THE FUTURE OF THE MANUFACTURING WORKFORCE

A report by the Centre for Science, Technology and Innovation Policy, at the Institute for Manufacturing, University of Cambridge.

Written by Jostein Hauge, Michael Kenward and Sarah Wightman.

ABOUT THIS REPORT

On 24th June 2019, researchers and policy analysts from leading international organisations came together for a roundtable meeting at Madingley Hall in Cambridge, UK. The aim was to share perspectives and research for understanding the future manufacturing workforce, in particular to identify opportunities to improve policy evidence-gathering, policy analysis and policy making.

This roundtable discussion was convened by the Centre for Science, Technology and Innovation Policy (CSTI), at the Institute for Manufacturing, University of Cambridge, with the Policy Links Unit and the Babbage Industrial Policy Forum. It brought together an invited group of representatives from the Organisation for Economic Co-operation and Development (OECD), United Nations Industrial Development Organisation (UNIDO), the World Economic Forum, and the United Nations Conference on Trade and Development (UNCTAD), as well as the UK government's Department for Business, Energy and Industrial Strategy (BEIS).

Important work has been done by each of these organisations to build an understanding of the issues facing the future manufacturing workforce. The Babbage Industrial Policy Forum, led by Professor Sir Mike Gregory, is positioned to bring this work together and facilitate open discussion among researchers and analysts to explore common threads. The group reflected on the evidence emerging from research initiatives, and the implications for industrial policies, industrial strategies, and national policies for economic prosperity, industrial competitiveness and innovation.

These discussions also inform the agenda for the Babbage Symposium, an annual event which brings together world-leading experts from economics, engineering and management with a shared interest in manufacturing and industrial policy. The Symposium's objective is to generate new insights with the potential to underpin industrial policies for economic competitiveness and growth.

ORGANISATIONS IN ATTENDANCE:

- Organisation for Economic Co-operation and Development (OECD)
- United Nations Industrial Development Organisation (UNIDO)
- United Nations Conference on Trade and Development (UNCTAD)
- World Economic Forum
- UK Department for Business, Energy and Industrial Strategy (BEIS) (observing)

HOSTED BY:

Institute for Manufacturing (IfM)
Part of the Department of Engineering at the University of Cambridge, combining expertise in management, technology and policy, with 20 research centres and education programmes for undergraduate and postgraduate students (Head of the IfM, Professor Tim Minshall, attended this meeting)

Centre for Science, Technology & Innovation Policy (CSTI)
A centre within the IfM, CSTI carries out applied research into programmes, processes and practices for translating publically-funded R&D (in particular science and engineering research) into new technologies, industries and economic wealth, directed by Dr Eoin O'Sullivan.

Babbage Industrial Policy Forum
An international community of senior academics in engineering, economics and management, all of whom have direct experience of, and engagement with policymaking in their countries. Convened by Professor Sir Mike Gregory.

Policy Links Unit (PLU)
Established as the not-for-profit knowledge transfer unit of CSTI, thanks to the support of the Gatsby Charitable Foundation, PLU works closely with governments and international policy practitioners to offer new evidence, insights and tools based on the latest academic thinking and international best practice, led by Dr Carlos López-Gómez.

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FOREWORD

Manufacturing is being transformed by a combination of forces. Emerging digital technologies are having far reaching implications for how we produce things, exchange information, and interact across supply chains and with customers. Set alongside population growth, climate change and the drive towards decarbonisation, and significant changes in geopolitics, these dynamics together represent fundamental changes in the likely demands on the future manufacturing workforce. While uncertainty is of course nothing new, it is the scale, speed and complexity of these tectonic shifts that makes adapting to them particularly challenging.

Policy makers need to anticipate and respond to these fast-changing conditions. Yet there is a lack of readily available information to support reliable predictions about the implications for industry and society.

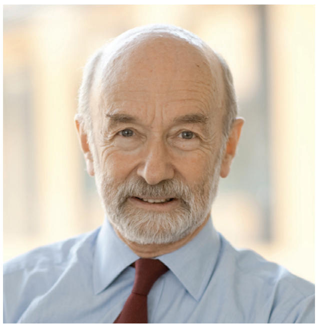
To explore these issues, in June 2019 the Babbage Forum brought together policy analysts from leading international organisations including the OECD, UNIDO, UNCTAD and the World Economic Forum, along with researchers from the Institute for Manufacturing, at a roundtable discussion at Madingley Hall in Cambridge, UK. This was a fascinating opportunity to share insights from research projects undertaken separately by each organisation, to discern common themes, and in particular to identify opportunities to improve evidence-gathering, policy analysis and policy making concerning the future manufacturing workforce.

The discussion largely focused on the predicted impact of the fourth industrial revolution on the manufacturing workforce. Themes addressed included:

- The evolving landscape for the future of manufacturing, and implications for skills required across the workforce.
- The impact of automation on jobs, and how policymakers can approach reskilling and occupational transitions.
- The impact of new technologies on economic growth and development in both high- and low-income countries, and issues around gaps in capabilities for using digital technology.

In this report, we share some of the discussion arising from the roundtable, including key points from individual presentations, and consider the context for policy development.

We are delighted that the Babbage Forum roundtable has evolved into an annual event, following enthusiasm from attendees who identify the value gained from the opportunity to hear about initiatives and research from other international organisations. While much insightful work has been done by these organisations to build an understanding of the issues, there are few opportunities to bring this work together and facilitate open dialogue among researchers and analysts to explore common threads. These discussions feed into our annual Symposium, a unique forum to develop new thinking at the interface of economics, engineering, and management.



PROFESSOR SIR MIKE GREGORY
Chair of Babbage Industrial Policy Forum

DR JOSTEIN HAUGE
Workshop Lead

INTRODUCTION

QUESTIONS ABOUT THE FUTURE OF THE MANUFACTURING WORKFORCE ARE MANIFOLD AND COMPLEX:

How will industry be reshaped by digitalisation, and by other tidal changes such as decarbonisation and geopolitical turbulence? What impact will automation have on jobs and on skills? How will the global distrubution of production change? And how will these impacts be felt across different industries, regions, and countries?

In recent years, various studies and initiatives have explored these issues, particularly the impact of digitalisation on changing workforce and skills demands, drawing on different data and approaching the topic from a range of perspectives. Together, these studies provide powerful insights into the possible demands facing the workforce, especially the skills that industry will need in order to sustain manufacturing.

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To bring together some of these different analyses, the Babbage Forum and the Institute for Manufacturing, University of Cambridge, convened an invited group of representatives from the Organisation for Economic Co-operation and Development (OECD), United Nations Industrial Development Organisation (UNIDO), the World Economic Forum, and the United Nations Conference on Trade and Development (UNCTAD), as well as the UK government, at a roundtable discussion in Cambridge in June 2019.

The workshop was an opportunity to share findings from their research into how changing patterns of manufacturing could affect the workforce and to compare, for example, experiences between high- and low-income countries, and perspectives for corporate leaders and policy makers in government. Are there common challenges that face these and other stakeholders? What opportunities are there for connecting research and thinking for stronger evidence-based policy making?

This report covers some of the themes that emerged from this dialogue, including key points from each presentation and questions for further investigation. The report has an emphasis on changes resulting from the digitalisation of manufacturing, reflecting the focus of the research projects presented by the participants.

SECTION 1

THE CONTEXT: A NEW INDUSTRIAL REVOLUTION

The digitalisation of manufacturing (see box) heralds a revolution that has undeniable implications for the workforce of the future. The world has experienced industrial revolutions before, but some argue that the pace of technological change has never been faster than we are currently experiencing.

As a term, the 'fourth industrial revolution' (4IR) describes the emergence in industry of a range of digital technologies including—but not limited to—cloud computing, advanced sensors, the internet of things (IoT), automation, virtual and augmented reality, Big Data and analytics, blockchain, machine learning, digital fabrication, and artificial intelligence. These digital technologies each bring significant new capabilities, but their real potential lies in their convergence and connectivity, with innovative firms identifying new business models and new ways to disrupt established ways of working. Such extensive and potential disruption requires industry and governments to prepare for radical change.

How will workers acquire the skills needed to work with these technologies? What will the effect of the changes be on workers whose skills are at risk from automation? Questions about the impacts on the workforce sit alongside debates about how, if at all, technological transformations might reverse the growing inequality gap between rich and poor. This is coinciding with growing social pressure to move toward environmentally sustainable development, as well as significant shifts in global geopolitical and economic power and influence.

4IR is a useful label for connecting discussions about the future of manufacturing and what companies and policy makers can do to anticipate and prepare for the changes that result from this digital transformation. As an umbrella term, it can help refer to a broad trend and its implications, and can also act as a catalyst for researchers and policy makers who want to understand how new technologies are changing manufacturing and employment.

