UNIVERSITY OF CAMBRIDGE
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POLICY LINKS

Study on digitalisation of the manufacturing sector and the policy implications for Ireland

A STUDY FOR IRELAND'S DEPARTMENT OF BUSINESS, ENTERPRISE & INNOVATION (DBEI)

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A study on the Digitalisation of the Manufacturing Sector and the Policy Implications for Ireland

A report prepared by Policy Links, IfM ECS, for Ireland's Department of Business, Enterprise and Innovation (DBEI)

Policy Links, IfM Education and Consultancy Services (IfM ECS)

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Contributors

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Executive Summary

New digital technologies are radically changing the ways firms manufacture products, the business models they adopt, and even how they innovate. The use of digital technologies, data and applications across industries is opening the potential for enhancing productivity, for (re)connecting manufacturing and innovation, and for creating entirely new markets based on new products and services. The digital transformation of manufacturing goes beyond automation on the factory floor, allowing faster development of new products, better integrated supply chains, and more customised products and services. Digitalisation has the potential to improve resource efficiency, help address supply constraints, and make production processes safer. As such, it is likely to require a paradigm shift in companies' manufacturing strategies. For governments around the world, the digital transformation of manufacturing poses opportunities and challenges in key policy areas such as employment, productivity, competitiveness, and sustainability.

In the context of this report, ***digitalisation of manufacturing*** *is defined as the use of digital technologies, data and applications to:*

- *deliver advances in manufacturing-related operations (including the broader value chain of manufacturing activities), and*
- *enhance the performance of manufactured products and related services, in both established and emerging sectors.*

The *digitalisation of manufacturing* is enabled by a range of emerging technologies that include cloud computing; advanced sensors; high-performance computing; advanced automated and autonomous systems; collaborative robotics; artificial intelligence (AI); machine learning; the internet of things (IoT); augmented/virtual reality (AV/VR); blockchain; big data analytics; and digital fabrication (including 3D printing), among others.

The impacts of each of these technologies are expected to be important in their own right, but it is their convergence and integration that makes them so disruptive. The World Economic Forum estimates that digitalisation could create US$100 trillion of value to industry and society over the next decade, while the European Commission reports that digitalisation could add €110 billion per year to Europe's industry.

A key policy concern is the effect that digitalisation may have on employment. Digitalisation is expected to reshape the skills that will be required from the workers of the future, driving significant disruptions in the labour market. Estimations of potential global job losses across the economy due to digitalisation range from 2 million to as high as 2 billion by 2030[1]. However, it is also believed that digitalisation can be a net job creator in some industries[2], with up to 6 million jobs potentially being created worldwide by 2025[3]. While it is difficult to assess the accuracy of such estimations, they reflect a common perception about the large-scale impact of digitalisation worldwide.

Digitalisation brings with it significant concerns about the cyber security of industrial systems and utilities. It threatens to disrupt business models in important sectors of the economy and offer opportunities for international competitors to gain market share. It has also raised concerns about the ownership of vast amounts of data being generated by firms and consumers. Fundamentally, the

[1] World Economic Forum (2016). Digital Transformation of Industries: Societal Impacts.
[2] The UK Made Smarter review, for example, estimates a potential net gain of 175,000 jobs throughout the UK economy over the next decade.
[3] World Economic Forum (2016).

digitalisation of manufacturing underlies the need for firms, industries and countries to reassess whether their manufacturing systems are ready to compete effectively given the potentially disruptive changes brought about by digitalisation, in the context of increasingly interconnected global value networks[4].

As the opportunities and challenges arising from digitalisation become apparent, major national policy programmes and initiatives are being established in countries around the world to support the 'digitalisation journey' of their industries. These efforts provide a useful international context to inform policy discussions in Ireland.

Against this backdrop, the Department of Business, Enterprise and Innovation (DBEI) has commissioned Policy Links, IfM Education and Consultancy Services (IfM ECS), to assess policy implications for Ireland arising from the digitalisation of manufacturing. The study is based on a review of international policy approaches and a broad consultation with Irish stakeholders, and has been guided by an analysis framework drawing from academic perspectives and concepts. The study goes beyond high-level analysis of basic technologies by more carefully considering the industrial structures and technological systems underpinning the digitalisation of manufacturing. In doing so, in addition to considerations on R&D and knowledge generation around specific technologies, the investigation covers issues relevant to the diffusion and deployment of those technologies in manufacturing sectors.

Addressing the digitalisation of manufacturing is particularly challenging due to its cross-cutting effect on firm operations and industry sectors. The boundaries of manufacturing industries are being reconfigured as digital capabilities and firms, traditionally outside of manufacturing, have become an integral part of emerging value networks. While the focus of this study has been on the opportunities for 'user industries' of digital manufacturing solutions (i.e. firms adopting digital manufacturing solutions to capture value from greater efficiency, flexibility, speed/responsiveness, precision, customisation, etc.), the critical role of ICT solutions suppliers and system integrators has been recognised throughout.

WHAT MAKES IRELAND DISTINCTIVE?

