms computerisation, digitalisation and automatability are widely used interchangeably.

18 "As a result [of occupation-based approaches; added by author], book-keeping, accounting and auditing clerks are assigned a 98 per cent probability of being automated in the near future, irrespective of the task variation across workplaces within this profession. However, according to our task data, many workers in such highly exposed occupations also perform tasks that machines struggle with, such as problem solving or influencing" (Arntz et al., 2017, p. 157).

machines is a daunting scenario for any country. However, from there to a scenario of about half of all jobs being at high risk represents a quantum leap.

A recent McKinsey study (McKinsey Global Institute, 2017) results in automatability scenarios that occupy a middle ground between the studies reviewed above. Based on a methodology that translates 800 occupations into 2,000 activities and 18 related broader capability requirements (based on the US economy and subsequently applied to other countries), the study concludes that only a small minority of jobs can be fully automated, whereas 60 per cent of jobs have a potential of at least 30 per cent automatable activities. Regarding different economic sectors, manufacturing is second only to “accommodation and food services” in terms of vulnerability to automation, with 73 and 60 per cent of jobs at risk, respectively.

As the preceding paragraphs have shown, there is a high margin of disagreement among different studies on future *technological* unemployment, depending on the methodology applied.[19] At the same time, the technological replacement risk represents a ceiling that is unlikely to be reached once *economic* factors are also considered. Moreover, moderate optimism seems to prevail on the potential scale of future job creation in new industries (Autor, 2015; European Commission, 2015; World Bank, 2016).[20] In this context, there is no question that frictional unemployment during an adjustment period (the length of which is hard to predict) will occur and call for targeted measures towards reskilling and upskilling – in light of an already significant general misalignment between available and required skills (OECD, 2016a).

At the same time, there is a broad consensus about the negative impacts of digital technologies on income distribution, inter alia due to the varying impacts on different types and levels of skills. This can take the form of polarisation (hollowing out of the middle-skill, middle-wage segment) or be reflected in mounting downward pressure, in particular on low-wage, low-skill segments of the labour force, which are the most seriously affected by – and vulnerable to – the new digital technologies. We return to these distributional issues in Section 3.4.

An economic perspective on industrial sectors

The question of how the digital revolution will work its way through the global economy and just how it will affect developing countries can only be answered by looking at sectoral specificities. The actual application of innovations in individual industrial sectors is the relevant transmission mechanism. In Section 2, it was shown that two-thirds of currently used robots are accounted for by the automotive and the electrical/electronics industries. Within a 10-year time horizon, these are also the sectors that are widely expected to lead the future adoption of robotic technologies, together with the machinery sector in general (see Figure 4).

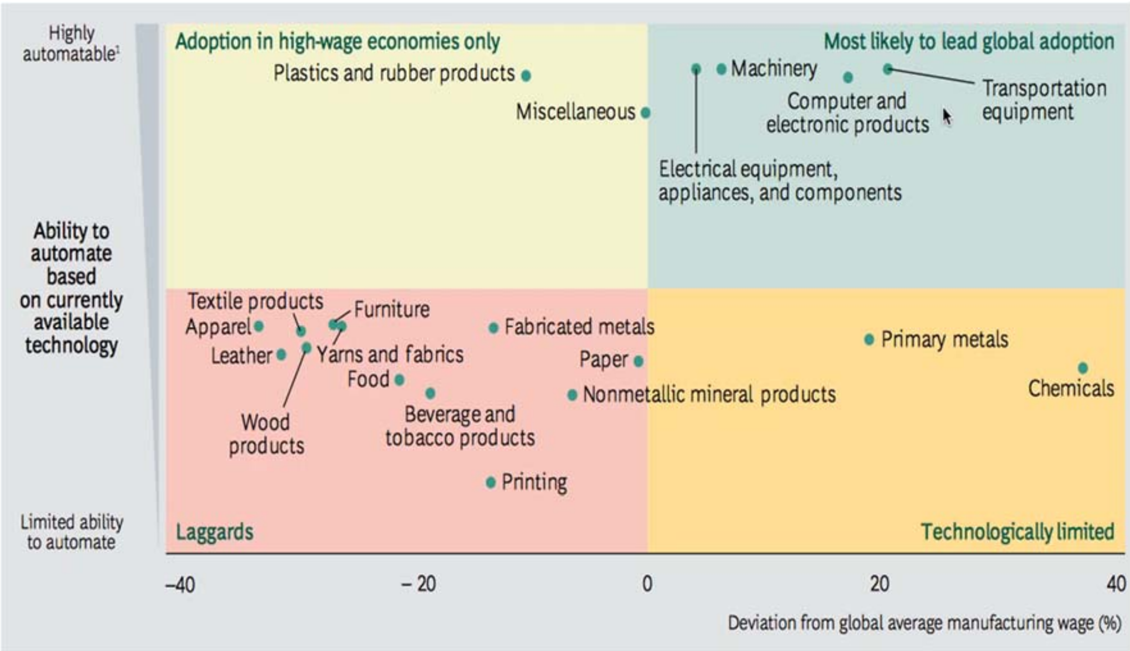
19 The review of studies is not comprehensive and does not consider many available industry surveys based on interviews (see e.g. World Economic Forum, 2016). A synoptic overview of the results of key studies is provided in Annex Table A1.

20 For Germany, a study based on a mix of company surveys and structural economic models concludes that, between 2011 and 2016, there was a positive net employment effect of 0.18 per cent annually resulting from the introduction of new digital technologies (Arntz et al., 2018).

This projection is based on two criteria that, taken together, determine the elasticity of substituting machines for human labour: the ease of the possible automation of production activities (plotted on the horizontal axis) and the cost-effectiveness of introducing new digital technologies (measured in terms of wage-level deviations from the global average, plotted on the horizontal axis). In these sectors, which represent most industrial activities that are accounted for under Standard International Trade Classification 7, it is estimated that at least 85 per cent of current tasks carried out by workers can be automated, as they involve repetitive tasks performed on rigid materials (BCG, 2016, p. 18).

The sectors least likely to become automated soon, inter alia include textiles, apparel and leather, that is, precisely those that are typically found in the early stages of industrialisation. It is these sectors that are both difficult to automate (soft materials are notoriously challenging for handling by robots) and characterised by comparatively low wage levels. However, enhanced machine vision systems and robots' capabilities to move and manipulate various materials are among the priority target areas in automation research and may soon call for a reassessment of automation potentials in these sectors.

Figure 4: Automatability and wages, by industrial sector



Source: BCG (2016 p. 17)

From this analysis, it broadly follows that medium- and high-income countries with more sophisticated, high-technology industrial structures will be most affected by the job displacement effects of the digital revolution, whereas low-income countries with rudimentary industrial structures would see less automation in the near future. According to a recent expert survey, specifically Latin America is expected (without explicitly stated reasons) to be among those regions that are likely to fall behind (Oxford Martin School & citi GPS, 2016, p. 28). However, this does not consider potential productivity gains and the resulting growth and employment prospects (see also Section 5).

This raises an intriguing quandary: What indeed is the meaning and significance of "falling behind", of experiencing "gains and losses" in this technology-driven competition? Should low-income countries be satisfied for the time being to be largely bypassed by the digital revolution? Will this enable them to maintain employment in some manufacturing industries, at least in the short to medium terms? Or should they be worried about remaining confined to low-wage industries, which will stifle their aspirations to upgrade and diversify their industrial structures? If indeed textiles and clothing industries enjoy a digital breathing space,[21] then, for instance, Lin's speculative scenario of these industries relocating from China to African countries may indeed materialise.[22] The questions then are how much time could effectively be bought by this redeployment and if the "winners" will be those countries that can stem the digital tide and delay the onslaught of robotics and automation or if there is an early-adopter premium in this technological race.

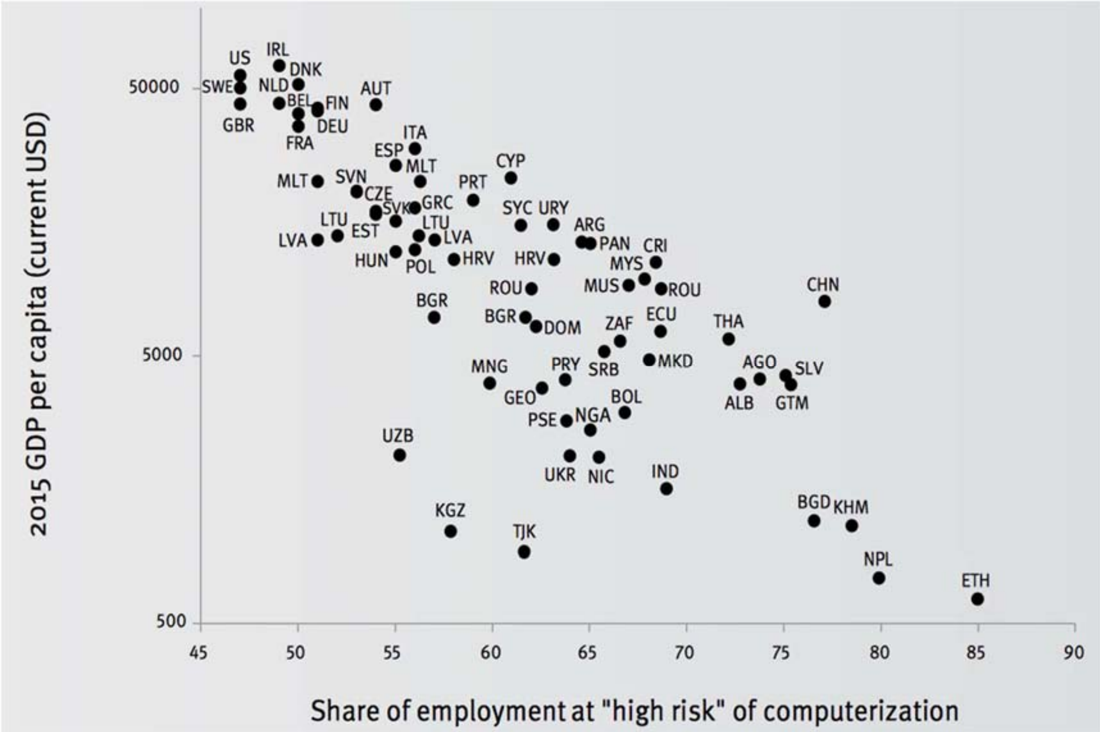
Cross-country comparison

The previous section touched upon the issue of how the impacts of digital technologies are likely to vary for countries at different levels of income per capita and in different stages of the industrialisation process. As underlined before, analysing this question in terms of the technological automation risks (automatability) is exceedingly sensitive to the methodology applied and the specific assumptions made in terms of occupation and task typologies. In Figures 5 and 6, the results of two recent studies are juxtaposed. As can be seen, they lead to *diametrically opposed* conclusions: In the first scenario (Berger & Frey, 2017), the correlation between jobs at risk and income levels is negative; in the second scenario (Hallward-Driemeier & Nayyar, 2018), it is positive.

21 "Textiles and apparel is […] the only highly traded subsector not expected to have disruption from automation in the near future" (Hallward-Driemeier & Nayyar, 2018, p. 137).

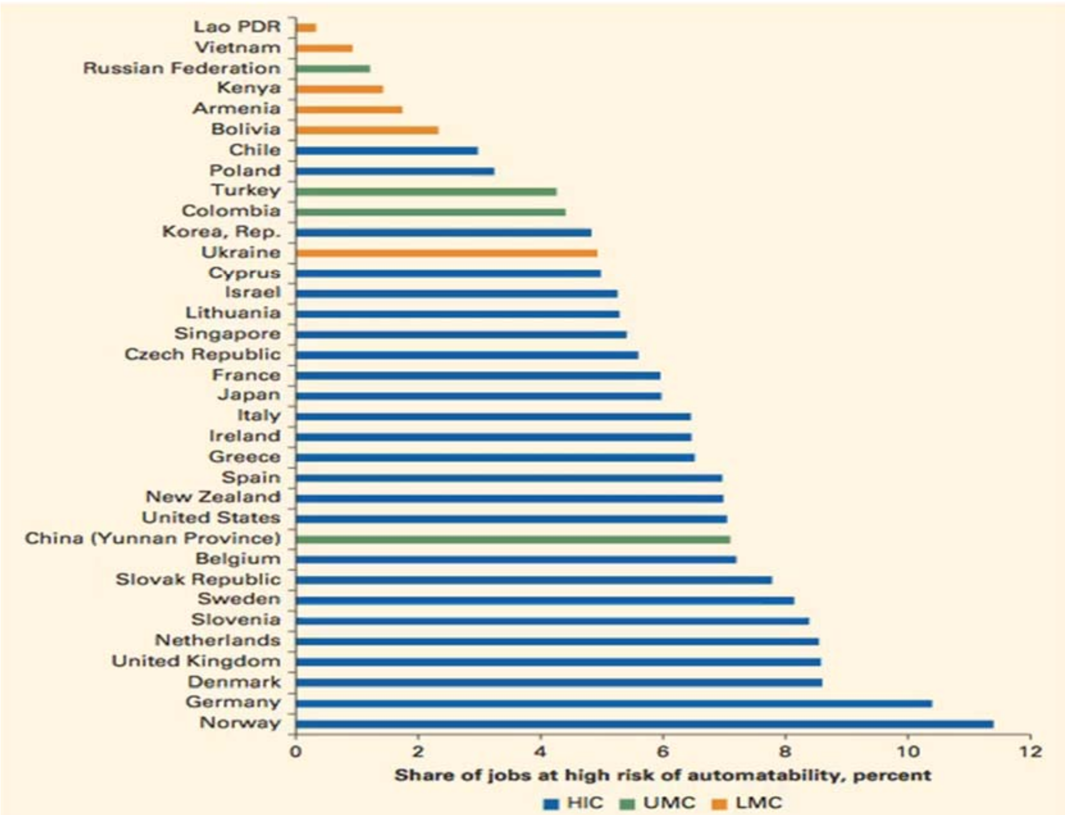
22 "Let's assume that as a result of rising wages, 1 per cent of China's production of apparel is shifted to lower-wage African countries. All things equal, that alone would boost African production and exports of apparel by 47 per cent. A 5 per cent shift of Chinese export-related investments in the industry could translate into $5.4 billion in additional exports – a 233 per cent increase" (Lin 2011, p. 30).