RESEARCH PERSPECTIVES

Research is being undertaken from academic, policy and commercial perspectives: The number of academic papers published spanning a range of topics relating to 4IR has grown fast in recent years, as have reports and whitepapers by policy analysts. This report draws on examples of such work by international organisations needing to address the policy implications.

There have also been studies initiated by individual companies. For example, BAE Systems produced the report *Future skills for our UK business*, with analysis of how new technologies could change the company's need for different skills, including the suggestion that "the jobs of the future may have names we don't recognise today". IBM has published its own study *The enterprise guide to closing the skills gap*. This sets out to be a guide for companies on how to "foster talent and close the skills gap". As IBM's report shows, one immediate issue that arises from emerging digital technologies is the profound effects they will have on the workforce and the skills needed to sustain industry.

Beyond skills and employment, several other factors come into play in any analysis of the projected impact of digitalisation. As well as the technologies involved, we need to understand the geography of manufacturing and consumption – where people make and buy things – and what this could do to the distribution of income and wealth between countries.

Other studies of 4IR also insist that this change in the world of manufacturing cannot ignore the wider issue of social inequality. Since the turn of the millennium, wages constitute a decreasing share of GDP. This was the underlying theme of the MIT report, *The work of the future: Shaping technology and institutions*[2], which sees today's challenge as "channelling technological progress and accompanying productivity growth into a strong labour market that delivers broadly distributed income growth and economic security, as occurred in the decades after World War II". In a similar vein, analyses of 4IR often discuss opportunities for digitalisation to support the demand for sustainable growth.

Klaus Schwab, the founder and chief executive of the World Economic Forum, summed up the challenge of juggling these pressures when he wrote in his influential book *The Fourth Industrial Revolution:* "Shaping the fourth industrial revolution to ensure that it is empowering and human-centred, rather than divisive and dehumanizing, is not a task for any single stakeholder or sector or for any one region, industry or culture."[3]

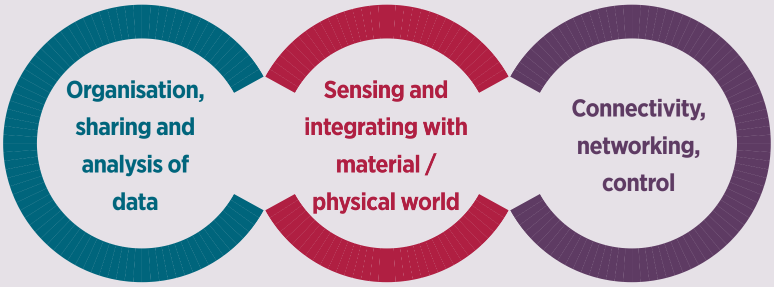
WHAT IS THE 'DIGITALISATION OF MANUFACTURING'?

By Dr Eoin O'Sullivan, Director of the IfM's Centre for Science, Technology & Innovation Policy (CSTI)

The 'digitalisation of manufacturing' is also commonly termed the 'fourth industrial revolution' (or 4IR). It refers to the use of digital technologies, data and applications to deliver advancements in manufacturing-related operations (including the broader value chain of manufacturing activities), to enhance the performance of manufactured products (and related services) in both established and emerging sectors. The family of technologies underpinning digitalisation includes: cloud computing; advanced sensors; high-performance computing; advanced automated and autonomous systems; robotics; artificial intelligence; machine learning; augmented/virtual reality; blockchain; big data; and digital fabrication (including 3D printing), among others.

The potential for improved productivity and competitiveness is emerging through the convergence of these technologies into applications and solutions, through:

- Improved sensing/interacting with the physical world
- Enhanced organisation/sharing/analysis of data
- Better connectivity/networking/control (of industrial-innovation activities)



The term 'Industry 4.0' has gained widespread international currency, including by governments, global companies, and the media. The term originates from the strategic initiative of the German government's High-Tech Strategy ('Industrie 4.0'). This anticipates the impact of a fourth industrial revolution whereby cyber-physical systems, the Internet of Things, and big data will more effectively connect and integrate manufacturing systems.

SECTION 2
FUTURE EMPLOYMENT AND SKILLS

An important aspect of past industrial revolutions has been that labour-saving technologies have affected the workforce. Workers who wanted to keep their jobs had to learn new skills to continue in their present employment, or, if automation replaced their occupations, to find jobs in different occupations or locations. The emergence of digital technologies is no exception. Digitalisation of manufacturing is making some occupations redundant, particularly tasks that can be automated.

Much of the discussion around 4IR has been on if and how it might displace existing jobs. However, it will also affect new recruits to the manufacturing workforce. As Jörg Mayer of UNCTAD put it, while we have to give existing workers the skills and knowledge needed to accommodate the new ways of working, we also have to train new workers to meet new challenges. Mayer underlines that the quality of work is also essential: As we have already seen in some countries' responses to the so-called 'gig economy', in an increasingly digitalised and rapidly evolving global economy, workers will seek what the International Labour Organization calls 'decent work'[4] — employment with good wages and labour standards.

So what evidence is there about the likely impact of digitalisation on workers and employers? And what considerations are emerging for policy makers?

OCCUPATIONAL MOBILITY, SKILLS AND TRAINING NEEDS (OECD)

Mariagrazia Squicciarini of the OECD Directorate for Science, Technology and Innovation presented to the Babbage Forum some of the findings from an OECD report, *Occupational mobility, skills and training needs*[5]. This research raises questions for policy makers around approaches to education and lifelong learning, to accommodate the potential need for 'mass reskilling'.

To begin to estimate the possible economic costs of such reskilling, Squicciarini explained, various factors need to be assessed including type of training, duration, variation of training needs between sectors, or between manufacturing and services. The likely different impact on younger and older workers is also an important component.

Squicciarini shared OECD findings looking at 123 different occupations across 31 OECD member countries. The research identifies jobs at high risk of automation, and considers the consequences of those workers needing to move to 'safe haven' occupations at lower risk of automation. For this purpose, it helps to think in terms of the transitions that workers can make between occupations. Squicciarini described a 'typology of transitions' – see Figure 1. 'Possible transitions' are transitions which involve similar skills and knowledge. 'Acceptable transitions' are a subset of possible transitions with limited negative impact – these may for example entail small wage reductions or unexploited skills, for example, but would still fall within acceptable parameters to the individual and from a broader socioeconomic perspective.

From this, three scenarios are set out, classifying 'small' training needs (equivalent to up to six months education and/or training), 'moderate' training needs (equivalent to one year) and 'important' training needs (equivalent to three years).

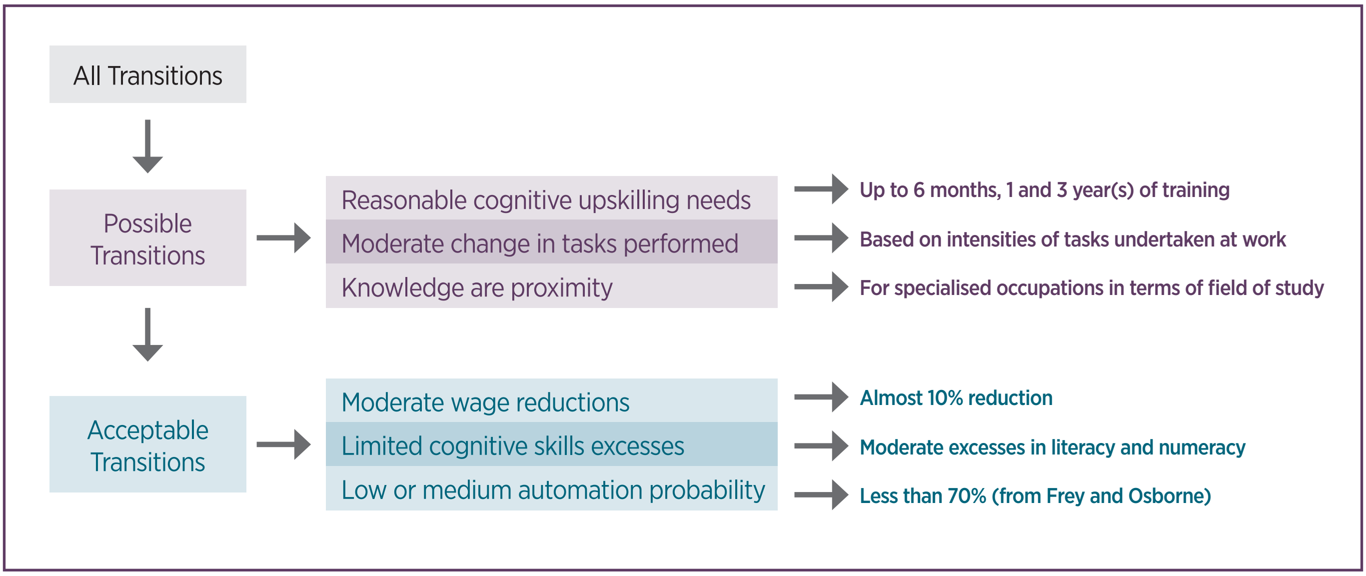


FIGURE 1: TYPOLOGY OF TRANSITIONS FOR JOBS AT RISK OF AUTOMATION[6]
Source: Bechichi, N., et al. (2019) OECD Science. doi.org/10.1787/30a12738-en

Almost all of the 123 occupations analysed in the OECD report appear to have at least one possible transition in the 'small' training needs scenario. However, Squicciarini explained that many of these possible transitions imply movements towards less skilled or less remunerated occupations, which may be unacceptable for individual workers and from a societal point of view. The report finds that acceptable transitions are much harder to identify for many occupations, particularly in the small training needs scenario. When pooling data from all countries included in the analysis, she reported, the researchers found that 46% of occupations do not have any acceptable transitions within approximately 6 months of training. But this drops to only 13% of occupations that do not have any acceptable transitions in the 'moderate' training needs scenario, allowing for one year of training.