Ireland is particularly well positioned to pursue opportunities arising from the digitalisation of manufacturing. The country has built important industrial capabilities over decades and hosts a disproportionate share of top global firms in a few manufacturing sectors (both process industries and product manufacturing), many of which have established globally strategic sites in Ireland. Ireland is also home to a thriving community of indigenous SMEs. The international makeup of Irish manufacturing and a relatively high export orientation has allowed the country to develop strong expertise in global supply chain management. The presence of world-leading software and ICT industries, and favourable enabling contextual factors add to the country's potential to drive the digitalisation of manufacturing forward, particularly if these ICT firms can be successfully linked to the manufacturing base.

Favourable contextual factors in Ireland include, for example, a relatively highly skilled workforce, efficient regulatory institutions and know-how, and a growing set of research collaborations between

[4] Global value networks can be defined as complex systems of interconnected (and geographically dispersed) firms that deliver value to end users, operating across the full range of business activities. Source: Adapted from Singh, J. and Christodoulou, P. (2014). Capturing Value from Global Networks. Institute for Manufacturing (IfM).

industry and academia and improving research infrastructure. Ireland's strong regulatory environment and expertise is also a distinctive factor and a potential source of future competitive advantage in supporting the technological transition of firms in the country.

Ireland's small size provides a possible advantage as it can allow relevant stakeholders to collaborate closely and implement change quickly. Existing industrial clusters, networks and linkages could help bring together capabilities, allowing firms to identify common digitalisation issues and develop and adopt relevant solutions. Finally, Irish enterprise agencies' continuous interaction with firms and accumulated industrial expertise represent another distinctive advantage when it comes to effective policy implementation and coordination.

WHERE IS IRELAND IN THE DIGITALISATION OF MANUFACTURING JOURNEY?

Some international studies have argued that Ireland is already well placed for industrial digitalisation thanks to its existing industrial base, forward-looking business conditions, and industrial technological sophistication. Such studies have portrayed Ireland as a 'digitalisation front-runner' in Europe because of the number of public initiatives in place to boost the digital economy in the country, the high level of digital integration in its economy, and the presence of a higher-than-average number of companies currently adopting artificial intelligence (AI) and automation technologies.

Stakeholder consultations carried out as part of this project suggested, however, that many Irish manufacturers are just starting to realise and exploit the benefits of digitalisation. Inputs captured from industry indicated that firms in sectors such as food and drink are further behind in the digitalisation journey. Other sectors such as pharmaceuticals, medical devices, and computers and electronics, are dedicating significant work and resources to digitalisation. In these sectors, some firms have established digitalisation visions and strategies and are developing implementation roadmaps. But while some firms might be 'ahead of the curve', stakeholders perceived significant opportunities for improvement in both large and small firms across all sectors. Overall, there was broad agreement that manufacturing firms based in Ireland will need to further exploit the potential of digital technologies to remain competitive internationally. There is a concern that other countries might already be ahead in the 'digitalisation journey' and, thus, lack of action could lead to loss of competitiveness.

KEY OPPORTUNITIES FROM DIGITALISATION FOR MANUFACTURING FIRMS IN IRELAND

Digitalisation holds the promise of significant opportunities for both MNCs and SMEs in Ireland. While some of these opportunities cut across sectors, they might manifest differently and be more or less relevant for firms in particular sectors. To explore these distinctions, opportunities across different 'dimensions' of manufacturing were analysed.

Cross-cutting opportunities (and underpinning capabilities) for Ireland's manufacturing firms identified during consultations include:

- **Product/service innovation.** Including enhanced new business models (through the provision of a range of data services to customers); and development of more functional products (by embedding digital functionalities such as GPS and connectivity to the Internet of things).
- **Process innovation.** Including improved factory productivity (through the use of real-time data for enhanced process and equipment control); improved factory and equipment utilisation

(through predictive maintenance and digital planning and scheduling; improved quality control through digitally-enabled quality management tools; reduced dependency on human error and manual labour (through the use of technologies such as co-bots); small-batch manufacturing and customisation (through use of flexible processes and digital fabrication); reduced energy and resource use (through the use of tools such as digital communication that reduce the need for paper); and improved training of factory workers (through the use of digital tools such as virtual and augmented reality (VR/AR)).

- **Supply chain innovation.** Including better supply chain integration and optimisation (using end-to-end supply chain communication tools); and improved traceability, including digital traceability methods for raw materials/supplies across supply chains, particularly relevant to highly regulated industries, as this could translate into opportunities for accelerated regulatory compliance processes.
- **Product/service delivery innovation.** Including improved knowledge of customer needs (using big data-driven business platforms); and more direct interfaces with customers (by using sales platforms that decrease the need for intermediaries).

The consultations captured information for two types of sectors: process industries (including pharmaceuticals, chemicals and food and drinks) and product manufacturers (including medical devices, computer and electronics, and the engineering sector). Grouping industries in these two natural groups helped to identify commonalities in the opportunities between the sub-sectors contained in those categories.