Figure 5: Jobs at high risk of automation, by country – scenario 1



Source: Berger and Frey (2017, p. 21)

Figure 6: Jobs at high risk of automation, by country – scenario 2



Source: Hallward-Driemeier and Nayyar (2018, p. 135)

In comparison, the McKinsey Global Institute (2017, p. 48) study yields less pronounced inter-country differences with predicted automation potentials of 46 per cent for the United States, 51 per cent for the five largest European economies (France, Germany, Italy, Spain, the United Kingdom), 51 per cent for China, 52 per cent for India and 56 per cent for Japan.

How can these significant deviations possibly be explained and reconciled? Without access to detailed information on the fine print of the methodologies applied, the following explanatory elements seem to be pertinent.[23] As mentioned above, the Berger and Frey approach considers the automatability of entire occupations based on expert judgement and generally arrives at relatively high shares of jobs at risk. These occupational profiles are then transposed and applied to other countries by way of correspondence schemes, that is, they are adjusted to the distribution of occupations in the country concerned. To take just one pertinent example, this rather mechanistic approach must assume that the task profile of an accountant in Germany is comparable to that of an accountant in Ethiopia. However, many jobs in low-income countries are typically characterised by a low degree of standardisation. In the specific example chosen, it must be presumed that the tasks performed by an accountant in Ethiopia are more interactive and situation-specific and less codified than those of a German accountant. In addition, it is likely that the dominance of the informal sector in developing countries (which is not reflected in official employment data and difficult to capture in the OECD-based PIAAC[24] survey) is not adequately factored in.

It would thus seem that the *positive* correlation between automation risks and income levels (based on a task methodology similar to that applied in Arntz et al., 2016) commands greater plausibility than a negative correlation. However, given its obvious importance, this is an area that calls for further research to shed light on the complex country-level relationships between current technology use in different economic sectors, automatability of jobs and tasks, and prevailing education and skill levels.

When factoring in the economic viability of automation, that is, the cost-effectiveness of replacing human labour with machines, it can be expected that the incipient labour-intensive stages of industrialisation will not be seriously affected in the short term (UNCTAD, 2017a). In other words: The relatively low labour costs widen the "gap between the probability that a job **could** be automated and the probability that a job **will** be automated" (International Labour Organization, 2017, p. 2; emphasis in original). Automation pressures rise, however, with higher levels of technological sophistication and industrial diversification and the related higher labour costs.

This points in the direction of a closing window for future latecomer industrialisation, in particular for countries already facing a middle-income trap (Ohno, 2009) in their upgrading efforts. More specifically concerning the emerging employment scenario, "manufacturing will likely continue to deliver on productivity, scale, trade, and innovation, but just not with the same number of jobs" (Hallward-Driemeier & Nayyar, 2018, p. 139). In light of the massive pressure to create new jobs for growing populations – and particularly for youth entering the labour market – this is bad news for policy-makers and political stability alike.

23 I am grateful to Ulrich Zierahn of the Center for European Economic Research (ZEW) for sharing some relevant reflections in a personal communication.

24 PIAAC is an adult skills survey (PIAAC = Programme for the International Assessment of Adult Competencies) carried out by the OECD and currently covering some 40 countries.

Elections are not won on promising scale and innovation but on offering credible prospects of actually delivering employment opportunities.

3.3 Impact on global value chains

The sectors identified in the previous section as being particularly highly exposed to automation risks (transport equipment, electronics, electrical machinery, etc.) are also those strongly represented in GVCs, that is, in the decentralised production networks of transnational corporations by which economic globalisation is being pushed through the world economy. More than half of the trade in goods and almost three-quarters of trade in services are generated by intermediate inputs, that is, products not intended for final consumers but that serve as inputs for further processing. As such intermediates often embody foreign technology that is superior to what is available in the importing country, they are also considered a significant source of productivity increases (Miroudot, Lanz, & Ragoussis, 2009).

Traditionally, GVCs were seen as conduits for the fragmentation of production processes, the optimisation of cost structures and the outsourcing of labour-intensive, low-skill operations to developing countries, where, in turn, latecomer industrialisation was fuelled, new employment created and skill-upgrading triggered. In overall terms, this process of intensifying cross-country production networks saw rapid and stable growth in the final decades of the 20th century driven by new means of transport (from air cargo to container shipment) and the spread of new communication technologies. However, along with decreasing trade growth in general, the dynamics of GVC growth were negatively affected by the 2008 financial crisis (even disproportionately strongly) and, coming as a surprise to many observers, there has not been a recovery in recent years (World Bank et al., 2017).

The critical question in the context of the digital revolution is thus whether or not the outsourcing process may come to a halt or even be reversed, that is, whether there will be a tendency for outsourced operations to be "backshored"[25] to their original home countries. In the past, bringing production back to home markets in industrialised countries was often induced by quality and delivery issues in production, or by dissatisfaction with the host country's regulatory environment or, more specifically, its intellectual property practices. Backshoring caused by disruptive digital technologies is a more recent phenomenon that can capitalise both on changing cost structures and on new flexibilities based on customised batch production at scale. However, so far documentation of this emerging trend remains rich on anecdotal evidence and non-representative surveys while being poor on serious studies (de Backer, Menoni, Desnoyers-Jamesi, & Moussiegti, 2016). It is fair to state that this question has remained greatly under-researched to date (for a literature review, see Stentoft, Olhager, Heikkilä, & Thoms, 2016). [26]

Currently, the potential impact of additive manufacturing on GVCs is receiving the greatest attention. As mentioned above, the trade-disruption potential of AM is anticipated to reach

25 The terms "backshoring" and "reshoring" are used here as synonyms.

26 A study conducted by the Global Supply Chain Benchmark Consortium (2016) concludes that in the case of the United States, the recent increase in manufacturing operations is mainly due to offshoring from European and Asian firms rather than being caused by a reshoring of operations on the part of US firms.

a considerable level of 5-15 per cent of global trade. Although hard to predict, expert opinion seems to converge around a medium-term scenario in which progress in this technological domain would pose a serious danger for many developing-country investment locations. It all hinges on how fast AM will move from its current focus on prototyping and product development towards the decentralised batch production of final goods from multiple materials. Only then would offshore assembly operations be seriously jeopardised. In such a scenario, which today remains highly speculative, "trade will increasingly consist of the international transfer of immaterial data (designs, blueprints, software etc.)" (OECD, 2017b, p. 22). In turn, this depends critically on the speed at which 3D printing prices will continue to fall. So far, patent expirations have led to falling printer prices by a factor of 40 in the period from 2009 to 2014 (European Commission, 2017b). Moreover, the rapidly rising speed of printing and the increasing energy-efficiency levels of bonding processes are also contributing to decreasing unit printing prices.

In the final analysis, GVCs would possibly not lose importance but rather change their profiles: Transnational corporations would continue to run decentralised subsidiary operations in many countries, but these would be less active in manufacturing and more focussed on the distribution of goods and services in close proximity to final demand. In business circles, it is anticipated that the new digital opportunities for flexible, customised batch production will put a premium on both direct interaction with customers and reduced time to market. This would imply a new role for many developing countries that probably would further marginalise low-income countries with small domestic markets.

In the context of the increasing service content of manufacturing (see Section 3.1), and hence the gradual replacement of traded goods with trade (i.e. transmission) of data, it is noteworthy that, in general, the domestic value added (local content) is significantly higher for traded services than for traded manufactured goods. For example, in the case of the emerging Asian economies, the local content shares account for 82 per cent for traded services, compared to 65 per cent for trade manufactures (Oxford Martin School & citi GPS, 2016, p. 12). From an employment perspective, the servicification of manufacturing may thus at least partly offer additional opportunities for job creation, which may offset some of the losses in more conventional industrial GVCs. Along somewhat more speculative lines, one could even envisage significant prospects for "virtual offshoring" as a new dimension of globalisation, with telepresence making it "possible for developing nation professionals to work inside G7 offices and universities without actually being there" (Baldwin, 2016, p. 298).

In conclusion, there is an undeniable possibility (and even a significant likelihood) that the latest generation of digital technologies may, to some extent, undo the expansion of GVCs, which, ironically, was made possible by earlier progress in digital communication technologies. The jury is still out, and systematic studies at both the corporate and sectoral levels are urgently required to move from conjectures to hard evidence.[27] Importantly, such studies must go beyond specific business cases in which a backshoring of production actually took place. It is equally – if not more – important to gauge the magnitude of new investments that are undertaken in company home markets *in lieu of* opting for outsourcing

27 Also the most recent in-depth analysis undertaken by UNCTAD results in ambivalent findings regarding the impact of digitalisation on the future of global value chains. However, it draws attention to an important policy aspect, which is the risk of digitalised value chains outstripping the regulatory capacities of governments (UNCTAD, 2017b, ch. IV.B).

alternatives. The few systematic studies available (in particular de Backer, DeStefano, Menoni, & Ran Sun, 2018) suggest that indeed the scope and speed of offshoring production from developed to developing countries are being reduced by robotics (a phenomenon referred to as "botsourcing"), whereas there is only scant anecdotal evidence of actual backshoring taking place.

3.4 Impact on income distribution and skills

As already observed above (see Section 3.2), the projections about the impacts of digital technologies on future employment levels are highly sensitive to the methodology applied and specific assumptions made in the various available studies. Accordingly, the results fall within a range of roughly 10-60 per cent of jobs considered at risk of being automated in the next two decades, coupled with widely varying assessments of the volume of new jobs likely to be created due to productivity enhancements and demand for innovative goods.

At the same time, there is widespread agreement about the negative consequences of digitalisation on the distributional pattern of future employment. There is a robust trend for the share of labour in GDP to fall across all major economies: Specifically in the case of high-income countries, the labour share decreased by approximately 12 percentage points from 1995 to 2012 (World Bank, 2016, chap. 2), which was significantly linked to the growing use of automation for routine activities. Against this backdrop, the World Bank concludes that "perhaps the biggest risk from technological change […] is that of widening income inequality" (World Bank, 2016, p. 118).

In the context of rising inequality, the rapid expansion of new forms of a "platform economy" (Uber, AirBnB, Deliveroo, etc.) deserves special attention. The combined result of rapid technological innovation and powerful networking effects has been the capturing of large market shares by new "superstar firms". It is these firms, in particular, that promote a "fissuring of the workplace" (Autor, Dorn, Katz, Patterson, & van Reenen, 2017, p. 26) through business models relying on bogus self-employment (outsourcing of activities to poorly paid freelancers and contractors) or, put differently, on a new breed of the "precariat" (Standing, 2011). Ironically, the new platform economy introduces a new informality into economies that have long been characterised by the formalisation of labour markets, be it in terms of collectively negotiated wage levels, strictly regulated working hours, conditions of work or various forms of non-wage entitlements.

Regarding the issue of the skill content of employment,[28] early studies for the United Kingdom have established that, at both ends of the skill and wage spectrum, there is a preponderance of non-routine jobs (simple manual jobs at low wages and cognitive, creative jobs at high wages), with most of the routine jobs to be found in the middle of the wage spectrum. By and large, with its emphasis on replacing codifiable, highly structured skills, digital technological change would thus hollow out this middle ground and result in a job structure in which both "lousy and lovely jobs" (Goos & Manning, 2007) would tend to

28 There are further aspects of job quality, such as safety, workers' health, working time and organisation of work, which are as yet difficult to assess and not considered in this discussion paper (BSR [Business for Social Responsibility], 2015; IBA Global Employment Institute, 2017).

survive within a "high-tech, high-touch economy"[29] that puts a premium on jobs relying on interpersonal, creative and social skills.

The trend towards a polarised labour market caused by routine-biased technological change has been confirmed by several, more recent studies, also for Japan and the EU countries (Goos, Manning, & Salomons, 2014; Graetz & Michaels, 2015; OECD, 2016b). This trend seems to hold at least for the incipient stages of digitalisation, which can be characterised as a period of harvesting low-hanging automation fruits. For the longer term, it needs to be factored in that a large portion of middle-skill jobs depend on the blending of different tasks that cannot easily be unbundled and are more likely to call for human–machine interaction in the future, that is, "employment polarization will **not** continue indefinitely" (Autor, 2015, p. 26; emphasis in original).

Generally it can be observed that, despite the overall trend towards the hollowing out of the middle-skill labour-market segment, there are declining risks of job losses with rising education levels and income levels (Arntz et al., 2016, p. 20). In a somewhat stylised perspective, new digital technologies are likely to *replace* more of the low-skill activities and *complement* more of the high-skill activities, thus leading to further productivity increases in the latter category (Lawrence, Roberts, & King, 2017, p. 29). This tendency signals the existence of a race between technology and education in which a premium is placed on creative, non-routine work requiring higher skill levels. (Some of the ensuing policy implications are addressed in Section 4.)