Does the type of job make a difference to the availability of alternative employment? According to the report, the number of acceptable transitions is closely linked to occupations' skills level. It finds that low-skilled occupations display fewer acceptable transitions, because most other occupations require higher cognitive or task-based skills. Conversely, transitions for many high-skilled occupations are often not acceptable because they entail important wage decreases or skills excesses.

Acceptable transitions for occupations at high-risk of automation are harder to find, and tend to require cognitive and task-based skills-related training. Occupations for which acceptable transitions cannot be identified in the small training needs scenario mainly belong to occupations such as professionals and technicians.

Squicciarini contended that, overall, the OECD's analysis supports the idea that countries need to invest in education and training to ensure that those at risk of losing their jobs because of automation are not left behind and can find a new job. The findings suggest that those in greater need of support are currently also those that receive less of it, with workers in occupations at high risk of automation appearing less likely to participate in on–the-job training.

The study's estimations of the monetary cost of employment transitions (complemented by work undertaken by other researchers such as Andrieu et al., 2019[7]), suggests that it might take between 1 and 5 percent of a country's GDP to retrain workers for acceptable transitions. However, not all workers need retraining at the same time, so that spending would be spread over some time. Figure 2 illustrates the minimum total cost for a worker in a job at high risk of automation to move towards a 'safe haven' occupation (on average, over the occupations assessed, in countries in four clusters). This analysis produces average per-person minimum costs of between $13,000 - $27,000 in the countries analysed[8].

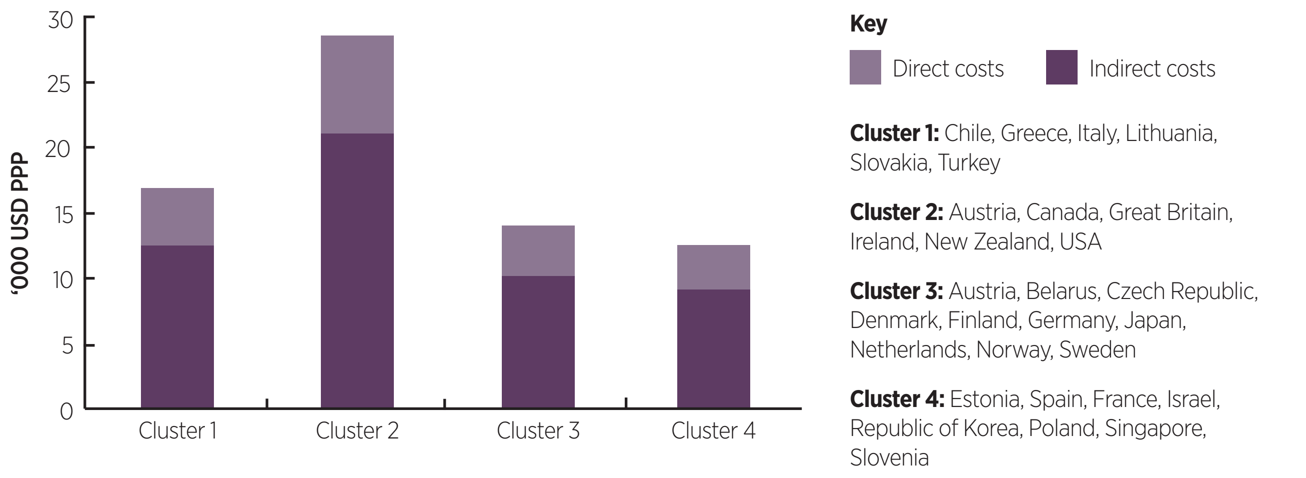


FIGURE 2: MINIMUM TOTAL COST FOR A WORKER MOVING FROM AN OCCUPATION THAT HAS HIGH RISK OF AUTOMATION TOWARDS "SAFE-HAVEN" OCCUPATIONS (AVERAGE OVER OCCUPATIONS AND COUNTRIES IN THE CLUSTER)

Source: Squicciarini's calculations based on Survey of Adult Skills (2012, 2015) and Education at a Glance (2018)

Could age also make a difference to employment transition? Squicciarini reported on further investigation by the OECD which suggests that acceptable transitions are harder to find for older workers. Data gathered in this analysis shows that older workers have, on average, fewer possible and acceptable transitions to alternative occupations which could be reached with retraining – as shown in Figure 3.

Such evidence raises questions for policy makers. Societies with older populations, such as Japan, could face higher costs of retraining. For any country, the efficiency and effectiveness of education and training resources needs consideration, especially for the lifelong learning that will be inevitable in an ever-changing environment for manufacturing. Do governments need to rethink the relationship between industry and education and how they deliver and fund lifelong training? What role can workplace learning play? Could this motivate people who rejected the idea of going to school, for example, to rejoin the education system?

And who is paying? Will the costs fall on governments or businesses, or both? In this new industrial revolution, is it acceptable for the public sector to pick up all of the costs of training and the social costs of unemployment? If companies complain about the lack of skilled workers, shouldn't they shoulder more of the costs of bridging that skills gap? Is it sensible to wait for people to be made redundant before they begin retraining? Or would it be better to begin that process while they are still employed?

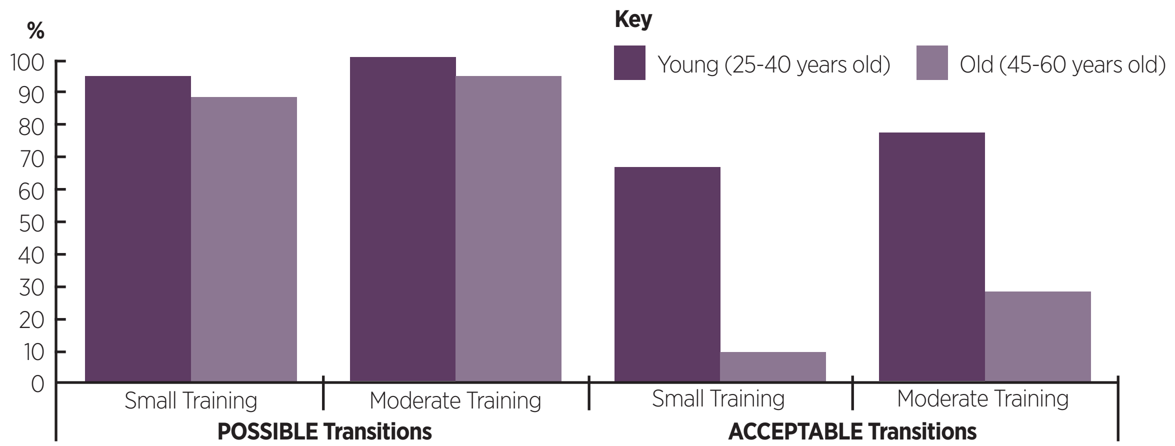


FIGURE 3: ACCEPTABLE TRANSITIONS FOR OLDER WORKERS ARE HARDER TO FIND: PROPORTION OF POSSIBLE AND ACCEPTABLE TRANSITIONS, FOR HIGH RISK-OF-AUTOMATION OCCUPATIONS, BY AGE CATEGORY

THE CHANGING NATURE OF JOBS IN MANUFACTURING (WORLD ECONOMIC FORUM)

The roundtable discussion heard insights from Maria Basso, representative of the World Economic Forum's Platform for Shaping the Future of Advanced Manufacturing and Production. According to interviews that the World Economic Forum has carried out with manufacturing companies, 80 per cent of manufacturers have a skills shortage inside their factories.