For **process industries** (including pharmaceuticals and chemicals, and food and drinks), the stakeholders who were consulted emphasised opportunities in the following areas:

- Improvements in plant utilisation, which represents a key cost driver in these industries, through better planning and forecasting as well as predictive maintenance.
- Increased levels of process automation using data in real time.
- Supply chain optimisation and more efficient inventory management through digital integration of cross-firm operations.
- Accelerated regulatory compliance processes and increased digital traceability by employing digital data gathering, management and analysis solutions.
- Improved quality through digitally enabled quality control.

For **product manufacturers** (including medical devices, computer and electronics, and the engineering sector), the stakeholders who were consulted emphasised opportunities in the following areas:

- Moving from simply offering products to offering digitally-enabled services and end-to-end solutions.
- Process optimisation and more efficient new process development using simulation tools, the modelling of a virtual factory, and the use of 3D printing for prototyping.
- Improved supply chain management using digital planning and forecasting tools.
- More efficient delivery of products and services using digital business platforms.
- Improved quality through digitally enabled quality control.

THE CHALLENGES AHEAD

Similarly to firms in other countries, many Irish manufacturers are still at the beginning of the 'digitalisation journey' and face **challenges** before they can reap the full benefits of digitalisation. However, by focusing on issues most relevant to the country's distinctive opportunities, and by taking advantage of the effective and responsive coordination capabilities of its government agencies, Ireland has the potential to tackle these challenges more effectively than other countries.

Key **challenges** identified during the investigation for Ireland's manufacturers to fully exploit the opportunities driven by the digitalisation of manufacturing include:

- **Challenges to knowledge and technology development.** Including perceived gaps in near-market business-oriented research funding and institutions; and challenges to more effectively integrate industry and academia. The development of digital application and solutions to respond to particular sector and firm needs involve system integration challenges at both technology and process levels.
- **Challenges to knowledge and technology diffusion**. Including lack of information about potential business benefits; lack of visibility of where the expertise in Ireland may be; cybersecurity and data sharing concerns; interoperability concerns and lack of information about standards; and lack of a national digital roadmap offering a common knowledge base and revealing common opportunities.
- **Challenges to knowledge and technology deployment.** Including challenges to develop firm-level technology roadmaps; lack of internal firm capability to identify application opportunities and coordinate implementation; skill gaps in the workforce and leadership; difficulties to identify and influence decision makers; high technology implementation costs; and challenges to adapt digital applications in existing processes and legacy systems.

THEMATIC POLICY PRIORITIES FOR IRELAND

Drawing from the diverse inputs gathered throughout this investigation, five priority policy themes have been identified to support the digitalisation journey of manufacturing firms based in Ireland. Examples of possible implementation approaches across each policy theme are presented, drawing from stakeholder consultations as well as an international review of recent policy programmes and initiatives. The thematic priority areas that emerged from this analysis are intended to indicate areas where policy intervention could support Ireland's digitalisation efforts. It is outside the scope of this study, however, to suggest a detailed implementation plan with specific responsibilities for Government departments and agencies, or to assess whether a policy agenda to drive digitalisation in Ireland forward can be implemented with existing institutions.

It is important to note that these priority themes are not centred around particular types of firms or manufacturing sectors. In fact, it is recognised throughout the study that the pervasive nature of digitalisation demands a concerted effort by all types of firms to bring together dispersed capabilities and ensure critical mass. Isolated actions by individual firms cannot address the system integration challenges involved in developing, diffusing and deploying the application and solutions required by manufacturers to fully exploit the benefits of digitalisation.

While many of the opportunities arising from the digitalisation of manufacturing are cross-cutting, an important consideration emphasised in this study is that their exploitation requires nuanced

applications and solutions to effectively respond to sector and firm-specific needs. The availability of a particular digital technology does not by itself guarantee its integration with other digital technologies, or its implementation in industrial processes. Expertise from different technology domains may need to come together to develop generic technology applications (for example, sensor technology, robotics and artificial intelligence may need to come together to develop advanced automation systems), which in turn require a combination of ICT and manufacturing expertise to ensure effective deployment in industrial processes (for example, to integrate such automation systems into production lines of firms in the engineering sector).

It is widely agreed that manufacturing firms need to build their know-how of digital technologies. But, at the same time, ICT and software companies also need to better understand manufacturing processes and environments to support the development and deployment of sector and firm-specific solutions. Both need to better understand mutual business opportunities to incentivise engagement and cooperation.

Collaboration between MNCs and SMEs is also required to fully exploit the benefits that digital capability offer. In particular, support from MNCs (foreign owned and indigenous) to SMEs in their digitalisation journey can lead to positive outcomes for both types of firms. For example, a more competent local supply base not only enhances the potential of SMEs to pursue new supply opportunities, it can also improve the value proposition of MNCs located in Ireland to their headquarters located elsewhere. Exploiting clustering and the strong linkages between MNCs and SMEs throughout Ireland is thus a key step in this direction.