Concerning the situation in developing countries, the evidence on technology-induced job polarisation is less clear (World Bank, 2016). To begin with, in countries with relatively low levels of per capita income, the formal labour market tends to be exceedingly small. The dominant informal sector, with its functional emphasis on petty trade, handicraft and micro-entrepreneurship, and its sectoral emphasis on simple agricultural processing activities does not lend itself easily to automation. Moreover, many of the assembly operations that have been offshored to developing economies in the past require skill levels that, on average, are higher than those for domestic activities in the informal sector, from which much of the labour force is being recruited. In economies that are characterised by the phenomenon of a "missing middle" (Altenburg & Lütkenhorst, 2015, pp. 72-77), the hollowing out of labour markets is almost a contradiction in terms. However, this raises the question about what will happen with the many workers with weak skill endowments "who will not be writing code and programming robot routines anytime soon, but who will not inherit unskilled jobs either" (Maloney & Molina, 2016, p. 13). [30]

The ASEAN countries are a case in point. In the past, they represented the quintessential example of the "flying geese" pattern of productive foreign investments moving from higher- to lower-wage locations, for instance from Malaysia successively to Thailand, Indonesia, Vietnam and Cambodia. Today, according to an extensive ILO survey, in many ASEAN countries up to 60 per cent of salaried workers in automotive and

29 This term was coined by Turner (2014) and refers to the future growth in creative jobs using new technologies as well as jobs dependent on direct human interaction in a "world of robots and apps, but also of fashion, design, land, and face-to-face services".

30 The question can be raised if – in response to diverging labour costs – some jobs may be automated in industrialised countries and remain intact in low-income environments, with the resulting effect of rising international productivity gaps.

electrical/electronics industries occupy jobs at high risk of automation. Moreover, given that significant shares of these jobs are performed by migrant workers (e.g. in the electrical and electronics industries in Malaysia and Thailand) the resultant loss of remittances will lead to shrinking family incomes and rising inequality, also in the home countries affected (Chang, Rynhart, & Huynh, 2016).

Looking at the firm-size spectrum, it cannot come as a surprise that, in general, SMEs lag behind larger enterprises in adopting new digital technologies. There is evidence from the EU countries pointing to significant gaps (see also Figure 2 above). Only some 15 per cent of small enterprises employ ICT specialists, whereas the same share is higher than 40 per cent for medium enterprises and around 75 per cent for large enterprises. Similar figures apply for the use of cloud services and big data facilities, whereas the sharing of electronic supply chain management data takes place in only 16 per cent of SMEs, compared to 29 per cent in large enterprises (European Commission, 2017a).

The likely result is a widening productivity gap that will put smaller enterprises at a competitive disadvantage and, in view of their generally higher employment intensity, jeopardise future jobs – not because of their automation but due to the lack or slow introduction of digital technologies and business practices. The reasons are manifold and include information deficits, lack of confidence in unknown technologies, insufficient skills and financial resource constraints. In many countries, particularly more advanced ones, dedicated SME support programmes are thus in place to speed up the adoption of digital technologies among the more traditional smaller enterprises (see Section 4).

Finally, most recent OECD research supports the existence of a U-shaped relationship between the risk of digitalisation and age, that is, "the highest automatability is found among jobs held by youth" (Nedelkoska & Quintini, 2018, p. 115), which would call for enhanced policy attention to the risks of youth unemployment, in addition to the present focus on the flexibilisation of retirement modalities.

3.5 Impact on resource-efficiency

The impact of digitalisation on environmental sustainability goals, specifically on energy and natural resource efficiency, is a new field of research that has not yet moved beyond some exploratory exercises and a number of industry case studies. A first overview of what can be expected to happen at the intersection of digital technologies, renewable energy systems and energy efficiency in manufacturing can be found in United Nations Industrial Development Organization (UNIDO, 2017b). This is to be seen against the fundamental challenge of promoting a decoupling of resource consumption from economic growth, at least in relative terms (decreasing resource intensity) or ideally in absolute terms (decreasing resource use).

Interestingly, the digitalisation challenge and the challenge of transiting towards a sustainable energy system – or, to use the internationally well-established German terminology: "*Industrie 4.0*" and "*Energiewende*" – share a number of common characteristics. Both are transformative in nature, defy the status quo and have to fight against powerful vested interests; both require huge investments by private companies into a range of new technologies and by public authorities into supporting infrastructure; both are faced with high levels of uncertainty regarding the long-term implications for future competitiveness; and both are faced with steep technological learning curves as well as the need to scale up innovations and create entirely new markets.

Also, both fields of innovation are intrinsically interconnected. Digital technologies can play an important role in managing renewable energy systems, and thus facilitate the transformation towards sustainability. Smart grids depend critically on the two-way connectivity of decentralised energy generation and consumption through real-time monitoring and control of supply and demand. In the emerging reality of increasingly distributed energy generation, the concept of "virtual power plants" assumes special significance. Simply put, they connect a variety of energy sources, energy storage systems and energy load scenarios into a virtual market, allowing for a cloud-based simulation of possible contracts and their implications (UNIDO, 2017b, p. 27).

Also, the time-sensitive and price-sensitive feed-in of, for example, solar and wind power into the electricity grid requires sophisticated digital control units with a view to contributing to grid stability. For many leading players in the renewable energy market, digital control components have become a crucial element in staying competitive. In very practical terms, they represent one of numerous examples of how the capabilities of physical goods (wind turbines or solar PV systems) depend on progress in data management. The International Energy Agency estimates that, in the EU, digital technology-enabled improvements in energy storage and demand management could "reduce curtailment of solar photovoltaics (PV) and wind power from 7 per cent to 1.6 per cent in 2040, avoiding 30 million tonnes of carbon dioxide emissions" (IEA [International Energy Agency], 2017, p. 18).

In general, the many possible applications of digital technologies aimed at increasing energy-efficiency are just beginning to be explored. An illustrative example taken from the sphere of information technology itself proves the point (McAfee & Brynjolfsson, 2017). Like all the technology giants, Google's operations depend on stable back-up from huge, energy-intensive data centres to power and cool myriads of servers under conditions of highly fluctuating demand. By involving DeepMind (a British artificial intelligence company), the challenge of cutting down the levels of energy consumption was subjected to machine learning based on available historical records (working load, operating hours, temperature, humidity, etc.), which served as inputs into neural data networks.

> They treated the data centre like a giant video game and instructed their algorithms to try to get a higher score, which in this case meant better energy efficiency. When control of an actual data centre was turned over to these systems, the results were immediate and dramatic. The total amount of energy used for cooling fell by as much as 40 per cent. (McAfee & Brynjolfsson, 2017, p. 78)

The above example vividly demonstrates the power of AI-based simulations (see also Figure 1) for machine learning, which can render industrial systems increasingly autonomous. The same applies to industrial robots, which are programmed to optimise their movements and speed within a set of rules geared towards saving energy, an area that has been explored in an EU research project (AREUS) together with General Motors, Daimler and KUKA as industry partners. Here again, achievable efficiency gains reach an order of 30-50 per cent. The increasing use of such optimisation algorithms is applicable not only to production robots but also to automated guided vehicles, conveyer systems and press lines (Lennartson & Bengtsson, 2016). In general, being able to draw on machine-specific real-time data of energy consumption (facilitated by the Internet of Things) opens up a new space for efficiency gains, inter alia through improved energy flows that can reduce machine downtime[31] (Shrouf & Miragliotta, 2015).

An extensive survey carried out among more than 200 medium and large manufacturing companies in China and Germany confirms the high expectations regarding efficiency potentials resulting from the future digitalisation of production processes. This assumes special significance, as both countries are characterised by playing a continued important role in industrial production and, by international comparison, both display atypically high shares of manufacturing in GDP.[32] Chinese companies, in particular, anticipate significant reductions in energy consumption (84 per cent of respondents), and even more pronounced reductions for materials consumption (88 per cent of respondents) based on digitalisation (Beier, Niehoff, Ziems, & Xue, 2017). However, the extent to which these will ultimately translate into lasting resource savings, will critically depend on the incidence of rebound effects.

Outside the realm of energy systems, additive manufacturing is the area that has received the most attention as a potential source of enhanced resource efficiency. In the public domain, overly optimistic assessments are the rule, and crude scenarios and fallacies abound. However, a great deal of caution and quite a number of qualifications are called for. The environmental implications of AM are manifold and, when seen in the broader perspective of life cycle assessments of related production processes, can be both positive and negative. Above all, they depend on the materials used and whether single or multiple materials are applied, with complex recyclability challenges appearing in the latter case. Moreover, there are considerable resource demands in both the pre-production stage (composing and preparation of materials) and the post-production stage (treatment/cleaning of 3D printer components). The latter alone – often relying on electrical discharge machining techniques – can run up to 25 per cent of total energy consumption in AM production (Kellens, Mertens, Paraskevas, Dewulf, & Duflou, 2017, p. 585).

There is no doubt that the *potential* environmental benefits from AM are impressive. They range from customised product functionalities (make-to-order manufacturing) to improved product durability; easier maintenance and replacement of broken parts (thus reducing obsolescence and waste); reduction of product weight; lower transport requirements; the possible replacement of plastics by other, more bio-friendly materials; and many more benefits (for a comprehensive overview, see Ford & Despeisse, 2016).

Even assuming that AM will progress fast and be mainstreamed beyond niche production by entrepreneurial start-ups,[33] in the ultimate analysis, "in terms of global resource depletion, 3D printing is unlikely to make significant changes even in the long term" (OECD, 2017a, p. 189). To what extent explicit environmental goals will be built into company strategies,

31 It is noteworthy that up to 30 per cent of energy consumption by machine tools is accounted for by stand-by modes.

32 In 2015, Germany's share was 20.6 per cent, compared to 13.8 per cent for all industrialised economies, while China's share stood at 32.2 per cent, compared to 20.4 per cent for all developing and emerging economies (UNIDO, 2017).

33 There are many examples of big industrial players, such as General Electric, Rolls Royce and Siemens, building up AM capabilities through partnerships and acquisitions as part of their long-term competitiveness strategies (Ford & Despeisse, 2016).

depends critically on the legal and regulatory framework, the financial incentives offered (from taxes to dedicated loans) and the standards adopted. The future sustainability dividend of AM is "not a foregone conclusion […] Since the industry is at a crossroads, well-placed incentives today might establish beneficial technologies for decades to come" (OECD, 2017a, pp. 205 and 207).

4 Policy responses: what can be done

The reference to "well-placed incentives" at the end of Section 3 immediately connects to the more general issue of industrial policy interventions. What role can industrial policy play in the digital transformation of our economies and societies? How can the digital revolution be shaped in such a way that desired impacts (related to productivity and innovation, new jobs, resource efficiency) are reinforced while negative consequences (related to inequality, technological unemployment) are curbed? Section 4 addresses some of these issues.

Section 4.1 is more descriptive in nature and reviews country-specific digitalisation initiatives, with particular emphasis being placed on the influential German "Industrie 4.0" strategy, moving on to other country cases selected and finally summarising efforts undertaken at the European Union level to coordinate and harmonise national approaches. Section 4.2 starts out by highlighting the renewed strong role of technology foresight approaches as a methodological foundation for policy design. It then proceeds to discussing the implications of digitalisation for both the conceptualisation and specific contents of industrial policy.

4.1 Current policy practice

4.1.1 Germany: concept and architecture of "Industrie 4.0"

German industry: a snapshot

The international discourse and national strategies around the digital industrial transformation have been greatly influenced and shaped by the German concept of "*Industrie 4.0*". In quite a number of countries, the concept was literally translated into "*industry 4.0*", whereas in other cases it has morphed into different labels with similar contents (see Section 4.1.2 below). In a way, this parallels the widespread dissemination of the German "*Energiewende*" approach, which has inspired many other national processes of energy transition.

From many angles, the German economy is an interesting case to consider in terms of digitalisation. Some of its key characteristics are worth recalling at the outset (data taken from UNIDO, 2017a; 2017c):

- To date, Germany has one of the highest MVA to GDP ratios worldwide: At 20.6 per cent (2015 data), it compares to 13.8 per cent for all industrialised economies and 13.9 per cent for all EU countries, respectively. Among the larger industrialised and industrialising countries, only China (32.2 per cent) and South Korea (29.3 per cent) report significantly higher ratios. Also, in terms of MVA per capita, Germany ranks fourth globally.

- The country's manufacturing industry has consistently been rated as the most competitive, based on UNIDO's Competitive Industrial Performance Index. It is highly successful in foreign markets, with a strong concentration on medium- and high-tech products, accounting for close to three-quarters (73 per cent) of all manufactured exports.
- Small and, in particular, medium-sized enterprises play a critically important role in industrial production and exports. At the same time, they are the source of more than 80 per cent of apprenticeships.
- The density of industrial robots in Germany is significantly higher than in most other industrialised countries, with the exception of some countries in East Asia. With 7.6 robots per industrial worker (2015), the ratio surpassed that of all EU countries (2.7) and the United States (1.6) by a factor of three to four. In addition, together with Japan, Germany is the leading producer and exporter of industrial robots (Dauth, Findeisen, Südekum, & Wößner, 2017, p. 7).

Being among the world's largest industrial powerhouses with a long track record of engineering excellence in various machinery sectors, a continued high share of industrial employment rooted in both large corporations and specialised medium-sized family enterprises, and a strong involvement on both the demand and supply sides of robotics, the stakes for Germany are high: The country will either manage to ride the digital transformation wave or else risk falling behind and gradually lose its economic clout. No surprise then that the German government and business community have fully embraced the digitalisation of industry, with the dual aim of becoming both a lead supplier and a lead market for its application. Although this high level of ambition can capitalise on the advantages underlined above, in particular on industrial and engineering know-how in key technologies, there are also weaknesses to be reckoned with, such as Germany's lagging digital infrastructure (e.g. compared to Scandinavian countries, the United States and South Korea) and an entrepreneurial culture that is not encouraging and rewarding risk-taking.

Against the backdrop of deindustrialisation trends in most developed economies (and evidence of premature deindustrialisation in the developing world; see Section 3.1 above), the distinct challenge for Germany, thus, is to align digital leadership with positive prospects for its strong manufacturing base. This is to be seen in light of projections that anticipate a heavy adjustment burden, in particular for manufacturing industries: Recent studies by the German Institute for Employment Research (IAB) point to a gradual employment shift from manufacturing to services, with robotics being responsible for a loss of 275,000 *industrial* jobs in the 1994-2014 period (Dauth et al., 2017). Although a scenario for 2015 predicts a rather limited *overall* loss of 30,000 jobs, this would go along with a significant labour-market turbulence of 7 per cent, implying 1.5 million existing jobs being eliminated and 1.5 million new jobs being created (Wolter et al., 2016).