Basso explained that the World Economic Forum's analysis, based on consultations with leading companies, confirms that the nature of jobs in manufacturing is changing. For example, while there is still a demand for design engineers, the tasks that they are called on to perform have changed, with the arrival of simulation, 3-D printing and cloud computing, technologies which have transformed the way design work is undertaken. Such developments create a need to update existing skills and to bring new expertise to the workforce.

The World Economic Forum research suggests that manufacturing companies may be ahead of other sectors in providing, and investing in, training.

However, it can be difficult to assess whether the training investment is being provided in areas that will address the skills shortage effectively, with research suggesting that more than 60 per cent of human resources decision makers reporting they do not know if they are investing in the right skills.

As Basso explained, the World Economic Forum's assessment is that it will take new approaches to training to keep up with demand and the pace of change. This will require new partnerships between manufacturing companies, academia and government. There is a window of opportunity now, according to the World Economic Forum, for individuals, businesses and governments actively to manage the transition to the future of jobs. In this way they can transform the learning ecosystem in manufacturing and start a global training movement to ensure that gains and opportunities are shared in a fair way and for the benefits of all.

The World Economic Forum is acting as a catalyst on this front by creating a high-level task force of Chief Human Resource Officers in manufacturing companies, together with experts from academia, labour and governments representatives to share best practices and take action proactively to manage the transition to the future of jobs.

Manufacturing companies already put considerable effort into mapping their existing skills against likely future needs, but they also find it hard to keep up with the pace of technological change.

As a part of its own activity, the World Economic Forum is creating a new framework to map the skills that will be critical for the future, which Maria Basso outlined at the meeting.

An important component of skills provision is the certification of training courses. Some companies have already started to work with schools and universities to establish courses and new certification programmes for workers. As yet, this happens mostly at the local level. For skills to be transferable, there has to be agreement that certification in one company can transfer to another manufacturing company. It does not help that there is no agreement on terminology and what different skills mean. A long-term goal would be to develop these courses and curricula, along with certification, at a global level and in line with the needs of manufacturing companies.

Like the OECD, the World Economic Forum has investigated the need to reskill workers whose jobs are at greater risk of automation. Here the idea is to plan possible job transition pathways for workers at greatest risk, and create cross-company reskilling hubs at the local level. One of the initiatives of the World Economic Forum advanced manufacturing taskforce is a cross-company alignment of what digital literacy in manufacturing means, and development of learning journeys for employees as well as students at universities to be upskilled on the critical manufacturing skills.

SECTION 3

FUTURE GEOGRAPHIES OF MANUFACTURING

Digital technologies will have (and are already having) a major impact on how factories operate, with the rise of the 'smart factory' and advanced manufacturing systems. But the impact also extends much more widely: across end-to-end supply chains, as well as how companies interface with their customers.

Individual technologies are each playing a significant role in supporting operational efficiencies or improved service. Many of these technologies (such as industrial robotics, 3-D printing, computer-aided design and machine learning) have been around for decades, but they are now coming together in more powerful forms that combine their possibilities, and are being used to extract value from data in new ways. These transformations have the potential not only to disrupt how things are made, but also where they are made.

So how are such developments shaping the geographic distribution of manufacturing production? Which countries are leading the way with technology creation, and which are falling behind? How does this affect international development issues? Research from UNIDO, UNCTAD and the Development Centre at the OECD was shared at the Madingley Hall meeting, with some fascinating insights into the likely future geographies of manufacturing.

TECHNOLOGY PROGRESS AT NATIONAL LEVEL, AND INTERNATIONAL DEVELOPMENT ISSUES (UNIDO)

Yee Siong Tong gave a presentation on work by UNIDO which examines international evidence on how different countries are responding to new technologies, and particularly how the impacts of digitalisation are likely to play out differently between high-income and low-income countries.[9]

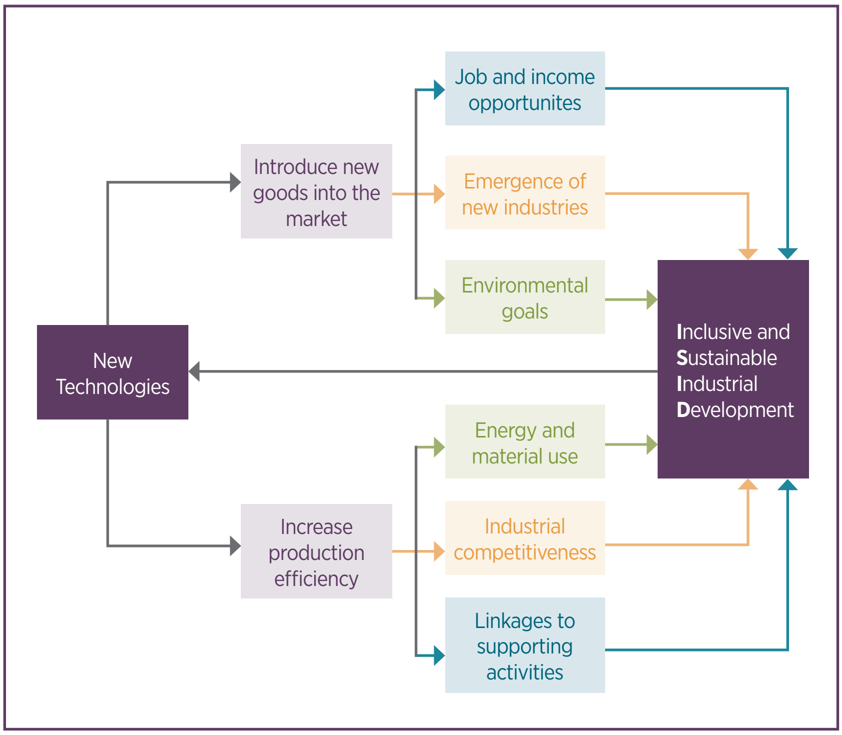


FIGURE 4: NEW TECHNOLOGIES DRIVE INDUSTRIALISATION
Source: UNIDO

Tong shared UNIDO's visualisation (Figure 4) showing how new technologies are driving industrialisation through two main routes, with the potential to lead to more inclusive, sustainable industrial development. The first route is via the introduction of new goods enabled by digital technologies, which leads to the emergence of new industries as well as opportunities to create jobs and increase incomes. The second route is via increased production efficiency, resulting in lower prices, improved energy and material resource efficiency, and a boost to industrial competitiveness.

UNIDO's research looks at which countries are currently leading the technology race, which are following these leaders, and which countries are being left behind. As a method for assessing this, the analysis uses patent data (drawn from the European Patent Office (EPO), the United States Patent and Trademark Office (USPTO) and the Japan Patent Office (JPO)), alongside trade data from Comtrade (see box).

Tong listed a number of challenges for developing countries around adoption of 4IR technologies. These include developing or acquiring the basic capabilities for integrating new technologies into existing systems. Crucially, technological adoption will become even more difficult for countries that struggle with provision of underlying hard infrastructure such as affordable and high quality electricity as well as reliable connectivity. On this basis, technology investments by individual firms may be viewed as too risky. In addition, there is a digital skills gap in many developing countries, at least beyond 4IR 'islands'. There are also issues of access and affordability of new technologies, with the limited number of technology-leading countries, or firms in those countries, often controlling and restricting access.

Nevertheless, Tong explained, there are routes for developing countries and technology latecomers to tap into the opportunities, including:

- Catching up: Adopting older technologies at lower prices, which leading countries or firms are more willing to transfer.
- Stage-skipping: Following the paths of technology leaders but skipping older generations of technology to move faster along the digitalisation path.
- Leapfrogging: Exploiting the emerging new generation of technology as soon as possible. This approach carries risks if new technologies are not as stable or reliable, and can have higher costs at early stages.

Recognising the need to avoid over-emphasising results from one set of data, Tong acknowledged that other analyses suggest that the spread of technology may not be clear cut. For example, in moving towards increased automation, China may buy more robots than other industrialised countries, but in terms of robot intensity, it lags behind the Republic of Korea, for example, which has a higher ratio of robots to employees[10].