The thematic policy priorities outlined here go beyond R&D. Even when new technologies are developed and made available in the market, many firms are unable to exploit their benefits. Significant efforts are therefore also needed to build the 'absorptive capacity' of firms to truly support their digitalisation journey. In this regard, the Department of Business, Enterprise and Innovation and its agencies can play a critical role in ensuring that firms have access to the various types of support available, and in fostering effective engagement with relevant stakeholders in the wider national innovation system, including government and academia.

The five priority policy themes that have been identified during the study to support the digitalisation journey of Irish manufacturing firms are described below.

1. Awareness raising and identification of user application needs

   Opportunities exist to improve Irish manufacturing firms' understanding of the concept of digitalisation, the potential business benefits of digital adoption, and the sources of existing capabilities in Ireland. There is also a need to capture information about specific nuanced digital applications and solutions of particular relevance for Irish manufacturing sectors. Policy initiatives could include, for example, the compilation of *use-cases* identified locally in online databases; the establishment of communities of practice to identify the most relevant digital applications for Irish manufacturing process industries and product manufacturers; facilitated events involving the domestic manufacturing and ICT communities; and the development of technology roadmaps through working groups.

2. Demonstration of application value

   The need for demonstrators to showcase the value of digital applications to Irish manufacturers was a clear message from stakeholder consultations. Demonstration facilities allow firms to

evaluate new digital technologies and their applications, providing key insights into their potential value capture opportunities, implementation challenges, and financial costs. The precise focus of any demonstrator needs to be chosen carefully, but stakeholder consultations suggested that demonstrators closer to final user applications might be more relevant to Ireland to complement the more basic technology R&D-related demonstration initiatives and facilities already present in the country. Policy initiatives in this area could include, for example, demonstrators of sector-specific applications of relevance to Irish manufacturers, and the provision of education services to understand the changes needed to implement digital applications in their processes.

3. Consortia building and application development

Even when digital technologies are available in the market, technical challenges exist to integrate them into digital applications and solutions that can be deployed into established manufacturing systems. Developing applications with the potential to succeed in the marketplace requires combined efforts from both user industries and solution providers. Policy initiatives in this area could include, for example, the formation of industry consortia bringing together relevant manufacturing and ICT expertise to develop applications demanded by the Irish manufacturing community; the development of affordable 'kits' for SMEs; the simplification of application procedures to allow funding of industry-facing endeavours; and the funding of participation in standards development activities.

4. Technical advisory services for application deployment

The 'journey' to adopt digital applications and solutions in manufacturing operations is fraught with technical challenges. Even when firms make efforts to upskill their workforce, they may not have the expertise necessary to address specific system integration challenges involved in the deployment of digital applications in manufacturing as they emerge. Policy initiatives in this area could focus on ensuring access to relevant advisory technical services to support firms' digitalisation efforts. Because many of the technical challenges are essentially firm-specific, manufacturers require tailored advisory services. These would need to respond to their particular technological and organisational configurations and levels of sophistication. Advisory services can help build digital capabilities across all firms in the manufacturing base in Ireland. However, how supports are deployed might be differentiated according to firm type. A variety of advisory services might be relevant, including: bespoke process upgrading and automation services; new process/product development and testing; standard compliance and certification; supply chain management; technology investment strategy; business model development; product delivery strategy; and firm-level technology adoption roadmapping.

5. Skills for deployment of digital applications (including factory technicians; production and ICT engineers; operation managers; and company directors)

Digitalisation is driving changes in the skill profile required in the manufacturing workforce of the future. For successful integration of digital applications in manufacturing operations, manufacturing professionals need to acquire new ICT skills, and ICT experts need to learn more about manufacturing processes and technologies. In addition to upskilling factory technicians and production and ICT engineers, efforts are needed to enhance the digital skills of company managers and directors. Policy initiatives in this area could include, for example, the development of a clear 'digital career path' or 'digital curricula'; provision of short industry-

defined modules for SMEs; creation of programmes for upskilling networks of SMEs; establishment of courses for managers; and the introduction of apprenticeships.

In addition to these thematic priorities, a few cross-cutting implementation requirements were highlighted by Irish stakeholders, including:

- **Industry needs-oriented funding mechanisms.** This includes recognising the importance of nearer-to- market, business-oriented research funding; accounting for the time and effort required to prepare applications create barriers to industry uptake; and pursuing a more effective coordination between industry & academia
- **Policy coordination.** This includes the recognition that the pervasive effects of digitalisation require responses across various policy areas; the establishment of "bridging functions" to improve coordination and support effective policy delivery; and the need for performance metrics to incentivise linkages, inter-disciplinarity and translation.
- **Appropriate institutional infrastructure.** This includes the need for institutions that can reach firms across the value chain and across regions in the country, with the ability to provide a range of capability building support functions.

NEXT STEPS: DRIVING THE DIGITALISATION OF THE MANUFACTURING AGENDA FORWARD

While it is outside the scope of this study to suggest a detailed implementation plan with specific responsibilities for government departments and agencies, thematic priority areas have been identified where policy action could most effectively support Ireland's digitalisation efforts. These priority areas provide a useful structure to guide the next steps for policy design and implementation.