Evolution of Industrie 4.0

Following its popularisation at the 2011 Hanover Fair, the birth of "Industrie 4.0" as a distinct and widely accepted concept dates back to the year 2012. In this year, the government's earlier High-Tech Strategy 2020 (initially launched in 2006 and updated in 2010) was complemented by an Action Plan comprising 10 long-term Future Projects, of which "Industrie 4.0" was one.[34] A dedicated working group led by acatech (National Academy of Science and Engineering) was established, which published its final report in April 2013.

Apart from putting forward a set of recommendations for action in fields such as standardisation, security, work organisation and regulatory frameworks, the report was crucial for defining the German "brand" of Industrie 4.0. The latter's characteristic feature is a pronounced emphasis on the key role assigned to "cyber-physical systems". Based on the Internet of Things, cyber-physical systems are seen as the next evolutionary step in moving from embedded systems (digitalised machinery) to fully networked, shared communication systems, both within manufacturing itself ("smart factory") and between machines, products and customers. From this perspective, the innovative digital production technologies are creating an industrial reality in which the material world of physical machinery is closely intertwined with the virtual world of electronic information flows, that is, a system in which intelligent objects are "talking to each other".

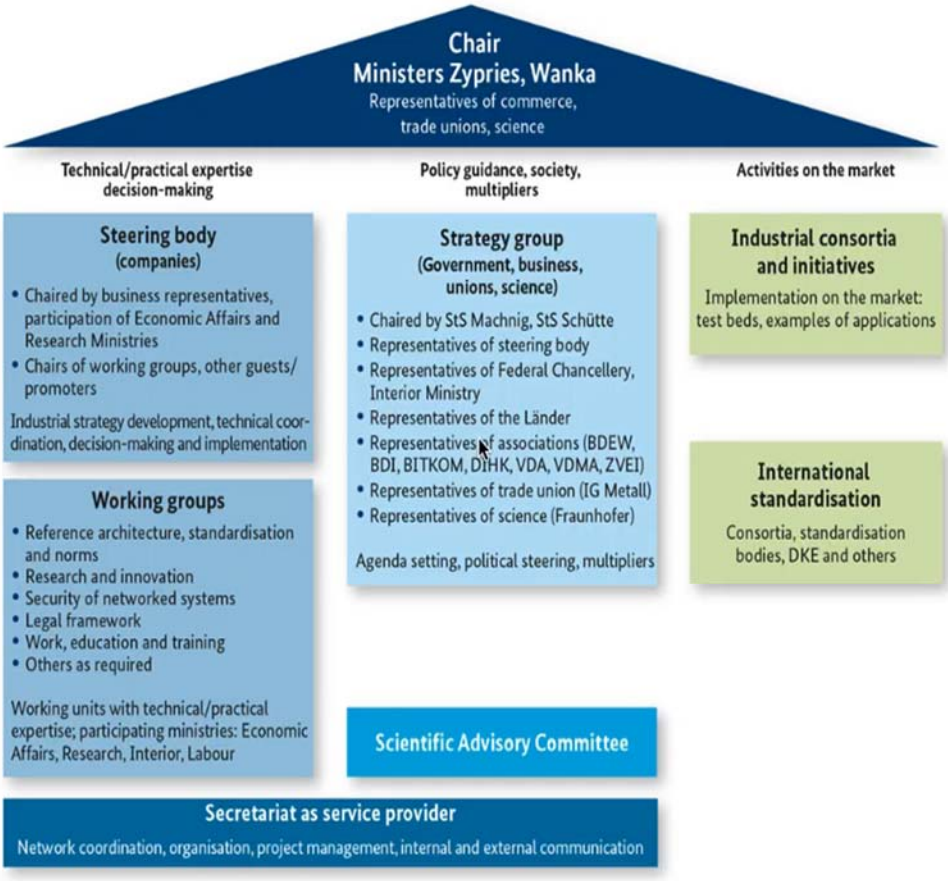
Specifically, the acatech report calls for the implementation of "horizontal integration through value networks, end-to-end digital integration of engineering across the entire value chain (and) vertical integration and networked manufacturing systems" (acatech, 2013, p. 10). The report's approach also tallies with the general assessment among industrialists and researchers, of which 64 per cent consider automation technology as the top driver for making Germany more competitive as an industrial location (Statista.de, 2017). This focus on optimising integrated manufacturing systems may seem self-evident. However, it is not – as we see in Section 4.1.2 when looking at different approaches being pursued in other countries.

The institutional architecture of Germany's Industrie 4.0 landscape comprises the country's leading business and research organisations as well as the majority of large corporations active in digital technologies. Orchestrated jointly by the Federal Ministry for Economic Affairs and Energy, and the Federal Ministry of Education and Research, the central instrument for collaboration is the Industrie 4.0 Platform (see Box 1), which unites all major public and private stakeholders under one roof. Its overall aim is more strategic than operational, with a focus on agreed recommendations rather than joint action.

34 Among the other nine future projects, four relate to transforming the energy sector (from climate-adapted cities to sustainable mobility), another three to various aspects of public health and well-being, and the remaining two to internet services and security (Federal Government of Germany, 2014).

Box 1: Germany's Industrie 4.0 Platform

The Platform was initiated in April 2013 on the basis of a cooperation agreement between three business organisations that, together, have more than 6,000 member companies: BITKOM (Federal Association for Information Technology, Telecommunications and New Media), VDMA (German Engineering Federation) and ZVEI (Electrical and Electronic Manufacturers' Association). In 2015 it was significantly expanded, and in 2016 it comprised a total of 140 members (84 companies, 32 universities and specialised research institutes, 12 business membership organisations, 11 federal and state ministries and one trade union). The Platform has an elaborate organisational structure consisting of a steering body, a strategy group and several thematic working groups, as summarised in the chart below.



Importantly, the Platform's aims remain in the precompetitive stage and focus on identifying the key trends and developments in Industrie 4.0, forging a common understanding of the main challenges across all actors and formulating recommendations for a sound regulatory framework. In recent years, the Platform has also engaged in international partnerships, for example with the Industrial Internet Consortium (IIC) on interoperability of standards and with the Japanese Robot Revolution Initiative on standardisation requirements in the industrial Internet of Things.

Sources: German Federal Ministry for Economic Affairs (2018); Germany Trade & Invest (2014)

So far, the provision of financial and fiscal incentives promoting Industrie 4.0 research and investments has remained limited. In addition to the core budgets of key research and development (R&D) institutions, such as various specialised Fraunhofer Institutes, there is an apparent dearth of dedicated funding windows.[35] A notable exception is to be found in terms of incentivising SMEs to adopt innovative digital technologies. Under the theme “future of work” and with an overall duration from 2014 to 2020, projects are supported – with co-funding coming from the European Social Fund (ESF) – that meet the following criteria (BMBF [Bundesministerium für Bildung und Forschung], 2017, p. 2016):

- Technological and social innovations (e.g. related to new forms of labour or human–machine interaction) are implemented in tandem by companies with a maximum of 1,000 employees and an annual turnover not exceeding €100 million.
- The project has a maximum duration of three years and is geared towards initiating a lasting innovation process.
- The project brings together partners from the business community (companies and associations) and the research community, with the former representing the majority of partners.
- All partners agree to actively contribute to the dissemination of results beyond the partnership itself and to support accompanying monitoring and evaluation exercises.
- Although the financial support is in the nature of a grant, the business partners commit to a co-funding level of up to 50 per cent.

“Leading-edge” clusters

As a more general approach of identifying and supporting multi-stakeholder innovation initiatives, the German government’s “leading-edge” cluster programme represents a highly competitive funding modality: “In a total of three competitive rounds, an independent jury selected 15 Leading-Edge Clusters from more than 80 competition entries. These clusters receive funding of up to 40 million euros each over a period of five years” (BMBF, 2015, p. 6). As such, the programme is broadly similar to the approach taken under the EU’s Horizon 2020 framework programme. This also applies to its spread of recipients, which are broken down into 21 per cent for universities, 11 per cent for other research facilities, 33 per cent for large enterprises, 29 per cent for SMEs and 6 per cent for other entities (BMBF, 2015, p. 7). Among the 15 clusters selected for support, there are four in the domain of digitalisation (“cool silicon”, “microTEC Südwest”, “Software Cluster” and “it’s owl”), of which the last one appears to be the most advanced in terms of tangible results (for details, see Box 2).

35 This is true, notwithstanding the fact that, in the budgets of federal and state ministries and in those of major research institutions, there are obviously allocations for a variety of digitalisation-related themes. However, in the end, one does not see the forest for the trees, and the impression remains that the coordination of a myriad of facilities leaves much to be desired (a detailed overview is provided in Mattauch, 2017).

Box 2: Germany's leading-edge digitalisation cluster "it's OWL"
"It's OWL" (Intelligent Technical Systems OstWestfalenLippe) is the most advanced of Germany's leading-edge clusters aimed at promoting innovative digital technology solutions. Located in an economically dynamic region hosting more than 400 companies in mechanical engineering, electrical and electronic as well as automotive component industries, the cluster comprises 24 core companies (with an R&D investment/turnover ratio of 8.4 per cent and an export quota of 56 per cent), 6 universities and 18 research institutes as well as more than 100 associated companies. The participating companies are engaged in about 50 different innovation projects that seek to commercialise and take to the market new technologies that are being developed in a limited number of cross-sectional projects in which universities and research institutes are exploring new technical solutions. The five cross-sectional projects comprise: self-optimisation (Heinz Nixdorf Institute), Human–Machine Interaction (Research Institute for Cognition and Robotics), Intelligent Networking (University Ostwestfalen Lippe), Energy-efficiency (University Paderborn) and Systems Engineering (Fraunhofer IEM). The results are being made available to other manufacturing companies through transfer projects and disseminated outside the cluster by engineering firms. They are subsequently being integrated into new university and further education programmes. The cluster also implements a dedicated SME technology transfer programme. From 2014 to 2016, more than 70 projects made new technology solutions available to SMEs, 36 per cent of which had less than 50 employees. In 2017, an Engineering Collaboration Lab (E-Co Lab) was opened together with Fraunhofer IEM. Its testing services will be made accessible to SMEs also outside the cluster itself. "It's OWL" is now moving into its second phase in 2018. While continuing and deepening the portfolio of projects under implementation, two new directions are discernible. First, a deliberate attempt is being made to engage in international (initially European) partnerships. Supported by the German government's programme on the internationalisation of leading-edge clusters (covering 10 clusters in 2018 and providing up to €4 million per cluster over a maximum of five years), a cooperation agreement was signed with a Finish cluster (DIMECC) covering innovation research, technology transfer and academic exchange. Second, the initial focus on exploring new technological solutions is being broadened to also cover organisational and social innovations. With the strong involvement of employee representatives, human resource departments and trade unions, efforts are being undertaken to understand the long-term implications and increase the social acceptance of human–machine interaction.
Sources: Compiled from It's OWL (2016a, 2016b, 2017), and http://www.its-owl.com

The "It's OWL" cluster also hosts one of the demonstration facilities that is operated under the SmartFactory initiative (SmartFactory KL, 2017). Founded in 2005, this public–private partnership is a demonstration and research platform that provides a testbed for new digital technologies and control architectures aimed at benefitting SMEs through a de-risking of their investments. Importantly, the research and development support and consultancy offered in modular pilot plants are manufacturer-independent and, thus, essentially free of direct commercial interests. Plant equipment, components and control elements from various suppliers can be tested, integrated and further developed beyond prototypes. In 2016, SmartFactory was recognised by the Federal Ministry for Economic Affairs and Energy (BMWi) as a regional competence centre for "SME 4.0" in Kaiserslautern (serving the two federal states of Rhineland-Palatinate and Saarland). SmartFactory, in turn, receives research support from the German Research Center for Artificial Intelligence (DFKI), with an emphasis placed on automation, human-technology systems and digital production processes.

The leading-edge cluster programme is complemented by a national programme promoting research clusters of excellence that is managed by the German Research Foundation (DFG) and the German Council of Science and Humanities ("*Wissenschaftsrat*"). Some 40 clusters are financially supported, with an average annual amount of €6.5 million each. Among these, the excellence cluster on Integrative Production Technology for High-wage Countries (based at the Rheinisch-Westfälische Universität Aachen) addresses the technical and economic challenges of maintaining competitiveness in a high-wage context. In cooperation with the significant capacities of specialised Fraunhofer Institutes, 25 Rheinisch-Westfälische Universität Aachen professors conduct inter-disciplinary research, for instance on self-optimisation production technologies (Rheinisch-Westfälische Universität Aachen, 2015).

Future orientation

With a view to setting an agenda for future advances, the Industrie 4.0 Platform issued a 10-point Action Plan in mid-2017 with the following recommendations (German Federal Ministry for Economic Affairs and Energy, 2017):

- establishment of an Industry 4.0 SME transfer network (led by BMWi and the Federal Ministry of Education and Research (BMBF) and in cooperation with all stakeholders, existing SME support initiatives are to be brought under one roof);
- addressing new themes (e.g. resource efficiency and sustainability of digitalisation);
- national and international standardisation to promote interoperability;
- shortening the time for bringing research results to commercial application;
- stronger emphasis on digital security as a quality feature (including through investing in skills-upgrading and academic degree programmes);
- strengthening the legal basis (including data protection) for Industry 4.0;
- creating acceptance among employees for digital technologies (starting from large-scale investment into school curricula and vocational training);
- networking and expansion of testing facilities for SMEs;
- stronger efforts to collect and publicise best practice examples of digital technology applications; and
- deepening of international cooperation.