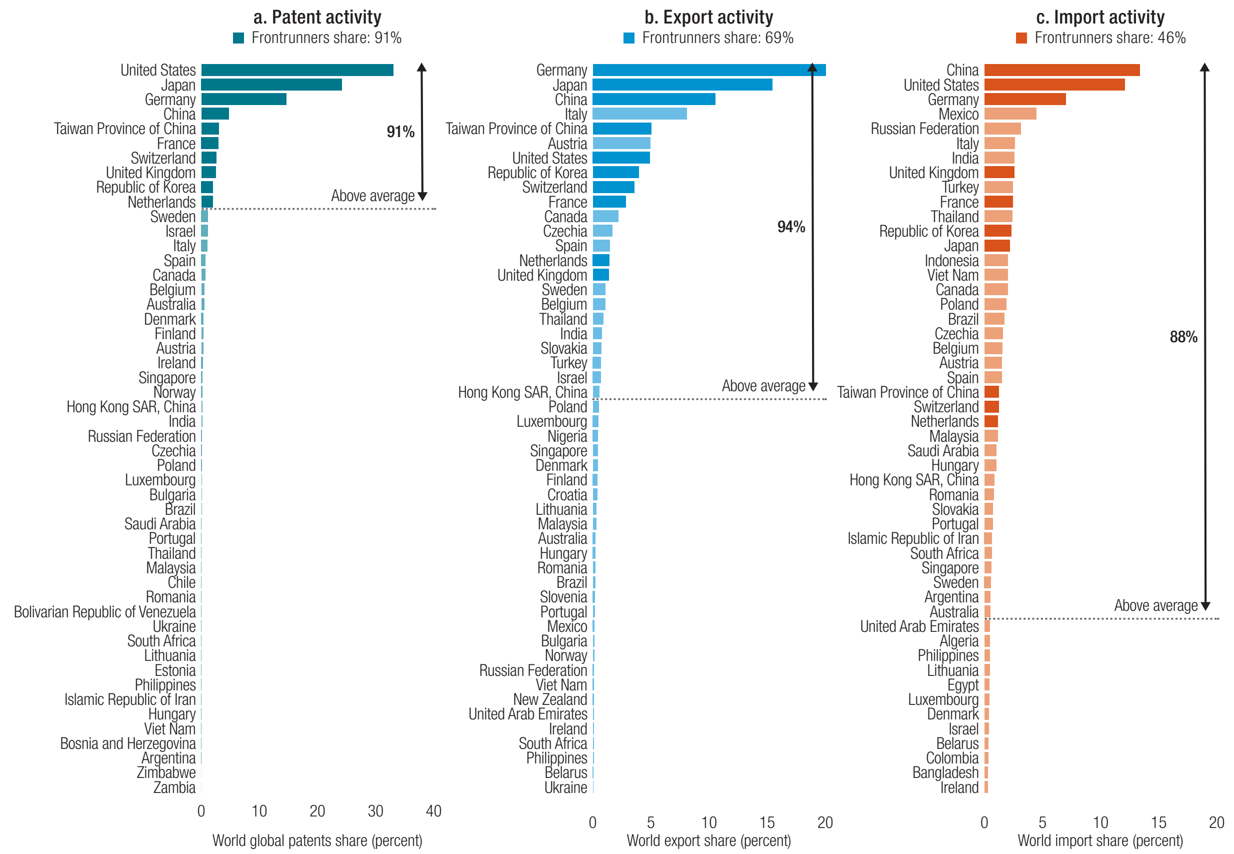
CONSUMER AND PRODUCER COUNTRIES

Almost 80 per cent of the world's exports of key technologies come from eight or nine countries, with a significant overlap in patenting and export activity. Sharing the results from recent UNIDO research, Yee Siong Tong explained how data on patent activity, imports and exports in those technologies categories can be used as a proxy for how technology is deployed and as an indicator of a country's ability to take up new ideas and technologies.

These different measures can help to distinguish between countries as leaders, followers, latecomers and 'excluded'. The assumption is that countries that are leaders are visible in analysis of their patenting and their export activity. Followers, on the other hand have less activity in patenting and less visibility as exporters.

The patent analysis, Tong explained, focuses on patents that have been filed simultaneously in different countries, as an indicator of higher quality patents[11], looking at patents relating to four key technologies – industrial robotics, 3-D printing, computer-aided design and machine learning.

Trade data from Comtrade has also been analysed, examining exports and imports in 2016 of specific goods (in the same four technology types as analysed in the patent research – industrial robotics, 3-D printing, computer-aided design and machine learning). From these data, Tong explained, the UNIDO study classifies countries as 'producers' of technology if that country accounts for more than 0.5% of global exports for these specific technology goods, or if they showed a revealed comparative



Note: Export and import values are in current dollars. Panel a refers to the cumulative number of global patent families in the last 20 years. Global patents are defined as those simultaneously applied for in at least two of the following patent offices: the European Patent Office, the United States Patent and Trademark Office, the Japan Patent Office and/or the China National Intellectual Property Administration Office. Panels b and c refer to the average export and import values of capital goods associated with these technologies for 2014–2016. The figure shows only the shares of the top 50 economies, but the averages are calculated considering all economies with non-zero values in each indicator. The horizontal line in each panel separates the economies above and below the average share.
Source: UNIDO elaboration based on dataset by Foster-McGregor et al. (2019) derived from Worldwide Patent Statistical Database 2018 Autumn Edition (EPO 2018) and BACI International Trade Database (Gaulier and Zignago 2010).

FIGURE 5: PATENT AND TRADE ACTIVITY IN FOUR ADVANCED TECHNOLOGY TYPES, BY COUNTRY. TECHNOLOGY TYPES: INDUSTRIAL ROBOTICS, 3-D PRINTING, COMPUTER-AIDED DESIGN, MACHINE LEARNING
Source: UNIDO Industrial Development Report: Industrializing in the digital age (2020)

advantage. Countries are classed as 'users' of a technology if they account for more than 0.5% of global imports in 2016 or show revealed comparative advantage in these four technology categories.

The separate analyses of patent and trade (export, import) data is illustrated in Figure 5. It shows a greater concentration in the production of technology compared to the consumption of technology. In patent activity for these four technologies, ten countries are above average and account for 91% of filings of patents. We can observe a significant overlap between dominance in patenting activity and dominance in exports, as the ten frontrunner countries in patenting activity account for 69% of world exports. The overlap between imports and patenting activity is not as high, as imports tend to reflect mostly market size and purchasing power of the domestic market.

Given the nature of the technologies and the difficulty of pinning down numbers, Tong was clear to avoid over-stating the accuracy of the statistics, but the analysis provides interesting insights into the broad geography of technology distribution, including how uneven it is at present. Table 1 shows a typology of countries, as technology 'leaders', 'followers' and 'latecomers. It reveals a high concentration in the creation and diffusion of technologies among a minority countries.

	Group	Definition of criteria used	List of countries
Leaders	Established exporting innovators	› Established innovator (world market share of triadic patent families in 4IR technologies above distribution average); AND › Relevant exporting activity (world market share of 4IR good exports above 0.5% OR positive normalised revealed comparative advantage in exports of 4IR goods)	China, France, Germany, Japan, Netherlands, Switzerland, USA, UK
Followers	Emerging exporting innovators	› Emerging innovator (world market share of triadic patent families in 4IR technologies between distribution median and distribution average); AND › Relevant exporting activity (world market share of 4IR good exports above 0.5% OR positive normalised revealed comparative advantage in exports of 4IR goods)	Austria, Belgium, Canada, Denmark, India, Israel, Italy, Taiwan, Rep. Korea, Spain, Sweden
	Emerging innovators	› Emerging innovator (world market share of triadic patent families in 4IR technologies between distribution median and distribution average); AND › Not relevant exporting activity (world market share of 4IR good exports below 0.5% AND negative normalised revealed comparative advantage in exports of 4IR goods)	Australia, Finland, Ireland, Norway, Russian Federation, Singapore
	Established and emerging users	› Established or emerging importer (world market share of 4IR good imports above distribution median) NOT included in any of the above categorie	Brazil, Hong Kong, Czech Rep, Hungary, Indonesia, Iran, Malaysia, Mexico, Poland, Portugal, Romania, Saudi Arabia, Slovakia, South Africa, Thailand, Turkey, Vietnam
Latecomers	Entering innovators	› Entering innovator (world market share of triadic patent families in 4IR technologies below distribution median) NOT included in any of the above categories.	Belarus, Bulgaria, Chile, Latvia, Lithuania, New Zealand, Philippines
	Entering exporters	› Entering exporter (world market share of 4IR good exports below distribution median OR positive normalised revealed comparative advantage in exports of 4IR goods) NOT included in any of the above categories.	Croatia, DPR Korea, Kygyzstan, Slovenia
	Entering users	› Entering importer (world market share of 4IR good imports below distribution median OR positive normalised revealed comparative advantage in imports of 4IR goods) NOT included in any of the above categories.	Algeria, Argentina, Azerbaijan, Bangladesh, Bosnia Herzegovina, Colombia, Costa Rica, Cote d'Ivoire, Ecuador, El Salvador, Ethiopia, Fiji, Kenya, Malawi, Mauritius, Myanmar, Pakistan, Peru, Serbia, Sudan, Tunisia, Turkmenistan, Uganda, Tanzania, Uruguay, Uzbekistan

TABLE 1: TYPOLOGY OF COUNTRIES AS TECHNOLOGY LEADERS, FOLLOWERS AND LATECOMERS

Source: UNIDO Industrial Development Report: Industrializing in the digital age (2020)

LOCATION OF MANUFACTURING ACTIVITIES (UNCTAD)

Emerging digital technologies are altering the factors for decision makers identifying where to locate manufacturing operations. For example, it is increasingly possible to customise products, and to produce goods in smaller quantities, changing the economics of where it is cost-effective to make things. Along with factors such as decarbonisation, these developments are likely to influence the geography of production as manufacturing companies move some of their production capabilities nearer to the major markets in order to meet the demand for rapid delivery.