The report does not attempt to assess whether the policy agenda to drive digitalisation of manufacturing in Ireland forward can or should be implemented by making use of existing institutions. It does, however, highlight that the successful delivery of a particular policy programme or initiative might be determined by the quality of institutions involved in delivering them, as much as by the approach adopted. Further consideration is required to make appropriate judgements regarding the need for new institutions, or for the reform of existing ones, to effectively deliver the digitalisation of manufacturing agenda in Ireland.

Overall, the information contained in this report helps inform the design of practical policy action plans for Ireland. By exploiting the distinctive opportunities and capabilities identified here, Ireland is well placed to take a leading international position in the digitalisation journey.

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1

Introduction

In recent years, the 'digitalisation of manufacturing' has emerged as one of the most important themes in the manufacturing and innovation policies of major economies. Emerging digital technologies have the potential to transform and disrupt the ways in which firms manufacture products, the business models they adopt, and even how they innovate. In particular, the convergence of distinct digital technologies offers the potential to more effectively connect and integrate manufacturing systems, which is anticipated to allow more rapid development of new products, more efficient logistics, and more customised products and services. New digital-enabled markets and business models are shifting the drivers of competitiveness, which could threaten important sectors of the economy, and allow new international competitors to challenge the position of incumbents. The digitalisation of manufacturing thus promises to reshape national manufacturing systems and redefine sources of competitive advantage. For governments around the world, this presents both opportunities and challenges in key policy areas such as employment, productivity, competitiveness and sustainability.

Estimates of the economic impact of digitalisation of manufacturing can vary widely. An often-cited figure is an estimated US$100 trillion of value that digitalisation could create for the global industry and society over the next decade, including US$1.55 trillion in logistics, US$1.28 trillion in telecommunications, US$667 billion in automotive, US$405 billion in aviation, and US$308 billion in the chemical and advanced materials industries[5]. Similarly, the European Commission estimates that the digitalisation of manufacturing could add €110 billion per year to Europe's industry[6].

A key policy concern is the effect that digitalisation may have on employment. Digitalisation is expected to reshape the skills that will be required from the workers of the future, driving significant disruptions in the labour market. Estimations of potential global job losses across the economy due to digitalisation range from 2 million to as high as 2 billion by 2030[7]. However, it is also believed that digitalisation can be a net job creator in some industries[8], with up to 6 million jobs potentially being created worldwide by 2025[9].

It is difficult to make a value judgement regarding the accuracy of these types of estimations. Studies conducted for the European Commission, for example, note that estimates regarding job creation and destruction arising from digitalisation heavily depend on the methodology used and the countries analysed[10]. However, such estimations certainly reflect a common international perception that digitalisation might have a potentially large-scale impact in manufacturing in the short, medium and long terms.

The 'digitalisation of manufacturing', defined in the context of this report as the use of digital technologies, data and applications to deliver advances in manufacturing-related operations (including the broader value chain of manufacturing activities) and enhance the performance of manufactured products (and related services) in both established and emerging sectors, is underpinned by a range of emerging technologies. Examples of these digital technologies include: cloud computing; advanced

[5] World Economic Forum White Paper Digital Transformation of Industries: Societal Impacts.
[6] European Commission (2016). Digitising European Industry: Reaping the full benefits of a Digital Single Market.
[7] World Economic Forum (2016). Digital Transformation of Industries: Societal Impacts.
[8] The UK Made Smarter review, for example, estimates a potential net gain of 175,000 jobs throughout the UK economy over the next decade.
[9] World Economic Forum (2016).
[10] CEPS (2017). Impact of digitalisation and the on-demand economy on labour markets and the consequences for employment and industrial relations. European Economic and Social Committee.

sensors; high-performance computing; advanced automated and autonomous systems; collaborative robotics; artificial intelligence (AI); machine learning; the internet of things (IoT); augmented/virtual reality (AV/VR); blockchain; big data analytics; and digital fabrication (including 3D printing), among others. The impacts of each of these technologies are expected to be important in their own right, but it is their convergence and integration that makes them so disruptive.

Ireland is particularly well positioned to pursue opportunities arising from the digitalisation of manufacturing. The country has built strong capabilities over decades, hosting some of the top global firms in some manufacturing sectors and a thriving community of indigenous small and medium enterprises (SMEs). World-leading software and ICT industries add to Ireland's industrial ecosystem, which positions the country in an envious starting place in the digitalisation journey. It provides Ireland's manufacturing base with great opportunity to make fast inroads in digital transformation if these firms establish networks, linkages, and/or consortia to tackle the firm level opportunities and challenges identified.

Against this backdrop, the Department of Business, Enterprise & Innovation (DBEI) has commissioned IfM Education and Consultancy Services (IfM ECS) from the University of Cambridge to assess the policy implications for Ireland from the impacts, opportunities and challenges arising from the digitalisation of the manufacturing sector. Completed between August and November 2017, the study draws heavily from targeted consultations with industry, academic and public body stakeholders in Ireland (see Appendix 1). Concepts and frameworks from the academic literature have helped inform the methodological approach, and an extensive review of international policy discussions and implementation efforts has provided a valuable context to the emerging priorities identified for Ireland. The study has benefited from strategic guidance provided by a Steering Group (see Appendix 2) with a mix of representatives from the relevant industrial, academic and policy communities in Ireland.