In terms of international cooperation, a significant step was taken in March 2017 with the conclusion of a trilateral partnership agreement between Germany’s Industrie 4.0 Platform and its French and Italian counterparts (Plattform Industrie 4.0, Alliance Industrie du Future, & Piano Industria 4.0, 2017). Under a joint steering committee, three specific areas of cooperation are addressed: standardisation and reference architecture (lead: Germany), engagement of SMEs and testbeds (lead: Italy) and policy support (lead: France), which are complemented by a horizontal group dealing with skills development and qualifications. In addition, a number of bilateral cooperation agreements have been concluded with Australia, the Czech Republic, China and Japan as well as with the Industrial Internet Consortium (IIC) (Mattauch, 2017a).

Cooperation with the IIC[36] is particularly important, given the importance of an early standardisation of new technologies and systems aimed at ensuring their maximum interoperability. The stylised choice is between internationally agreed common standards for "individual modules, components, devices, production lines, robots, machines, sensors, catalogues, directories, systems, databases and applications" (Kagermann, Anderl, Gausemeier, Schuh, & Wahlster, 2016, p. 23) or a myriad of proprietary and isolated standards developed and imposed by leading business players, with the risk of standards developed in the largest national markets becoming a "quasi norm" internationally. Not only is an early international standardisation a key precondition for smooth operations within multi-country and multi-sector value chains, it is also essential to allow for SMEs, as standard-takers, to participate in the digital economy without being forced into captive power relationships with individual, large corporations.

To date, the German Industrie 4.0 initiative has been successful in establishing an internationally recognised "trademark", setting up platforms and alliances for consensus-building, creating awareness for the main digitalisation challenges, and formulating key recommendations for government and industry. However, although there are identifiable leading actors in both the public and the private sectors and some related funding mechanisms, there is a noticeable lack of specificity concerning the results to be achieved.

This becomes particularly evident when comparing Industry 4.0 to other long-term technology strategies in Germany, such as the energy transition or electric mobility. In the two latter cases, concrete quantitative targets and timelines were set, supported by highly structured public–private partnerships that derive their strength from politically agreed flagship projects and a broad-based, competitive project selection. In the case of the energy transition, also the early promulgation of a national law (Renewable Energy Law – EEG) defining entitlements to financial incentives has played a critically important role. In comparison, the main features of Industrie 4.0 remain somewhat elusive and vague in their application. Maybe this is the nature of the "digital beast" and the price to be paid for the pervasiveness of new digital technologies that indeed cut across the entire economy in all its sectors. As a consequence, it is exceedingly difficult to define boundaries. Also, the level of uncertainty in the future of digitalisation is arguably much higher than in the case of renewable energy technologies.

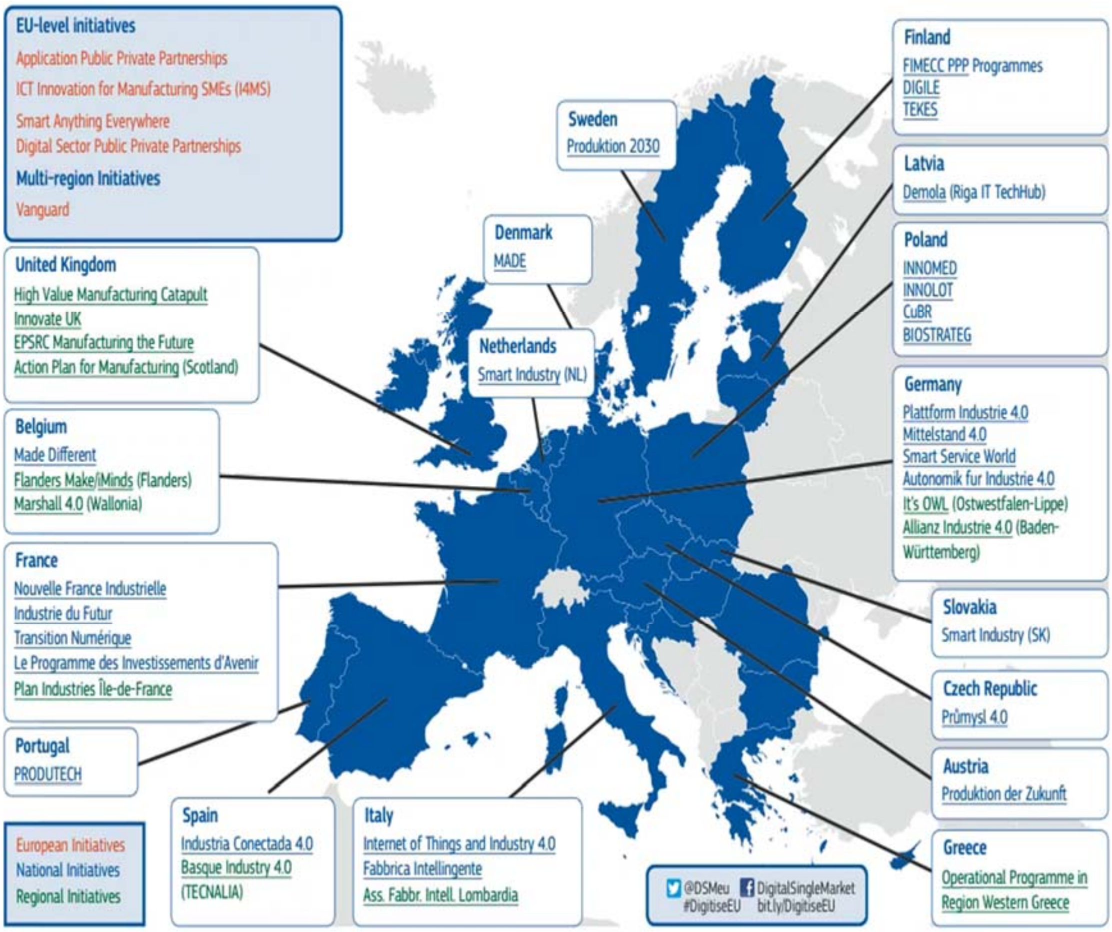
4.1.2. Comparative review of national Industry 4.0 strategies

Partially triggered by the early adoption of an Industrie 4.0 strategy in Germany, recent years have seen a mushrooming growth of similar initiatives in other countries, both within Europe and beyond. An overview of the national initiatives in the European Union is provided in Figure 7. In this section, we take a cursory look at some of the approaches being pursued and measures being taken as well as, in a comparative perspective, try to distil some characteristics and defining elements of the various approaches. Hence, the aim is distinctly *not* to review any of the selected approaches in greater detail, which would be beyond the scope of this discussion paper. Rather, it is intended to demonstrate both the similarity and

36 As an open membership organisation with currently more than 250 mostly corporate members, the IIC does not exclusively deal with standards. However, it represents one of the most effective platforms to advance the standardisation agenda as, over the years, it has moved from an initially US membership focus to a more global organisation.

the variations in national approaches (for details, see Kagermann et al., 2016; Larosse, 2017; Lazaro, 2017; Mattauch, 2017a, 2017b; OECD, 2017a).

Figure 7: Overview of European initiatives on digitalising industry



Source: European Commission (s.a.)

France

The Alliance Industrie du Futur (AIF) programme was launched in 2015 under the auspices of the Ministry of Economy. It is explicitly linked to the country's new industrial policy ("La Nouvelle France Industrielle") and is managed by a governing body comprising leading industrial companies (with the CEO of Arcelor Mittal as its president), professional organisations, trade unions and research institutions. The AIF aims to support the development of key digital technologies (with a focus on AM, the Internet of Things and augmented reality applications) and to assist a total of 2,000 SMEs through regionally organised platforms (e.g. in carrying out baseline audits and designing worker upskilling programmes) and the provision of generous tax incentives and subsidised loans. Strong emphasis is placed on European and international cooperation.

In keeping with the French tradition of a proactive and centralised industrial policy ("planification"), the work of the AIF is linked to the Conseil National de l'Industrie (CNI) as the government's permanent consultation body on issues related to industrial policy. It is organised under one of 14 strategic value chains (“*filières*”), which have been assigned a cross-cutting function. In early 2017, a special partnership between the AIF and the CNI was launched with a view to identifying the digital-upgrading requirements in all 14 value chains. Furthermore, the AIF is connected to the country’s regional cluster programme and promotes digital projects in almost 50 per cent of all industrial clusters (34 of a total of 71 “Pôles de Compétitivité”).

Italy

Launched in late 2016, the Piano Nazionale Industria 4.0 (PNI4.0) brings together six ministries[37] (with the Ministry of Economic Development in the lead), the presidency of the Council of Ministers, the country’s major universities and research centres, the largest trade unions and the Association of Manufacturing Companies (CONFINDUSTRIA) under a National Steering Committee. Its aim is to promote higher productivity levels and increased flexibility within a technology-neutral approach that encompasses nine technology drivers: advanced manufacturing solutions (robots and sensors), AM, augmented reality, simulation (process optimisation through real-time data), horizontal/vertical integration, industrial internet, cloud computing, cyber security and big data. In May 2017, the concept of a national Industry 4.0 network was launched, which rests upon three interconnected components: Digital Enterprise Points (focussing on one-stop support shops operated by decentralised chambers of commerce), Innovation Hubs (focussing on digital skills training and technology transfer) and National Competence Centers (focussing on experimental R&D projects and showcasing).

Generous tax incentives (in the EU, Italy is second only to Ireland in this regard) are being offered for both domestic and foreign investments into digital technologies, in particular for venture capital support to innovative SME start-ups, providing for a 30 per cent deduction from personal or corporate income taxes. Furthermore, a Guarantee Fund was established covering up to 80 per cent of company loans. However, there is evidence that, to date, most of the financial and R&D support has actually been absorbed by large corporations as opposed to SMEs.

Sweden

The Swedish economy is highly export-oriented, dominated by powerful industrial champions and is already today characterised by comparatively high levels of digitalisation. Sweden’s “Smart Industry” initiative was launched in January 2016 and, from the outset, has been contextualised as a countermeasure to the perceived gradual deindustrialisation (and overemphasis on the service economy) of the country and, importantly, as a direct complement to the country’s sustainability strategy. Becoming fully digitalised as well as resource-efficient and climate-friendly is considered to be an interconnected, objective function. In May 2017, the Minister for Digital Development presented a new strategy paper that puts great emphasis on digital-skills upgrading as a basis for innovation.

At the same time, the Smart Industry Action Plan issued by the Innovation Minister has an Industry 4.0 vision at its core and builds on regionalised support schemes for SMEs within

37 Economic Development; Economy and Finance; Education; Universities and Research; Labour and Social Policy; Agriculture; and Environment and Protection of Land and Sea.

an "automation region" cluster approach and dedicated SME digitalisation consulting facilities. Furthermore, similar to the German Industrie 4.0 Platform, a multi-stakeholder "Produktion 2030" was created and organised into eight thematic working groups.[38] In June 2017, Produktion 2030 issued a call for testbed projects specifically focussed on new digitalised production systems in the manufacturing industry – providing funding of 60 per cent or more per project (maximum of 8 million Swedish krona each). Also, a strong role has been assigned to the country's procurement agency, with the aim of using public procurement as a tool for digital innovation.

United Kingdom

Even more pronounced than in the Swedish case, the United Kingdom's digitalisation strategy is cast in terms of reversing the country's massive deindustrialisation[39] and closing the productivity gap that has emerged compared to other leading European economies (Her Majesty's Government, 2017). The country's currently seven High Value Manufacturing Catapult centers (with three more in the pipeline) represent the cornerstone of the industrial innovation strategy (for details, see Innovate UK, 2017). Managed by the United Kingdom's innovation agency "Innovate UK", these centres (with the strong involvement of leading universities) allow businesses and researchers to jointly test proven technologies regarding their commercial applicability and, where appropriate, take first pilot steps towards their market deployment with a view to reducing the risks of innovation. The centres most relevant to digitalisation are the Advanced Manufacturing Research Center, the Manufacturing Technology Center and the Center for Process Innovation.

In general, the position of the United Kingdom is considered as being strong in terms of industrial R&D capabilities (inter alia capitalising on some of the world's most renowned universities), yet comparatively weak when it comes to the readiness of companies to innovate and translate research results into new processes and marketable products (Kagermann et al., 2016).

United States

In the United States, the digitalisation discourse has a much broader scope than in most European countries (and notably compared to the German Industrie 4.0 notion) and covers fields such as health, entertainment, energy, transport and public administration on par with developments in the manufacturing industry itself. This is reflected in both the origins of the debate and its nomenclature: In Germany, the Industrie 4.0 Platform owes its existence to an initiative taken by the federal government, whereas the US Industrial Internet Consortium was founded by AT&T, Cisco, General Electric, IBM and Intel. In addition, a number of further key initiatives – such as the Smart Manufacturing Leadership Coalition, the AllSeen Alliance and the Open Connectivity Foundation – originate from business interests.

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38 Specifically: resource-efficient production; flexible production; virtual production; people on the production system; circular production systems and maintenance; integrated product and production development; as well as the cross-functional topics of digitalisation and sustainability.

39 The UK share of manufacturing in GDP was down to 8.5 per cent in 2015 compared to an EU average of 13.9 per cent and a share as high as 20.6 per cent in Germany (UNIDO, 2017).

The US government has established a number of innovation centres, of which, however, only one (the Digital Manufacturing and Design Innovation Institute) operates under a mandate that concentrates on Industry 4.0 challenges at the company level. Generally, "advanced manufacturing" issues are geared towards next-generation materials and their industrial applications.