Jörg Mayer, Senior Economist at UNCTAD, described the organisation's work to build a deeper understanding of the nature of challenges and opportunities that face incumbent workers and new entrants in manufacturing, as they seek employment with decent wages and labour standards in an increasingly digitalised and rapidly evolving global context[12,13,14].

The UNCTAD study looks at three broad areas of manufacturing activity: i) research and development (R&D) and design services; ii) production; and iii) marketing and sales services. With traditional manufacturing, most of the value added by R&D and design is in the higher-income countries often referred to as the 'North', likewise value from marketing and sales are mostly added in the North. Production may be in lower-income economies, often referred to as the 'South' where, while it may add less value than these other processes, it is still important.

Digital technologies, Mayer explained, are reshaping the geography of production and reorganising distribution of value add across value chains. This raises questions for lower-income economies: For example, how can the South avoid substantial production operations moving back to the North ('reshoring'), taking economic activities away from the South? How can the South encourage more pre- and post-production (R&D and sales and marketing) operations to relocate to the South?

The increasing adoption of digital technologies in the South could reduce the disparities with the North in the value-added chain. But for that to happen, and for a country to retain or attract production and employment, developing countries need the infrastructure to support digital manufacturing including reliable connectivity. There are examples of infrastructure development happening rapidly in developing countries: In Asia Pacific, for instance, mobile broadband grew by over 20 percent from 2015-2016, rising from 38 to 47 percent of inhabitants in that short time period. But in many developing countries, infrastructure including localised broadband connectivity remains a challenge which inhibits digital adoption.

In terms of employment challenges for the manufacturing workforce, Mayer drew from the research to posit that the adverse effects of robotisation are often exaggerated, because in situations where it is technically feasible to automate, it is not necessarily economically profitable to do so. While automation will allow some sectors to move production to the North to be nearer to markets, he said, some industries are less susceptible to automation. So while robots and automation have made significant inroads into some domains, such as the automotive industry, they have had limited impact on some labour-intensive manufacturing such as textiles, apparel and leather – as indicated in Figure 6.

So, for the time being at least, labour-intensive manufacturing can still be a route to economic development for lower-income countries. However, the falling cost of automation could change this pattern as robotics makes it possible to replace even those low-cost jobs that currently sustain employment in labour intensive manufacturing.

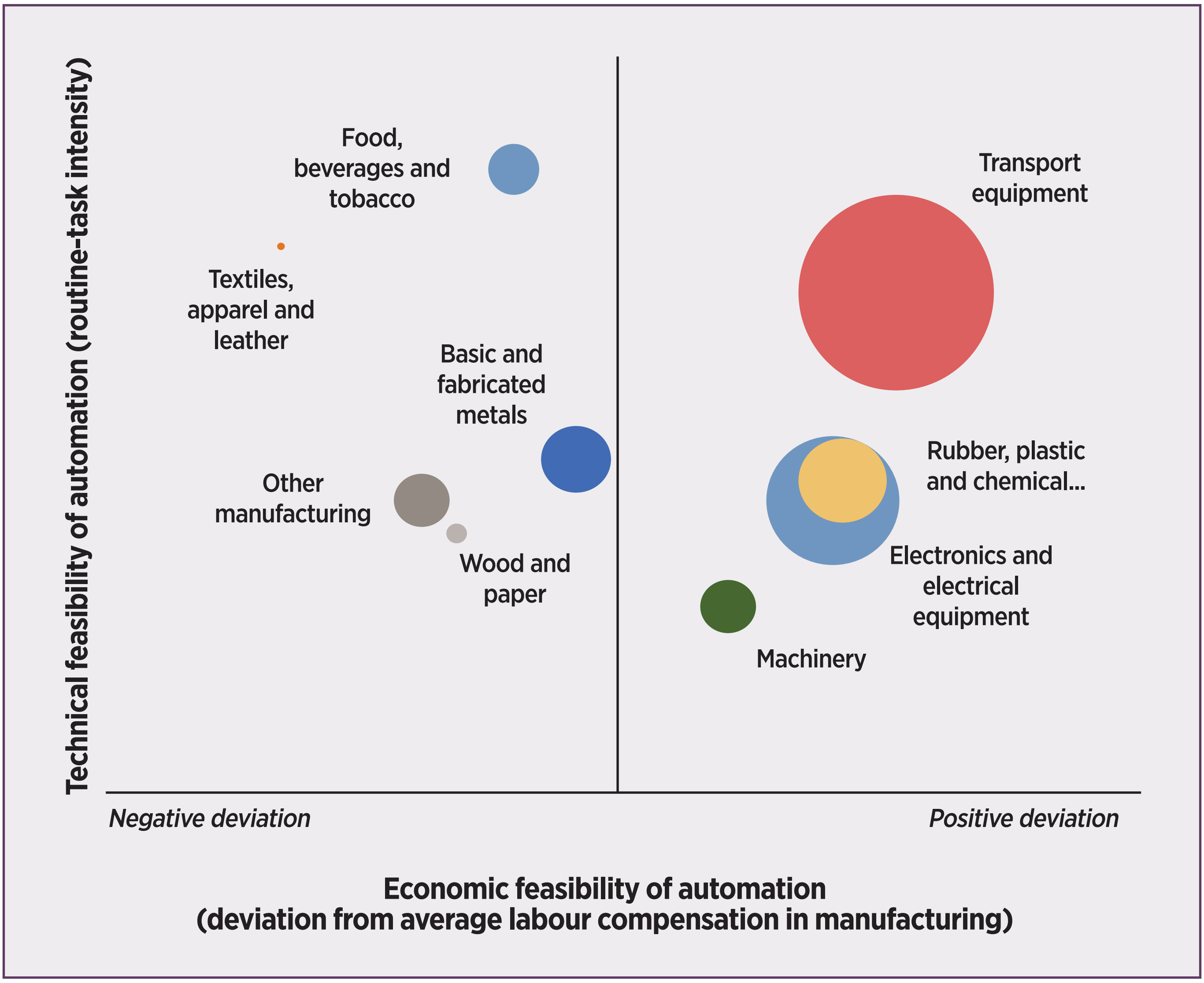


FIGURE 6: TECHNICAL AND ECONOMIC FEASIBILITY OF AUTOMATION

The figure shows the proximate relationship between technical and economic feasibility of routine-task automation, and estimated stock of industrial robots, by manufacturing sector. The size of bullets reflects global use of robots.[15]

Source: UNCTAD secretariat calculations, based on Marcolin et al., 2016; the Conference Board, *International Labour Compensation Comparison* database; and the IFR database.

SECTION 4
POLICY CONSIDERATIONS

Skills and future workforce requirements are key topics for policy makers, with growing pressure to identify and prepare for those 'decent work' (as described by the International Labour Organization, see Section 2). This demands consideration of a broad range of issues encompassing equality, international development and sustainability.

As countries try to meet these aspirations, they have sought policy advice on how to transform their economies and meet demands for improved environmental sustainability by exploiting the potential of new technologies.

PRODUCTION TRANSFORMATION POLICY REVIEWS (OECD)

To meet this need, the OECD developed the Production Transformation Policy Reviews (PTPRs), to provide policy measures that countries can take. The PTPRs have been developed in the framework of the OECD '*Initiative for policy dialogue on global value chains, production transformation and development*'[16]. The PTPRs provide tailored strategic and future-oriented policy advice on how to promote effective economic transformation based on a comparative assessment of countries' assets, upgrading potentials and priorities, in-depth domestic consultations, dialogue with the business community and international peer-assessment. At the roundtable discussion, Vasiliki Mavroeidi from the Structural Policies and Innovation (SPI) team at the OECD Development Centre explained that two of the reviews published so far, those of Colombia[17] and Chile, work on the understanding that there is no unique road to development. Every country will have to build its own path, but there are some common methods and lessons that can guide countries.

As Mavroeidi explained, the OECD Development Centre's analysis shows that even when a country depends on particular industries, it sometimes fails to implement policies that ensure these are a lever for production transformation. For example, in its PTPR of Chile, the world's largest copper mining country, the OECD found that R&D intensity in mining was much less than in some other major mining nations.[18] Chile also has large skills gaps in mechanical engineering — an important profession for mining. The result is slow, or even negative, productivity growth in the industry. Chile also concentrates on exporting raw materials rather than processed copper, which has left it vulnerable to price shocks in a sector that is very important to the country's economy.