The study has sought to go beyond high-level analysis of basic technologies by more carefully considering the industrial structures and technological systems underpinning the digitalisation of manufacturing. In doing so, it goes beyond considerations on R&D and knowledge generation around specific technologies, to cover issues relevant to the diffusion and deployment of those technologies in manufacturing sectors. Another distinctive contribution of the report is the review of international policy approaches to support the digitalisation of manufacturing, which helps position discussions in Ireland in the context of international competition. The structured approach followed by this study has helped to more clearly reveal distinctive opportunities and challenges for Ireland, while helping to identify policy options that are more actionable.

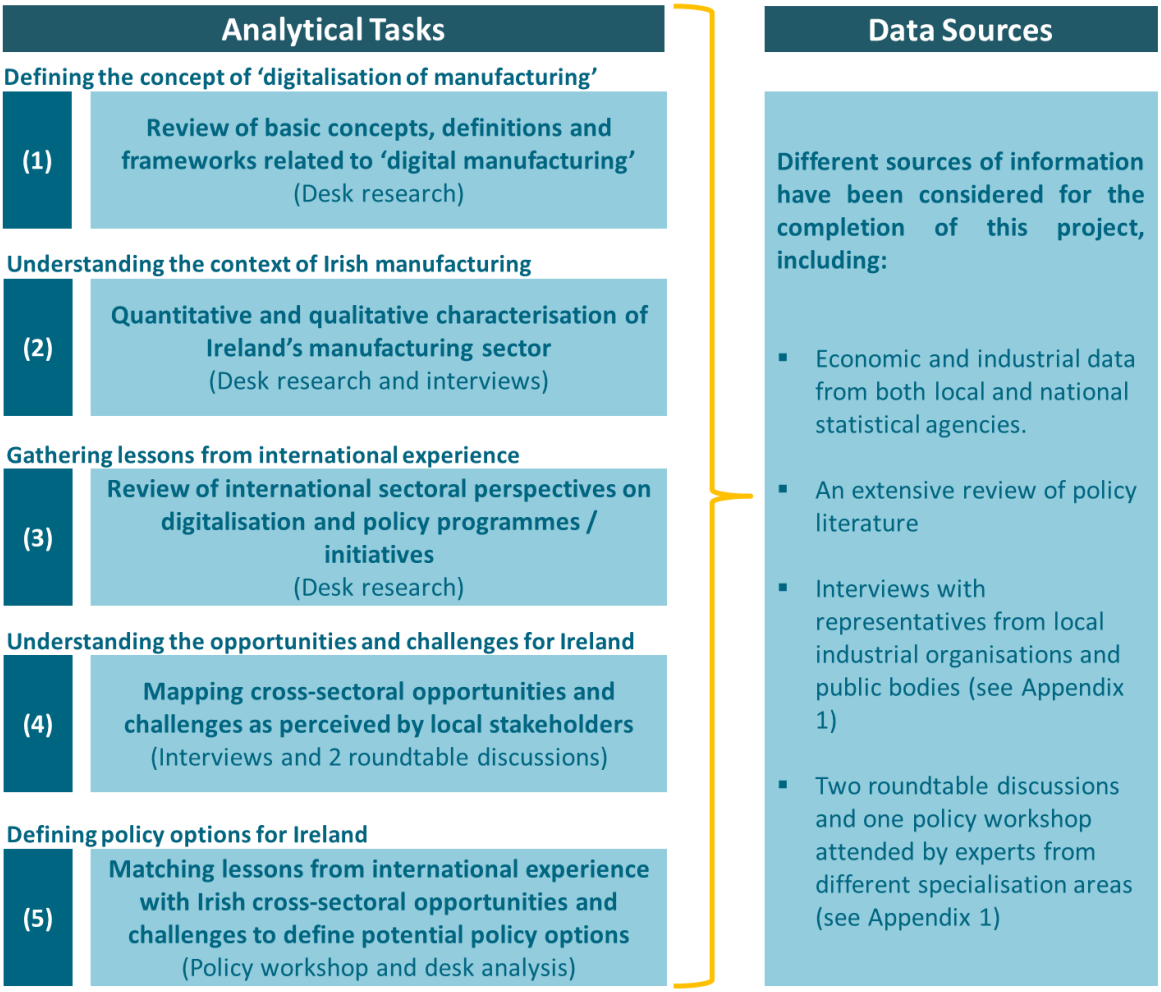
Addressing the digitalisation of manufacturing is particularly challenging due to its cross-cutting effect across firm operations and industry sectors. The boundaries of manufacturing industries are being reconfigured, as digital capabilities and firms, traditionally outside of manufacturing, have become an integral part of emerging value networks. While the focus of this study has been on the opportunities for 'user industries' of digital manufacturing solutions (i.e. firms adopting digital manufacturing solutions to capture value from greater efficiency, flexibility, speed/responsiveness, precision, customisation, etc.), the role of ICT solutions suppliers and system integrators has been emphasised throughout.