Japan

In Japan, the debate around Industry 4.0 is akin to the German approach. In both countries, a strong industrial base has been maintained amidst the general transition to a service economy, and the importance of manufacturing has remained high within an export-dependent economy. No surprise, then, that also in Japan the optimisation of manufacturing processes, industrial robotics, the integration of physical and cyber systems, and the adoption of internationally valid standards are among the key themes. Likewise, the close cooperation between government, academia and industry is a key feature and has led to multi-stakeholder alliances, such as the Robot Revolution Initiative and the IoT Acceleration Consortium, in which government funding plays a key role.

In addition, given the fact that Japan is the fastest-aging society, there is a particularly strong emphasis being placed on robotics applications outside the domain of manufacturing, for instance in the health sector and in care services for the elderly. This is one of the elements that has led Japan (and even the Japanese Business Federation Keidanren) to place more of an emphasis on "Society 5.0"[40] than on "Industry 4.0" (Granrath, 2017).

South Korea

Based on strong government leadership and an active industrial policy, the South Korean economy has delivered one of the most remarkable success stories of latecomer industrialisation. The country is also well-placed to benefit from the digital production revolution. The blend of powerful conglomerates (*chaebols*) with millions of SMEs and a strong information technology sector (initially built on semiconductor production) can provide an effective conduit for digital innovation. "Sandwiched" between the more advanced digital capabilities of Japan and the competitive cost pressure coming from China, the country is eager to disseminate digital technologies, in particular in its SME sector. A total of 17 regional Creative Economy Innovation Centers provide business support to innovative start-ups with a view to linking them to large corporations. As in the case of Germany, there is a strong policy emphasis on promoting the early adoption of international standards that allow for the interoperability of different systems.

In accordance with the Korean economic development model, national efforts related to Industry 4.0 are largely driven by the government. All relevant initiatives (the regional centres mentioned above, the Korean Smart Factory Initiative and Foundation, and the Smart City Testbed Initiative) owe their existence to government policy priorities and funding. In October 2017, in an effort to consolidate the various existing initiatives, the Presidential Fourth Industrial Revolution Committee was established and tasked to concentrate on autonomous vehicles, smart factories and drones as the leading technology fields.

40 Based on typology that portrays societal development as moving from the hunting society to the agrarian society, the industrial society, the information society and eventually the super-smart society.

A stylised comparative perspective

The selective and compact review of some country-level digitalisation initiatives has shown that a remarkable degree of similarity exists among the various national strategies. This applies to the main objectives being pursued, the involvement of stakeholders from the public and private sectors, the targeted digital technologies as well as many of the specific support schemes, which place special emphasis on bringing SMEs on board.

At the same time, historic and contextual factors play a significant role (see the country specificities distilled in Gausemeier and Klocke (2016) which have partially informed this section). There is an apparent paradox involved, whereby countries – even in dealing with *disruptive* changes – display elements of *continuity*, and thus path-dependence. This allows for making a distinction between different shapes of country responses that could be captured with a highly stylised typology along the following lines (Table 3).

Table 3: Regional typology of digitalisation initiatives

	European approach	East Asian approach	US approach
Overall goal	Socio-economic transformation	Competitiveness	New business models for enhanced customer value
Main action level	National level: “beyond economics”	National level: economic focus	Business level
Key driver	Technology-driven (engineering capabilities)	Productivity-driven (process improvements)	Market-driven (product innovation)
Lead agent	Multi-stakeholder: government, business and civil society	Government	Business

Source: Author

Indeed, the tentative nature of this typology cannot be overemphasised. It represents an attempt to accentuate differences, hence it disregards nuances and paints a broad-brush picture. As such, it is aimed at stimulating further debate. Clearly, as shown in the cases of Germany and Sweden, there is a discernible tendency in European countries to emphasise the instrumentality of digital technologies as agents of broader societal transformation and to connect them to social and sustainability agendas – unlike in the United States, with its entrepreneurial and market perspective on digital innovation, and in East Asia, where an economic focus on maintaining and expanding future competitiveness is predominant. Also, there is no doubt that the leading role of state agencies is more prevalent in East Asia compared to an inclusive multi-stakeholder approach in Europe and a stronger business orientation in the United States.

It would thus seem that the societal embedding of the digitalisation discourse also depends on the overall perspective on the role of capitalist growth. In this context, a view towards broader societal implications (for the future of work, the impact on natural resources and the broader public acceptance of transformative change) is more typical for the mature European economies. This notwithstanding, it needs to be reiterated that Table 3 and the ensuing reflections are provisional and indicative in nature.

4.1.3 Coordination efforts at the European Union level

In the majority of EU member states, dedicated initiatives related to Industry 4.0 have been launched. According to the European Commission, this is currently the case in 17 out of 28 countries (see Figure 7 above). With a view to aligning and harmonising these national initiatives, the last couple of years have seen a proliferation of efforts by the European Commission to provide support to EU member states. The most significant elements are briefly captured below, organised into advisory services, convening function, operational support, and monitoring and evaluation.

The ultimate goal is for the various coordination and support measures to culminate in a Digital Single Market that would allow for the seamless cross-border exchange of digitalised industrial data. Hence, harmonisation efforts aimed at data security, standards and interoperability are given high priority.

Advisory services

In 2014, the Strategic Policy Forum on Digital Entrepreneurship was set up as a time-bound advisory body composed of industry representatives, civil society organisations, trade unions, academia and public authorities. The Policy Forum was active for two years and, as envisaged, published its recommendations in early 2016 (European Commission, 2016b). Although the recommendations spanned a wide field of issues (ranging from urban and regional digital infrastructures to company-level training requirements), they put special emphasis on two challenges. First, the need was underlined to introduce a new generation of digital security solutions. Such solutions (technologically based on artificial intelligence and predictive algorithms) are considered to require EU-wide infrastructural support, interoperability standards for digital identities (within the IoT) and, importantly, reliable third-party validation and certification. Second, a number of recommendations stressed the need to encourage digital entrepreneurship and invest into the digital upskilling and reskilling of the work force. Specifically, a new pan-European financial scheme was proposed for large-scale digital reskilling programmes that cannot be covered by the current facilities, such as Horizon 2020 and the ESF. The Academy Cube[41] – initially founded in Germany in 2013 and meanwhile present also in Italy, Portugal, Spain and the United Kingdom – was seen as a model to follow.

Convening function

A number of interconnected regular events bring together the main actors to foster an exchange of experiences at the EU level. These include semi-annual High-level Roundtables and, as of 2017, an annual European Stakeholder Forum. In addition, a European Platform of all national Industry 4.0 initiatives was launched in March 2017 to promote cooperation, trigger joint investments, develop common approaches to regulatory challenges and exchange lessons on reskilling efforts.

41 For details see http://www.academy-cube.com

Operational support

In relation to the various advisory, monitoring and convening services provided by the European Commission, the specific operational support is less pronounced and left largely to the national initiatives themselves. However, there are several ongoing support programmes financed under the Horizon 2020 umbrella. One of them is the Factories of the Future public–private partnership, with €1.15 billion in funding for the 2014-2020 period, which has so far supported 150 R&D projects implemented jointly by leading industrial companies, SMEs and research institutions and covers the full range of manufacturing operations.[42]

In addition, with a smaller budget of €110 million, the I4MS (ICT Innovation for Manufacturing SMEs) initiative provides direct technology support to SMEs and mid-caps (representing 75 per cent of the programme's industrial partners) and helps them to access European digital competence centres and innovation hubs. The technology focus is on four areas, comprising high-power computing, cloud-based simulation services; advanced laser-based equipment; industrial robotics systems; and cyber physical systems for high-precision production (European Commission, 2016c).

Monitoring and evaluation

To allow for a consistent monitoring and cross-country comparison of progress in digitalisation, the European Commission has developed a Digital Transformation Scoreboard, which combines both a survey-based and an indicator-based approach (European Commission, 2017d). The latter juxtaposes digital enablers and digital technology integration, thus allowing for an assessment of how potentials are translated into actual performance. More specifically, a Digital Transformation Enablers Index (composed of indicators for digital infrastructure, access to finance, digital skills, e-leadership and entrepreneurial culture) is contrasted with a Digital Technology Integration Index. Both indices are the basis for clustering countries into leaders (mostly Scandinavian and north-west European countries) and laggards (mostly eastern European countries).

In addition, the various national Industry 4.0 strategies are subjected to a comparative assessment in terms of funding structure, stakeholder involvement, leverage effects and results achieved (European Commission, 2017c). Although this comparison lacks a well-defined impact model and must not be equated with a rigorous evaluation exercise, it leads to a number of policy-relevant findings. These include a stronger emphasis on:

- the key role of network members agreeing on common norms and standards;
- a strategic role of sectoral and/or regional clusters as agents of change and as counterparts for policy interventions;
- the need to define measurable and time-bound targets for each initiative;

42 The 2018-2020 work programme covers five areas: (1) agile value networks: lot-size one – distributed manufacturing; (2) excellence in manufacturing: advanced manufacturing processes and services for zero-defect and innovative processes and products; (3) the human factor: developing human competences in synergy with technological progress; (4) sustainable value networks: manufacturing driving the circular economy; and (5) interoperable digital manufacturing platforms: supporting an eco-system of manufacturing services (European Factories of the Future Research Association, 2016).

- a higher level of co-financing from industrial partners, with a view to increasing the leverage factor of public funds;
- a strong commitment of the organised private sector (business membership organisations and labour unions) to enhance sustainability; and
- a broadening of the focus to go beyond technological deployment issues and address long-term company strategies, in particular for SMEs.

From the review of current policy practice, we will now move into more general conceptual issues of industrial policy in the face of digitalisation challenges.

4.2 Implications for industrial policy supporting the digital revolution

4.2.1 Renaissance of technology foresight

In virtually all country-level policy initiatives seeking to understand the future implications of the digital production revolution, a renewed strong reliance on technology foresight exercises can be observed. This signals a clear shift in the methodology being applied for identifying prospects for technological change and economic competitiveness as a basis for supportive policy measures. A recent dominance of quantitative methods based on trade data (see below) is gradually giving way to more qualitative approaches, which are primarily informed by expert opinions and stakeholder consultations.

The current renaissance of technology foresight is taking place at the national, regional and international levels alike. Illustrative country-level examples inter alia include participatory, multi-stakeholder processes in Germany ("BMBF Foresight"), the United Kingdom ("UK Foresight"), Finland ("Finnsight"), Japan ("Revitalisation of Japanese Industry"), the United States ("Manufacturing Foresight") and South Korea ("New and Emerging Signals of Trends" – NEST). It is noteworthy, however, that in a fundamentally different approach, China's long-term strategy for digital technology leadership is based on a centralised, top-down approach "in stark contrast to the pivotal role of enterprise initiative in the bottom-up process in Germany, the United States and many other countries" (Wübbeke, Meissner, Zenglein, Ives, & Conrad, 2016, p. 17).

Regional foresight approaches, for instance, have been launched for the EU ("Digital Futures") and Latin America ("eLAC Delphi"), whereas the international coordination of lessons learnt[43] has taken place within the remit of the UN (for more detailed information see: European Commission, 2016a; Hilbert, 2017; OECD, 2017a; Pietrobelli & Puppato, 2015; UN-ECOSOC [United Nations Economic and Social Council], 2016).

Directly related to the long-term employment implications of new digital technologies, an insightful international Delphi Study on the future of work in 2050 was organised by the German Bertelsmann Stiftung under the auspices of the Millennium Project (Daheim & Wintermann, 2016). Its results are based on an open-ended survey conducted with some 300

43 One of the main findings includes that "institutionalizing technology foresight as part of existing policymaking and national development planning processes can assist countries to make the best use of the opportunities offered by digital developments and simultaneously address challenges" (UN-ECOSOC, 2016, p. 15).

experts, of which 70 per cent were of North American and European origin, whereas more than half of the remaining 30 per cent were from Latin America and the Caribbean. In a nutshell, the key expectations comprise:

- a gradual and accelerating takeover of jobs by robotics and artificial intelligence, which affects nearly the entire spectrum of professional groups;
- a rise in the global unemployment rate to almost 25 per cent and a growing social gap, unless fundamental countermeasures are taken;
- a shift from today's increasingly mobile work to a future scenario in which much of the work will be carried out in the collective virtual space ("metaverse");
- a concentration of new human jobs on activities requiring high levels of empathy and social interaction, such as in leisure, recreational and health sectors;
- the need for workers to acquire basic technological and programming skills that command a premium in rapidly changing labour markets; and
- the readiness to design new economic and social systems commensurate with a declining need to engage in paid labour, with 60 per cent of experts favouring the introduction of a universal basic income (UBI).

Although the experts emphasise the exceedingly high level of uncertainty regarding the specific course the digital revolution will take, they consider the above conclusions to be valid within a time horizon of 10 to 20 years, which is seen as a transformational phase, after which the new economic and social scenario will take root.

In all countries, industrial policies – as the deliberate attempt by governments to steer a country's economic development in a socially desirable direction – require robust analytical tools for ensuring that both their design and implementation are evidence-based and build upon realistic prospects. In turn, this calls for preparing proper models of current economic structures with a view to being able to identify future comparative, competitive advantages. The better that policy-makers can predict future developments accurately, the easier it becomes to set medium- and long-term priorities.

However, it is notoriously difficult to identify the technology fields and economic sectors that offer realistic growth opportunities in the medium to long run. Such assessments invariably require a smart mix of quantitative and qualitative instruments (for a review, see Altenburg, Kleinz, & Lütkenhorst (2016), on which this section partly draws), especially given the dramatic technological revolution we are currently experiencing. In recent years, there has been a noticeable preponderance of approaches that have been quantitative in nature (mostly building on production and trade data) and have relied on *past* development patterns as signposts for future competitive advantages. Typical yardsticks applied have been the factor endowments and development trajectories of comparator countries (Lin & Monga, 2010), the technological proximity of previously created export capabilities (Hausmann & Klinger, 2006) and various historic characteristics of technological life-cycles (Lee, 2013).