Chile has taken measures to tackle productivity in mining, with government and industry coming together to see what they could do about the gap in R&D and innovation, skills shortages and the importance of global standards. One aim was to encourage the development of local supply networks. An important part of the PTPR of Chile was to provide a comparative assessment of Chile's strategic programme in mining. The work also considered industrial developments that might affect the mining sector. For example, it considered the possible effects of global moves towards electric cars, a trend that could increase the demand for copper in the automotive sector.

Other lessons from this activity included the need to broaden consultation beyond the large companies and government players that usually participate in policy discussions. Where are the smaller players that will be a part of the supply chain or wider ecosystem, such as machinery suppliers.

The OECD's PTPR also looked at Chile's solar energy sector. In the Atacama Desert, Chile has excellent solar resources and the potential to generate inexpensive solar energy. But such is the nature of the local sunlight, with its high intensity and UV-B radiation that is 65 percent above the European average, that imported photovoltaic solar cells would 'burn'.

As Mavroeidi said, this might look like a great opportunity to develop indigenous solar manufacturing. But manufacturing of solar cells is not an easy industry to break into, especially with competition from production in China. Analysing Chile's strengths and weaknesses led to the idea of developing global partnerships to conduct applied R&D in Chile and then to establish a research consortium to develop the industry. Indeed, based on the OECD's input, this idea grew to encompass the wider domain of renewable energy.

The OECD's work sheds light on disparities and inequalities between countries. To reap the benefits of new technologies, according to the Development Centre's SPI team, developing countries need to be able to address major gaps such as infrastructure. Analyses from the OECD allow countries to benchmark their positions in areas such as internet connection speed, and number of users sharing connections. For example, they can see that broadband speed in Africa is the lowest in the world: downloading a 7.5GB high definition movie can take a day in Congo compared with 20 minutes in Singapore. While these limitations and inequalities exist, the gap between technology leaders and those left behind is likely to continue to grow.

Mavroeidi expressed that the lesson from this exercise is that when trying to develop industries in new areas of technology, or to improve the performance of existing sectors, it is important to look at future trends, learn from other countries and to adopt a value-chain approach.

The OECD Development Centre's analysis shows that even when a country depends on particular industries, it sometimes fails to implement policies that ensure these are a lever for production transformation.

MANUFACTURING LIGHTHOUSES AND REGIONAL HUBS (WORLD ECONOMIC FORUM)

WORLD ECONOMIC FORUM

Collaboration is a key part of the World Economic Forum's approach in its research into the impact of digitalisation. Maria Basso explained that the organisation tackles the topic from the perspective of public-private cooperation, with a remit to "provide a unique space for leaders from government, industry, civil society and academia to shape the global agenda and drive action and impact".

Among the World Economic Forum's core activities is its '*Platform for shaping the future of advanced manufacturing and production*'[19]. Initiated three years ago, with a community of more than 130 organisations, the work focuses on four main challenges, starting with an investigation of how technologies are disrupting production.

Drawing on the input of more than 70 leading manufacturing firms, the work involves analysing of how factories can adopt new technologies at scale. It also investigates how these evolving technological trends are affecting workers and how to enable the production workforce to acquire the skills to work with new manufacturing technologies.

A common issue for the companies that the World Economic Forum works with is the desire not just to change their manufacturing operations, but also to transform their business models and how they work with supply chain partners. To address this need, the World Economic Forum's work has included development of the Global Lighthouse Network, identifying factories that are most advanced in integrating new technologies into modern manufacturing and production. This forms a useful set of examples for other manufacturing companies, especially SMEs, to come together and learn from these leaders. Lighthouse companies were "chosen for their leadership in applying Fourth Industrial Revolution technologies to drive financial and operational impact"[20].

In parallel with this activity the World Economic Forum has established a network of Regional Advanced Manufacturing Hubs. These connect local leaders to address regional challenges affecting industry and society, and to share global best-practices and lessons and experiences. So far there are hubs in Michigan in the USA, Andhra Pradesh in India and Guangdong in China.

Certain common issues can be identified across these World Economic Forum programmes. These include common threads within particular sectors: For example, in the machine tools industry, which are often medium sized companies, it is evident that companies need to do more to equip managers with an understanding of how developments in artificial intelligence will affect their businesses, in order for them to recruit the people with the skills to fit evolving business needs for this technology. Examples such as this also illustrate the importance of ensuring SMEs do not get left behind while large companies invest in expensive new technological systems.

Another common theme that emerges concerns the approach taken to how new technologies are adopted. Frequently firms take a decision to implement a technology, and only then attempt to 'push' it out on the shop floor, a tactic which can be counterproductive in terms of worker buy-in and motivation. Often a more successful approach is to 'pull' technologies from the production workforce, with employees enabled to come up with their ideas on how to use new technologies in more efficient ways.

The conclusion from this experience, says Basso, is that "people, not technologies, remain the most important source of competitive strength". After all, the data tell us that more than 70 per cent of tasks are still done by humans. The World Economic Forum lighthouse factories are demonstrating that if companies give people the right skills and the room to innovate, ideas for effective uses of technologies will be generated by the people who need to use them, which can then be pulled into production.

UNDERSTANDING THE EMPLOYMENT OPPORTUNITIES (UNCTAD)

Further to UNCTAD's research described in Section 3, Jörg Mayer also discussed policy implications of structural changes resulting from industrial digitalisation. Opportunities and related policy measures will vary, he said, depending on a country's skill level and state of industrial development.

Employment opportunities are often exaggerated, according to the research, and are heavily determined by levels of digital skills and manufacturing experience, coupled with supportive policies.

Mayer observed that the employment opportunities in global value chain-based manufacturing, and stemming from foreign direct investment, are likely to depend on the strategy of a lead firm or platform in the value chain. Changes are likely to be seen in the nature rather than the magnitude of employment and trade in manufacturing, with uncertain effects on income distribution. Indeed there is a risk of greater concentration of market power and income in the hands of existing lead firms.

The largest employment and income opportunities, Mayer said, are probably in countries with indigenous manufacturing activities.

However, realising these opportunities could be very challenging. Policy support is essential not only for addressing digital skills requirements, but also for going substantially further to nurture economic development, and avoiding a widening gap between high and low-income economies caused by differing digital capabilities.

SUMMARY AND QUESTIONS FOR FURTHER RESEARCH

Researchers and policy analysts from leading international organisations and from the Institute for Manufacturing at the University of Cambridge came together on the 24th of June 2019 to share perspectives and research for understanding the future of the manufacturing workforce, in particular to identify opportunities to improve policy evidence-gathering, policy analysis and policy making.

The roundtable discussion at Madingley Hall in Cambridge was convened by the IfM's Centre for Science, Technology and Innovation Policy (CSTI), together with the Policy Links Unit and the Babbage Industrial Policy Forum. It brought together an invited group of representatives from the Organisation for Economic Co-operation and Development (OECD), the United Nations Industrial Development Organisation (UNIDO), the World Economic Forum, and the United Nations Conference on Trade and Development (UNCTAD), as well as the UK government.

The meeting focused on the topic of anticipating "The future of the manufacturing workforce", with discussions around the many challenges and opportunities for the future workforce driven by the changing nature of production. In particular, this group of researchers and analysts explored ways to better conceptualise future manufacturing systems and skills, and the implications for future workforce capabilities. The box below highlights some of the key topics that were discussed during the workshop.

In this report, we have highlighted some of the discussions arising from the workshop and presentations during the workshop. In the following, we summarise the key sections from this report.

REPORT SUMMARY

In Section 1, we explained some of the key developments in emerging technologies that are shaping the future manufacturing workforce. These technologies often revolve around the 'digitalisation' of manufacturing, also commonly termed the 'fourth industrial revolution' (or 4IR). The family of technologies underpinning digitalisation includes: cloud computing; advanced sensors; high-performance computing; advanced automated and autonomous systems; robotics; artificial intelligence; machine learning; augmented/virtual reality; blockchain; big data; and digital fabrication (including 3Dprinting).

In Section 2, we highlighted future employment and skills needs. Maria Squicciarini from the OECDs Directorate for Science, Technology and Innovation presented some of the findings from an OECD report, *Occupational mobility, skills and training needs*. Looking at 123 different occupations across 31 OECD member countries, the research identifies jobs at high risk of automation, and considers the cost of workers needing to move to 'safe haven' occupations, which are at lower risk of automation. The study suggests that it might cost between 1 and 5 percent of a country's GDP to retrain workers for acceptable transitions. However, this spending could be spread over some time. Squicciarini further reported that acceptable transitions are harder to find for older workers.