It is important to note that detailed implementation plans, outlining responsibilities of specific local institutions, were outside the scope of the project, as this would require an extensive analysis of the domestic institutional framework. Similarly, the project was not intended to provide new evaluations of international implementation mechanisms. Instead, the focus has been on identifying priority areas, where policy action would have the most impact for addressing challenges and opportunities arising from the digitalisation of manufacturing, for Irish manufacturing sectors.

Project approach and structure of the report

The project consisted of five key research tasks, each bringing together various sources of evidence, including statistical data, industrial studies, international policy documents and strategies, as well as stakeholder consultations, as outlined in Figure 1.

Figure 1: Project approach – Research tasks and sources of evidence



The remainder of the report is organised as follows:

- Section 2 provides a working definition of the concept of 'digitalisation of manufacturing' and establishes a framework of analysis to guide the subsequent sections.
- Section 3 analyses key sources of distinctiveness for Ireland including the composition of its manufacturing sectors, discusses Ireland's position in the digitalisation journey, and identifies the main challenges and opportunities for Irish manufacturing arising from digitalisation.
- Section 4 provides key observations from an extensive international review of national policy programmes, and initiatives and mechanisms aimed at supporting the digitalisation of manufacturing.
- Section 5 discusses thematic policy priorities arising from the digitalisation of manufacturing for Ireland, and suggests policy options relevant to address these priorities.
- Section 6 offers concluding remarks.
- Appendices:
    - Appendix 1 provides details about the consultation activities and the list of consulted organisations.
    - Appendix 2 provides a complete list of the Steering Group members for this project.
    - Appendix 3 presents a macroeconomic analysis of the Irish manufacturing sector, outlining its structural composition and highlighting key characteristics.
    - Appendix 4 provides a series of sectoral briefs that draw attention to important qualitative features of Ireland's manufacturing sub-sectors.
    - Appendix 5 presents a review of selected policy programmes and initiatives in major countries addressing challenges arising from the digitalisation of manufacturing.

2

Digitalisation of Manufacturing: Key Concepts and Analysis Framework

This section introduces key concepts related to the digitalisation of manufacturing, provides a working definition, and establishes a framework of analysis to guide the subsequent sections.

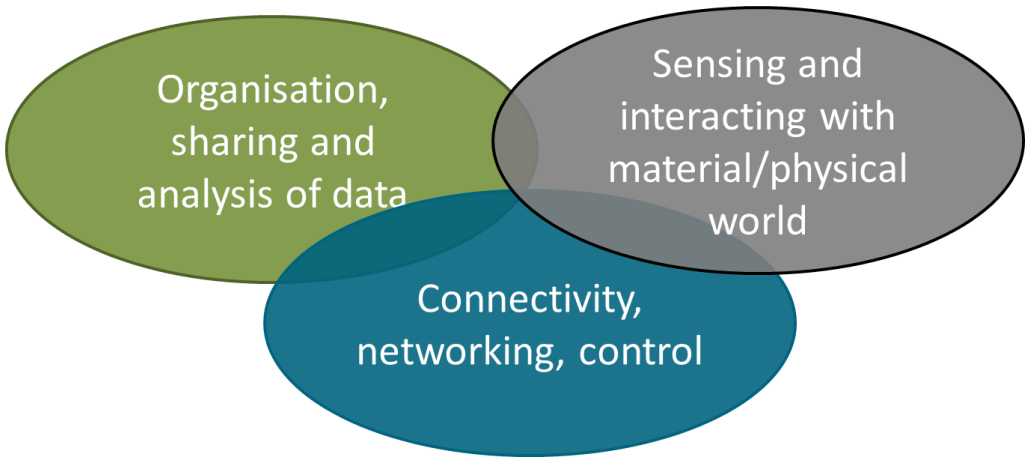
2.1 What is the 'digitalisation of manufacturing'?

For the purpose of this study, 'digitalisation of manufacturing' 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 digitalisation of manufacturing is supported by the convergence of these technologies into applications and solutions, offering the potential for improved productivity and competitiveness through the following (see Figure 2):

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

Figure 2. Capabilities enabled by the digitalisation of manufacturing



Internationally, variations exist in terminology and emphases related to the digitalisation of manufacturing, reflecting differences in stakeholder perspectives and industrial contexts. A range of similar and related terms used in different countries include 'digital manufacturing', 'smart manufacturing', 'fourth industrial revolution', 'industrial internet', 'smart factories', 'cloud manufacturing', and 'cyber-physical production systems'. These terms do not necessarily have a one-to-one correspondence and are not necessarily defined or used consistently.