Even using value chain analysis (i.e. an approach based also on analysing qualitative power constellations and value chain governance) for identifying future competitiveness, remains subject to an important "single loop" caveat,[44] insofar as it is essentially based on an analysis of prevailing constellations, thus limiting the relevance of its conclusions for future scenarios. This becomes particularly important when technological and/or institutional change is disruptive and fast.

This is where technology foresight can offer clear advantages. In its various methodologies and tools, neither past experiences, proximities or spillovers, nor issues of power and governance are placed at the centre of attention. Within a dynamic, future-oriented perspective, technology foresight adopts a "double loop" approach, that is, it is not confined to a given context, but it can fundamentally question whether currently prevailing conditions are likely to remain as they are. Foresight activities are used to passively predict, reactively manage and proactively create a still uncertain future with a focus on ways to steer development towards a desired direction. This future-oriented approach is able to identify drivers, anticipate what might happen under certain circumstances, and examine relevant variations and interactions. It helps to predict and anticipate emerging opportunities and problems, and thus can identify priorities and design commensurate strategies. (For a synoptic comparison of the various tools for identifying future competitive advantages, see Annex Table A2.)

Technology foresight in its various manifestations saw a peak in its policy-oriented application in the 1980s and 1990s and is now experiencing a renewed wave of attention. By adopting a principally open perspective on the whole menu of available technology choices, it provides a set of tools "for collectively exploring, anticipating and shaping the future" (Cassingena Harper, 2013, p. 6) within an overall scenario of high uncertainty and limited predictability of future economic and technological trends.

Indeed, identifying potential competitive advantages invariably involves a high degree of uncertainty, above all in an environment characterised by widespread policy interventions and by waves of disruptive change that tend to invalidate both historical patterns of development and trend extrapolations. Different foresight methodologies, instruments and implementation practices have been developed over time that all – though in various configurations – combine data analysis and expert knowledge. Considering the high degree of uncertainty that is inherent in the anticipation of emerging trends in technologies and markets, expert opinion plays a particularly important role in foresight exercises. Hence, we can generally observe a "wide participation of a large number of stakeholders and experts, namely, the government, science, industry and civil society" (UNIDO, 2005, p. vi).

Although not rigorously codified and more in the nature of a soft, qualitative approach, technology foresight has evolved over time and is often positioned today as an integral element of an innovation system designed to respond to uncertainty. From this perspective, technology foresight can also be considered as an instrument aimed at overcoming coordination deficits between fragmented actors: "Foresight could be seen as reducing uncertainty by enabling creation and pooling of knowledge. Without an intervention firms might dissipate their technological efforts over too wide a range of activities and fail to achieve critical mass" (Cassingena Harper, 2013, p. 9). The two central contributions of

44 According to Argyris and Schön (1978)(1978), "single loop" learning means that actions are adjusted when they do not lead to the desired result, whereas frame conditions are considered as given. In contrast, "double loop" learning takes place in case adjusting actions are insufficient and frame conditions must be revised as well.

foresight exercises to societal search processes thus lie in the systemic coordination of a multitude of actors and in the provision of a shared assessment and vision of the future, especially in times of disruptive change when linear extrapolations from the past provide little guidance. Put differently, technology foresight approaches can create the legitimacy for a "national project" to direct structural change and transformation, which, in turn, must be regarded as a key element of an effective industrial policy.

4.2.2 A strengthened case for strategic industrial policy

In both literature and practice, there has been a long and protracted debate on the rationale for industrial policy – defined here as deliberate measures taken by governments to drive structural change in a desired direction. This debate has seen frequent pendulum swings towards either a more interventionist or a more hands-off approach. The evolution, and the twists and turns of this discussion, have been described elsewhere and will thus not be revisited here (for greater detail, see Altenburg & Lütkenhorst, 2015; Cimoli, Dosi, Nelson, & Stiglitz, 2009; Naudé, 2010; Rodrik, 2004). A certain degree of convergence, however, is striking and should be noted. Gradually, fierce ideological arguments have given way to a more balanced and nuanced assessment. Following its declared death by the Washington Consensus institutions, the concept of industrial policy has regained credibility in international think tanks, multilateral institutions and also among mainstream economists. The more constructive part of the discussion has moved essentially from the question *if* to engage in industrial policy to *how* to apply it and what instruments to select, and the common ground gained is remarkable. Compared to earlier dogmatic arguments around the potentials and the perils of industrial policy, today's discourse focusses more on empirical evidence and the appropriateness of different methodologies (as exemplified in Lin & Chang, 2009).

Most importantly, anchoring the case for industrial policy *exclusively* in correcting market imperfections is insufficient. Although justifying policy interventions in response to failing markets is almost trivial, the essential point to make is that even the outcomes of perfectly functioning markets may not be acceptable from a broader societal perspective: "Markets represent a *process norm*, which must be subjected to *outcome norms* in terms of what a society considers as both necessary and desirable" (Altenburg & Lütkenhorst, 2015, p. 10; emphasis in original). Put differently, industrial policy is part of a *normative* societal undertaking to achieve and balance a variety of goals – from creating employment to ensuring distributional fairness, limiting climate change or, indeed, managing disruptive technological change. In the final analysis, industrial policy needs to be embedded and discussed within an overall vision of the "public good".[45]

Moreover, it can be demonstrated that smart industrial policy can escape from "picking winners" in terms of individual companies, guide private investment through clarity about

45 The distinction between outcomes being normative and markets being a process or an instrument, is in itself questionable. As Sandel has pointed out, "markets are not mere mechanisms. They embody certain norms. They presuppose – and promote – certain ways of valuing the goods being exchanged" (Sandel, 2012, p. 64). Moreover, the socially acceptable boundaries of markets (slavery, human trafficking, trade in human organs, child labour, etc.) have been redrawn in the course of history (Chang, 2001). More broadly, Sedlacek has documented the systematic elimination of values, of normative judgement and of social context from mainstream economics, with his apt conclusion being that "it is a paradox that a field that primarily studies values wants to be value-free" (Sedlacek, 2011, p. 7).

long-term goals (labelled as “directionality” by Mazzucato, 2013), avoid costly failures by relying on transparent processes and strong monitoring efforts, and build on competitive mechanisms in its implementation (Pegels & Lütkenhorst, 2018, in press).

As an instrument supporting societal transformation processes, industrial policy thus must assume a more strategic role. *Strategic industrial policies*, as defined by Lauridsen (2010) are aimed at managing the adjustment to new goals and changed environments. They deliberately redirect industrial investments, create inter-sectoral linkages, promote new areas of value addition and stimulate learning – not levelling but “*tilting the playing field*” (Mazzucato, 2017, p. 5) in favour of desired goals and patterns of economic development. This strategic orientation has manifested itself, for instance, in policies promoting the green transformation of societies (from renewable energy systems to electric mobility and smart cities). It is even more relevant for managing the digital transformation, which has a number of defining features that need to be accounted for in attempts to direct its future course and shape its manifold implications. Specifically, the following aspects can be highlighted – harking back to the technological trends reviewed in Section 2 above and focussing on their implications for industrial policy.

First and foremost, we are dealing with *long-term* transformative processes that are unfolding with a high degree of uncertainty. Whereas existing conventional technologies are becoming rapidly obsolete and replaced, the contours of newly emerging technological trajectories are as yet fuzzy and remain, to some extent, unpredictable.

Second, we are faced with a speed of technological change that would have been unfathomable only a few years ago. Put differently, and in a slightly stylised perspective, technology is in the lead, and political and social systems are desperately seeking to catch up and respond – another perfect example of what Ogburn (1922) defined as the “cultural lag” syndrome. This constitutes a noteworthy contrast to the transformative change in energy systems. In the latter case, technological innovation has been stimulated by a proactive industrial policy, which enacted changes in the legal and regulatory environment (e.g. priority grid access for electricity from renewable energy sources) and offered a whole range of generous incentive schemes (such as guaranteed feed-in tariffs), that is, we saw a deliberate attempt to create *policy-induced* markets. Quite the contrary in the realm of new digital technologies: Technological advances are often perceived as happening too fast, thus putting policies in an uncomfortable “response mode”. Rather than creating new markets, the policy challenge is often defined as slowing down the commercial use of new technological opportunities as long as their security and social implications are not fully known and understood. Clearly, in the co-evolutionary dynamics between technology, policy and market development, the digital sphere is predominantly *technology-driven*.

Third, the digital revolution is both systemic and global in nature. It transcends sectoral boundaries by weaving manufacturing and services into a seamless continuum of operations, linking the physical and the cyber worlds, and reinventing industrial processes, business models and products alike. At the same time, these developments take place across national borders and redefine global value chains, for example through newly configured factor cost relations and by gradually shifting the balance from the movement of physical goods towards the exchange of electronic files.

Fourth, although the new digital technologies originate from the sphere of production, they find wide-ranging applications in all dimensions of life, from transport to health, communication, entertainment, leisure, education and learning, and consumption patterns in general, of course. They have fundamental consequences for our individual and social behaviours that call for a forward-looking impact assessment of hitherto unknown threats and risks alongside the many new opportunities.

What does all this imply for a strategic positioning of industrial policy? Essentially – in particular in advanced economies – it calls into question any policy support that is narrowly focussed on specific manufacturing sectors. It puts a premium on a manufacturing *systems* perspective, which acknowledges the increasingly complex networks of production itself and their connections to related embedded and embodied services (O'Sullivan, Andreoni, López-Gómez, & Gregory, 2013). In economies in the early stages of industrialisation, there may still be breathing space for some traditional sectors (such as the clothing, food-processing and leather industries, as argued in Section 3.2 above) where the introduction of digital technologies is more challenging and has not yet taken hold. Here, it may remain justified to provide sectoral support measures (aimed at safeguarding existing jobs) while trying to prepare and upgrade other sectors to compete in the global digital economy. The balance depends on the individual country situation; there is a real risk of prolonging the economic lives of sectors that are doomed to lose their labour-cost advantage and may ultimately disappear.

At the same time, not only are the dividing lines between manufacturing sectors and services becoming increasingly blurred, but the distinction between horizontal and vertical policy measures is also becoming increasingly difficult to make because "new technologies and changing globalization patterns increase the complementarities between economy-wide and targeted approaches" (Hallward-Driemeier & Nayyar, 2018, p. 204). Not that this distinction was ever convincing. Allegedly horizontal (i.e. sector-neutral) policies invariably have sectoral biases: This is as true for exchange-rate policies (favouring or disfavouring export-oriented sectors) as it is for investments in tertiary education (generally favouring knowledge-intensive sectors) or in transport infrastructure (with advantages for specific locations) etc. (Altenburg & Lütkenhorst, 2015, p. 45; Economic Commission for Africa, 2016, p. 29).

The most important point to underline is that any economic development process is characterised by both its *growth rate* and its *direction* (Mazzucato, 2017, p. 5). The latter, in today's digitalised world, can only be meaningfully supported by policies that take up the challenge of transforming entire economic systems encompassing a multitude of different sectors. Whether one calls this "mission-oriented innovation policy" or normative, strategic or goal-oriented industrial policy is irrelevant. However, the central precondition for any such approach to work is to organise a dialogue of all relevant societal stakeholders aimed at building consensus on the objectives to be pursued and their implications for technology choices (Altenburg & Pegels, 2012). This puts a spotlight on approaches such as the German Industrie 4.0 Platform, which has placed a strong emphasis on reaching a common understanding for policy requirements, with a view to minimising resistance later on during policy implementation. In the final analysis, industrial policy-making in the face of challenges such as digitalisation cannot be reduced to a technocratic exercise but must build on a broad-based and transparent stakeholder dialogue about societal implications in the long run.

4.2.3 Main policy areas: old and new

Although the present discussion paper cannot meaningfully address all relevant industrial policy fields, this final section provides a few pointers on key areas to focus on. It is quite obvious that, in preparing economies and societies for the digital revolution, there is a premium on tackling interrelated education, training and skills challenges. This is by no means a new insight. In the successful latecomer industrialisation of East Asian economies, heavy investment into basic education and technical-skills upgrading were key contributing factors, both for productivity growth and for social inclusiveness, as demonstrated, for instance, by Cheon (2014) in the case of South Korea. Hence, the nexus between broader educational policies and more narrow industrial-upgrading policies has been, and remains, an important factor and, incidentally, represents a further example of the close entanglement of horizontal and vertical policy interventions.

In various sections above (see Sections 3.2 and 4.1.1) it was emphasised that the *aggregate* employment effects of the rapid introduction of digital technologies are as yet uncertain and controversially debated. At the same time, there is no doubt that the rate of labour-market turbulence is increasing, thus leading to a new *structural* composition of available work. Millions of routine jobs (from factory workers to truck drivers, from legal analysts to travel agents) will disappear or, rather, be taken over by robots and expert software, whereas new job opportunities (both currently known and unknown) will emerge. Moreover, a large portion of existing jobs will change their skill profiles and depend in the future on the willingness and ability of workers to interact with intelligent machines.

The implications for the skills that underpin future economic growth are manifold and not easy to grasp (Broadband Commission for Sustainable Development, 2017; OECD, 2016c). They involve a combination of genuine ICT skills (e.g. programming, creating code-based digital content, handling complex databases), complementary ICT skills required for working in digital environments (e.g. planning digital work processes, adjusting to rapid information flows), foundation skills (literacy and numeracy skills) as well as a set of soft general competencies. For the latter, there is a growing premium on creativity, emotional and social skills that seem to constitute the ultimate line of resistance to digital automation. Labour-market projections are unequivocal in anticipating rising demand, above all for professions related to teaching, health care, various residential and social support services as well as different types of online transactions. In response to the latter, it is noteworthy that the German Federal Institute for Vocational Education and Training (BIBB), together with business partners, has developed a new three-year training occupation for "management assistants in e-commerce", which will go live in August 2018 (Federal Institute for Vocational Education and Training, 2018).