In Section 2, we also highlighted work by the World Economic Forum, presented by Maria Basso. According to interviews that the World Economic Forum has carried out with manufacturing companies, 80 per cent of manufacturers have a skills shortage inside their factories. Like the OECD, the World Economic Forum

KEY TOPICS THAT WERE DISCUSSED DURING THE WORKSHOP

Policy analysis revealing the impact of technology within and between countries:

- Which countries are leading the emerging technologies race, which are followers, and which are left out? What data sources are available to reveal these trends (such as patent data), and how representative are they for giving a view of the creation and diffusion of technology?
- Is a digital capability gap being created between developed and developing countries, and is that gap widening, given that access and affordability of technology tends to be controlled by a small number of wealthy countries?
- What are the trends around 'reshoring', with companies in developed countries reversing the 'off-shoring' trend and bringing production back home? How much is automation dictating this trend, as low-cost labour previously gained through off-shoring is now replaced by even lower-cost automated production?

Understanding workforce restructuring and skills requirements

- In the context of automation and constantly changing skills requirements, how should policymakers be approaching education and lifelong learning?
- If "mass" reskilling is required in order to equip the workforce with skills matching new technologies, how much is that going to cost economies, and who should pay? What are the costs of not doing it?
- How do we understand the cost of skills, and treat them as valuable assets that should not be wasted?
- Is there a difference between the cost of reskilling younger workers versus older workers, or between jobs in services or manufacturing?

Anticipating the impact of automation on jobs

- As automation increases in scale and pace, what is the actual impact on jobs? Firms may see increases in productivity, but how are people affected? How can we measure this?
- Predictions indicate that there will be job displacement due to automation – many jobs will be made redundant but new types of jobs will be needed. But will these new jobs be suitable for the same workers who have lost jobs? What is the impact on deprived communities and regions where unemployment is likely to be higher?
- Because advanced manufacturing technologies are going to displace some jobs, there is a need to identify 'safe haven' occupations (which are more resilient to automation). How can we characterise and identify these 'safe haven' occupations? What are the costs associated with such a restructuring of the labour force?

has investigated the need to reskill workers whose jobs are at greater risk of automation. Their idea is to plan possible job transition pathways for workers at greatest risk, and create cross-company reskilling hubs at the local level. One of the initiatives of the World Economic Forum Advanced Manufacturing Taskforce is a cross-company alignment of what digital literacy in manufacturing means, and development of learning journeys for employees as well as students at universities to be upskilled on the critical manufacturing skills.

In Section 3, we focused on the future geographies on manufacturing. Taking a global perspective, we asked: what are the gaps between countries' capabilities in new technological realms, like the 4th industrial revolution? What does this mean for value added and profits at different production stages of value chains? Yee Siong Tong gave a presentation on work by UNIDO on how the impacts of digitalisation are likely to play out differently between high-income, middle-income, and low-income countries. He showed how almost 80 per cent of the world's exports of key technologies (like industrial robotics, 3-D printing, computer-aided design, and machine learning) come from eight or nine countries, with a significant overlap in patenting and export activity. Tong explained how data on patent activity, imports and exports in those technology categories can

... the adverse effects of robotisation are often exaggerated, because in situations where it is technically feasible to automate, it is not necessarily economically profitable to do so.

be used as a proxy for how technology is deployed worldwide and as an indicator of a country's ability to take up new ideas and technologies. These different measures can help to distinguish between countries as 'leaders', 'followers', 'latecomers' and 'excluded'. Leaders will have a high degree of patenting and export activity relative to other countries. Followers, on the other hand, have less activity in patenting and less visibility as exporters.

In Section 3, we also underscored work done by UNCTAD, presented by Jörg Mayer, on how digital technologies are reshaping the distribution of value and profits in global value chains. For example, how can the South avoid substantial production operations moving back to the North ('reshoring'), taking economic activities away from the South? How can the South encourage more pre- and post-production operations (R&D, and sales and marketing), which are significantly more valuable than manufacturing assembly, to relocate to the South? The increasing adoption of digital technologies in the South could reduce the economic disparities with the North. But for that to happen, and for a country to retain or attract production and employment, developing countries need the infrastructure to support digital manufacturing, including reliable connectivity. This remains a challenge. In terms of employment challenges for the manufacturing workforce, Mayer drew on UNCTAD's research to show that the adverse effects of robotisation are often exaggerated, because in situations where it is technically feasible to automate, it is not necessarily economically profitable to do so. While automation will allow some sectors to move production to the North to be nearer to markets, he said, some industries are less susceptible to automation.

In Section 4, we moved on to policy considerations, most importantly to work presented by Vasiliki Mavroeidi at the OECDs Development Centre. They have developed something called Production Transformation Policy Reviews (PTPRs), to provide policy measures that countries can take. The PTPRs have been developed in the framework of the OECD 'Initiative for policy dialogue on global value chains, production transformation and development'. The PTPRs provide tailored strategic and future-oriented policy advice on how to promote effective economic transformation based on a comparative assessment of countries' assets, upgrading potentials and priorities, in-depth domestic consultations, dialogue with the business community and international peer assessment.

QUESTIONS FOR FURTHER RESEARCH

This workshop answered many questions for the future of the manufacturing workforce, but it also raised questions for future research avenues. Many of these questions were about what type of evidence we need to manage workforce transitions. For example, do we have the trainers to retrain workers, or the right institutions? Moreover, there is a need for more structured taxonomies, for example in terms of skills types needed in the future, foundational technologies that are shaping the manufacturing workforce, functional activities within manufacturing firms and factories, and policy levers at the disposal of policymakers.

In the context of developing countries, the evidence on the absorption of digital technologies is scarce, something that needs to be improved. More generally, the lack of data on the productive structures of developing countries remains a challenge. The technology divide between the North and the South also raises questions with respect to global governance: how can we achieve international cooperation for a more equal distribution of scientific knowledge and the production of high-value technologies, if at all?

Although we do need a lot of new data to answer these questions, it is not only about collecting more data, but also about collecting the right data, and counting the data in the right way. For example, the failure to distinguish the automatability of jobs from the actual employment impact of automation on jobs will result in drastically different predictions regarding the impact of automation on the future of the manufacturing workforce.

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Average per-person minimum cost to move from high risk-of-automation to 'safe haven' occupation:
Cluster 1: ~$17,000; Cluster 2: ~$27,000; Cluster 3: ~$14,000; Cluster 4: ~$13,000.

Countries included in this study were:
Cluster 1 - Chile, Greece, Italy, Lithuania, Russian Federation, Slovak Republic, Turkey
Cluster 2 - Australia, Canada, Ireland, New Zealand, United Kingdom, United States
Cluster 3 - Austria, Belgium, Czech Republic, Denmark, Finland, Germany, Japan, Netherlands, Norway, Sweden
Cluster 4 - Estonia, France, Israel, Korea, Poland, Singapore, Slovenia, Spain
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Note: The axes have no scaling to underline the proximate nature of the relationship shown in the figure. Bubble sizes reflect the stock of industrial robots. All data are for a sample of 20 countries and refer to the latest available year. The routine task intensity index refers to 2011-2012. Labour compensation reflects sector-specific medians for the period 2008-2014.

Robot data refer to 2015. Calculating labour compensation on the basis of means instead of medians or on data for 2014 instead of 2008-2014 averages, or using larger country samples for labour compensation and stocks of robot results in only marginal variation in the cross-sectoral relationship shown in the figure.

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Institute for Manufacturing (IfM)

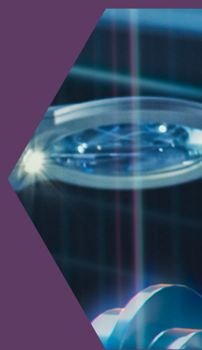
The IfM is part of the University of Cambridge's Department of Engineering. It brings together expertise in management, technology and policy to address the full spectrum of issues which can help industry and governments create sustainable economic growth.

Centre for Science, Technology & Innovation Policy (CSTI)

The Centre for Science, Technology & Innovation Policy carries out applied research into programmes, processes and practices for translating publically-funded R&D (in particular science and engineering research) into new technologies, industries and economic wealth. CSTI is an applied policy research unit exploring what makes national innovation systems effective at translating new science and engineering ideas into novel technologies and emerging industries. Research projects are designed to support the evidence needs of Science, Technology & Innovation (STI) policymakers, in particular those officials in public research agencies who are responsible for programme design, portfolio management and strategy development. The CSTI research agenda is shaped in collaboration with policy and research agency partners.

IfM Education and Consultancy Services (IfM ECS)

IfM ECS provides consultancy and executive development – based on the ideas and approaches developed at the IfM – to help manufacturing and technology companies around the world create and capture value more effectively.



IfM MANAGEMENT TECHNOLOGY POLICY

Institute for Manufacturing
17 Charles Babbage Road
Cambridge CB3 0FS
United Kingdom
www.ifm.eng.cam.ac.uk