In view of free-riding behaviour in a highly competitive business context, and thus underinvestment into skills-upgrading from a societal point of view, there is a distinct role for industrial policy in creating a skill profile that corresponds to future requirements in terms of mastering new technologies and mitigating their labour-market implications. More specifically, this involves general educational policies to develop the soft transferable skills for complex manufacturing-service systems, but also for complementing formal education with technical and vocational training, engaging the private sector in partnerships aimed at designing innovative training programmes, encouraging on-the-job training and, in particular, making financial incentives available to stimulate investments into training (Albaladejo & Weiss, 2017).

Obviously, the case for support is greatest for smaller enterprises. Not only are SMEs resource-constrained in implementing their own skills-upgrading programmes, but they are further disadvantaged by the fact that existing training programmes are often not adapted to their specific needs. Many good practice examples exist of dedicated SME training support programmes, such as subsidised training consortia in South Korea and the "Skillnets" facility in Ireland, which is state-funded but enterprise-led and supports networks of SMEs in upgrading their workforce (OECD, 2016b, p. 26).

Beyond technical-skills upgrading programmes, the new digital technologies pose a range of challenges and opportunities for enhanced organisational and regulatory flexibility, which cannot be discussed here in greater detail (ample examples are provided in Jacobs, Kagermann, & Spath, 2017). The recent flexibilisation of both working times and workplaces in the Netherlands can serve as an illustrative example (Traurig, 2016). The Flexible Work Act, introduced with effect on January 2016, offers employees the right to request a reduction, increase or change in working hours, which can only be denied by the employer on the basis of important business reasons. The act also provides for a right to home-based work and, in case this is rejected, puts the burden of proof on the employer. Similarly, the growing co-existence of employees with stable (fixed-term or permanent) contracts and others working as freelancers calls for regulatory adjustments addressing the tension between social security concerns and business strategies.

The above examples lead straight into broader societal policy issues that are currently being controversially discussed. The question is being raised as to how digital technological innovations can best be translated into social innovation aimed at ensuring that adjustment costs are curbed and benefits evenly spread. Much of the discourse on digitalisation has indeed been too narrowly technology-focussed, that is, claiming inevitability instead of opening up a space for society to discuss possible futures (Buhr, 2015). In addition to more conventional discussions around transitional support measures for temporary unemployment and social safety nets for permanent unemployment, three more fundamental issues stand out: universal basic income, a radical overhaul of the taxation system and new models of capital ownership.

The debate around UBI is by no means new. Various models have been proposed over the years either by neoliberal proponents (with the objective of cutting the welfare bureaucracy and moving towards a "minimal state") or by left-wing proponents with a view towards fostering greater income equality and freedom of choice. However, so far, no UBI approach has ever been implemented on a country-wide basis. Various limited experiments have been carried out in developing economies within broader poverty-reduction programmes (Norton, 2017) and, more recently, in a policy pilot in Finland, with 2,000 citizens receiving €560 a month for two years.[46] In the context of digitalisation, UBI is considered as a possible means to delink income from work, and thus prepare for a future with lower levels of aggregate employment.

46 The key problem is that the experience gained from such limited experiments cannot be generalised, as recipients are aware of the time-bound nature, which influences their attitude and behaviour.

Obviously, the provision of UBI presupposes that sufficient state funds are generated by taxes. To gradually delink the tax base from labour incomes, the introduction of a machine tax (at times referred to as "robot tax") is being discussed. Here again, no such system has been fully introduced yet. However, the South Korean government is currently considering taking a first small step in this direction by reducing tax-deduction benefits for investments in automation.

Finally, there are numerous proposals towards broadening capital ownership so that the profits from digitalisation would be more equally shared. This could, for instance, be achieved through establishing a Citizens' Wealth Fund that would invest in company shares and other assets on behalf of the public to convert private wealth into publicly owned wealth, or by Employee Ownership Trusts, which can control companies on behalf of their employees, who would be receiving dividends (Lawrence et al., 2017, Section 5).

In essence, the current phase of development represents a fundamental transition and "we are suffering […] from the growing-pains of over-rapid changes, from the painfulness of readjustment between one economic period and another" (see the Keynes quote at the beginning of this discussion paper). This transition opens a window for experimentation and innovation, be it at the level of technical and managerial changes within companies, at the level of broader educational and training systems or at the level of overall societal innovation. In the corporate world, the imperative of "ambidextrous management" (Tushman & O'Reilly, 1996) has gained broad acceptance. This approach calls for combining short-term stability with long-term, radical change inter alia by creating niches in which non-incremental change can be tested. It would seem that such a spirit of experimenting with non-conventional policy tools should also be applied to the broader realm of policy-making.

5 Outlook: some implications for developing countries

The main view taken in this discussion paper has been that, to date, research on the impact of digitalisation remains fraught with many uncertainties. More specifically, depending on the assumptions made and the methodology applied, there is a considerable range in the employment effects predicted, even in the case of mature economies for which robust and reliable data sets exist. For developing countries – often characterised by weak data availability and mostly positioned at the receiving end of technological innovation – this applies *a fortiori*.

As a result, the implications of the digital revolution for the prospects of latecomer industrialisation are exceedingly difficult to discern. As was shown above in Figures 5 and 6 (see Section 3.2), even the broad cross-country direction of employment effects is still subject to debate: Answers differ significantly as to whether they are likely to be relatively stronger in low-income countries or in developed economies. At the same time, with a view to taking precautionary policy measures, it would be critical to know if low-income and lower-middle-income countries indeed will enjoy a breathing space before being fully hit by the consequences of digitalisation, that is, if assembly operations (from garments to shoes, from automotive components to consumer electronics) will suffer and, if so, in which sectors this will happen first. How fast will robots be capable of processing lumpy materials into textiles? How fast will additive manufacturing technologies take over the manufacture of parts and components, and thus gradually replace trade in tasks by trade in files? Put differently: Will labour-cost advantages be further eroded and lose their significance as an asset for building prosperous economies?

A survey carried out by the International Labour Organization in South East Asia sheds some light on these questions. South East Asia is a prototypical region that has successfully embarked upon latecomer industrialisation. Here, serious concerns prevail concerning the future of employment in key export-oriented manufacturing sectors (Chang et al., 2016):

- The automotive and auto parts industry is being redefined by electric mobility, new light materials and robotic automation in manufacturing processes. Estimates put more than 60 per cent of workers in Indonesia – and even more than 70 per cent in Thailand – at risk of losing their jobs to automation.

- In the textiles, clothing and footwear industry, disruptive changes are mostly expected to result from additive manufacturing techniques, body scanning machines, wearable technology and robotic automation. Although this will put a premium on higher skill levels, it may negatively affect two-thirds of all jobs in Indonesia, and even close to 90 per cent in Viet Nam and Cambodia.

- The region’s electrical and electronics industry is bracing itself for the full impact of robotic automation and additive manufacturing (in particular in low-skill packaging and assembling jobs), yet it may benefit from the productivity-enhancing impact of linking producers and suppliers through the IoT. However, the combined net effect puts about 60 per cent of the sector’s workers in Indonesia, the Philippines and Thailand at risk.

Anecdotal digitalisation evidence from Viet Nam includes the country’s leading ceramics and porcelain ware manufacturer, which has reduced the number of workers through automation from 400 to just 20 without any productivity losses; a fabric-cutting enterprise with a major digital automation investment that amortised within 18 months; and a food manufacturing company, which has fully automated egg-grading and processing with machinery imported from the Netherlands (Viet Nam Economic Times, 2017). Importantly, these illustrative examples refer to *domestic* companies and, in the case of food processing, a company primarily serving the domestic market.

The domestic nature of ownership and market orientation stressed in the previous paragraph is noteworthy in connection with a recent study by the Asian Development Bank (Asian Development Bank, 2018), which paints a rosy picture of future technology-induced employment effects in the region. While acknowledging the negative impacts of digital technologies on jobs at the low to middle segments of the skills spectrum, it underlines the positive effects originating from rising productivity and demand levels overall. Specifically, a major trend is perceived in terms of gradually replacing export-led growth with an enhanced role of domestic demand based on rapidly growing middle classes. This may actually turn out to be correct. However, assuming that such a trend might halt the digital automation of production lines, and the resulting pressure on employment levels, is likely to be a fallacy. Also, domestic companies serving domestic markets will be operating under tough competitive conditions, both against each other and vis-à-vis imported goods. Just like globally operating corporations, they will have every reason and incentive to adopt new digital technologies as a means to reduce labour costs and enhance flexibility.

Also for the Latin American region, the importance of productivity effects leading to expanding output and aggregate demand is being stressed as a countervailing force against the negative employment effects resulting from the substitution of digital technology for workers (Dutz, Almeida, & Packard, 2018). However, compared to countries in South East and East Asia, the Latin American region has fallen behind in economic complexity and diversification, which is inter alia reflected in the high concentration of robot use in the transport sector, at the expense of robotics application in electronics industries: “The Asian middle-income countries could develop such dynamics in accumulating robots in different industries due to the capabilities which they developed during the period of increasing economic complexity (the 1990s and 2000s)” (Nübler, 2017, p. 315).

At the same time, an interesting new perspective is opening up for low-income developing countries. With few exceptions, they have so far been less integrated in global manufacturing value chains and will thus not suffer massively from possible changes in global companies’ outsourcing strategies. Yet, there are significant future employment opportunities originating from innovative IT-enabled services. These range from more conventional business process outsourcing activities (the “Bangalore” model) to novel services such as those related to impact-sourcing, image-tagging and generally the rapidly growing “app economy”. Various IT-service clusters in Kenya and Rwanda can serve as illustrative examples (Melia, in press). In addition, the digitalisation of a whole range of services – from online purchase transactions to online banking – can be a powerful driver of productivity.

As emphasised in the introduction to this discussion paper, we are generally faced with the dilemma of *predictable* job losses coupled with highly *uncertain* job gains. The digital revolution bears the risk of speeding up the process of premature deindustrialisation in developing countries, whereas in parallel, it may also accelerate the transition towards innovative services as a growth escalator. Much will depend on the relevant time lags between the technological feasibility and the commercial viability of introducing new digital technologies. However, by and large, a healthy dose of scepticism seems to be in order. Indeed, there may be “very little chance that other countries will be able to replicate the export-oriented miracles of East and Southeast Asian countries” (Rodrik, 2017, p. 39).

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Annex

Annex Table A1: Overview of selected recent studies on the impact of automation on future employment

Carl Benedikt Frey and Michael A. Osborne	Citibank with Frey and Osborne	OECD	World Economic Forum	McKinsey Global Institute
Date				
September 2013	January 2016	June 2016	January 2016	January 2017
Unit of analysis				
Jobs/occupations	Jobs/occupations	Tasks	Not applicable	Work activities
Scope				
US labor market	50+ countries and regions	21 OECD countries	15 major developed and emerging economies	46 countries representing about 80% of global labor force
Approach summary				
Analysis of 702 occupations (70 hand-labeled working with ML researchers, followed by a tailored Gaussian process classifier to estimate others and confirm hand-labels) to approximate the impact of future computerization on the US labor market	Extension of Frey-Osborne (2013), using World Bank data, to estimate impact of automation globally. Further analyses include examination of demographic changes, global value chain, etc.	Estimates of automatibility of tasks were developed based on matching of the automatibility indicators by Frey-Osborne and the PIAAC data occupational codes, followed by a two-step, tailored regression analysis	Analysis of large-scale survey of major global employers, including 100 largest global employers in each of WEF main industry sectors, to estimate the expected level of changes in job families between 2015–20 and extrapolate number of jobs gained/lost	Disaggregation of occupations into 2,000 constituent activities and rating each against human performance in 18 capabilities. Further analysis of time spent on each activity and hourly wage levels. Scenarios for development and adoption of automation technologies
Key relevant findings				
▪ About 47% of total US occupations are at high risk of automation perhaps over the next decade or two ▪ Wages and educational attainment show a strong negative relationship with probability of computerization	▪ Building on Frey and Osborne's original work, data from the World Bank suggests the risks are higher in many other countries; in the OECD, on average 57% of jobs are susceptible to automation. This number rises to 69% in India and 77% in China	▪ On average, 9% of jobs across the 21 OECD countries are automatable ▪ There are notable differences across OECD countries when it comes to automation (e.g., the share of automatable jobs is 6% in Korea vs. 12% in Austria)	▪ Automation and technological advancements could lead to a net employment impact of more than 5.1 million jobs lost to disruptive labor market changes between 2015–20, with a total loss of 7.1 million jobs—two-thirds of which are concentrated in the office and administrative job family—and a total gain of 2 million jobs in several smaller job families	▪ Almost half of work activities globally have the potential to be automated using current technology. <5% of occupations can be automated entirely; about 60% have at least 30% of automatable activities ▪ Technically automatable activities touch 1.2 billion workers and $14.6 trillion in wages. China, India, Japan, and the United States constitute over half ▪ Automation's boost to global productivity could be 0.8–1.4% annually over decades

Source: McKinsey Global Institute (2017, p. 21)

Annex Table A2: Synopsis of key methodologies guiding industrial policy on identifying future competitiveness

Highlighted determinants of diversification and upgrading	Growth identification & facilitation framework (Lin & Monga, 2010)	Product space analysis (Hausmann & Klinger, 2006)	Techno-logical life-cycle approach (Lee, 2013)	Value chain analysis (various authors)	Technology foresight (various authors)
Basic factor endowments and historical experiences of slightly more advanced countries	x				
Technological proximity to previously created (export) capabilities		x			
Length of technological life-cycles and intensity of competition with incumbents			x		
Power constellations within value chains affecting conditions for entry, upgrading and rent capture				x	
Data analysis, modelling and pooling of expert knowledge on "likely futures"					x

Source: Slightly modified from Altenburg, Kleinz and Lütkenhorst (2016, p. 17)

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