In particular, the term 'Industry 4.0' has gained prominence internationally, and is now widely used by governments, international firms, management consultancies, and the media. The term originates from the strategic initiative of the German government's High-Tech Strategy ('Industrie 4.0'). It refers to an anticipated '4th industrial revolution' whereby cyber-physical systems, internet of things, and big data will more effectively connect and integrate manufacturing systems. The term is typically used to cover all efforts to integrate and connect vertically, horizontally and along product lifecycles, by contrast with terms such as 'smart factories', 'smart manufacturing' and 'digital manufacturing' which often have narrower definitions.

In the United States the term 'digital manufacturing' [11] is often associated with the use of digital representations of objects and their subsequent manufacture. 'Smart manufacturing', by contrast, often refers to the integration and networking of manufacturing system elements within a factory, enterprise and supply chain, and is using model-based decision-making to enhance processes, downtime of machines, logistics, supply chain management, etc.

[11] O'Sullivan, E. (2016). A review of international policy approaches to supporting research & innovation for the digitalisation of manufacturing. Centre for Science, Technology and Innovation Policy, Institute for Manufacturing, University of Cambridge.

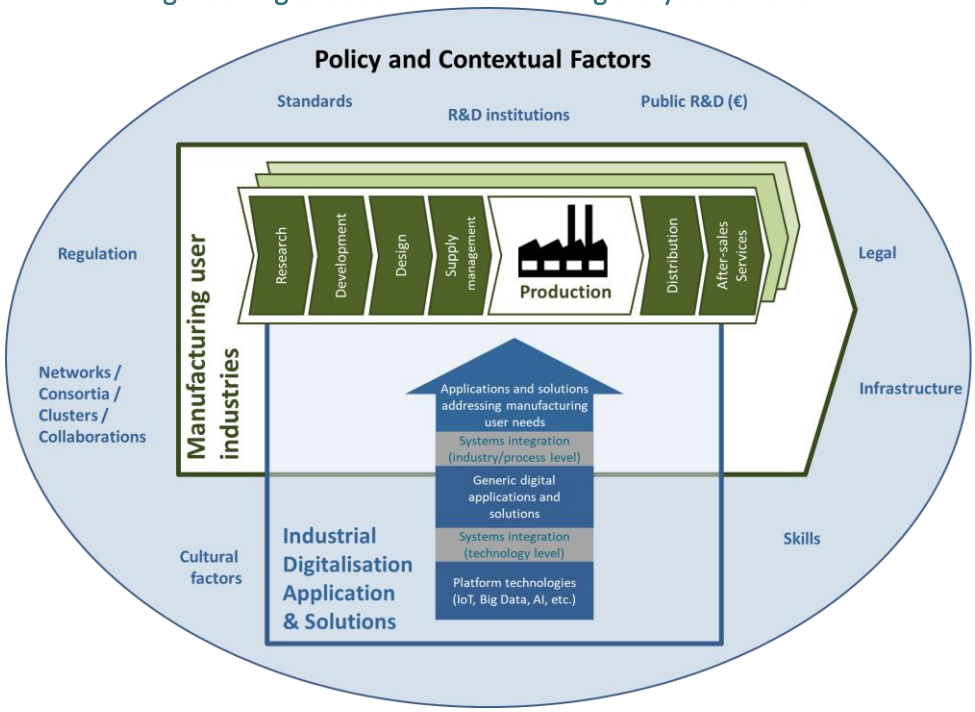
2.2 Understanding opportunities and challenges for firms arising from the digitalisation of manufacturing: analysis framework

This section introduces the analysis framework used to guide the analytical tasks involved in this study. The framework draws from the academic literature, previous studies on the digitalisation of manufacturing, and ongoing work at the Institute for Manufacturing, Cambridge University[12].

The framework involves three core elements, discussed below, and shown in Figure 3:

- Manufacturing user industries and the possibilities for digital applications (i.e. firms adopting digital manufacturing solutions to capture value from greater efficiency, flexibility, speed, customisation, etc.)
- Industrial digitalisation applications and solutions
- Policy and contextual factors

Figure 3. Digitalisation of manufacturing analysis framework



Source: CSTI / Policy Links

2.2.1 Manufacturing user industries (and the possibilities for digital applications)

A key point highlighted by the framework is that digitalisation is not only opening possibilities for particular manufacturing processes or technologies, but for the broader value chain of manufacturing activities, including manufacturing-related producer services. This means digital applications can be used to drive change, not only in physical transformation processes, but also in the wider set of

[12] In particular, research work at the Centre for Science, Technology & Innovation Policy and studies carried out by Policy Links/IfM ECS.

manufacturing activities involved in modern industrial networks: from design and R&D to logistics and marketing.

While a number of policy discussions focus primarily on the vertical integration of production systems ('smart factories'), digital technologies are also driving the horizontal connection and integration of inter-company value chains and networks ('smart supply chains'), and the whole product lifecycle integration across the entire value chain ('smart end-to-end engineering'). Therefore, because modern industries are increasingly interrelated, it is difficult to isolate the impact of digitalisation on individual sectors without considering the wider value networks in which they operate. Modern industries often involve complex interactions and interdependences between a range of firms that provide a variety of components, materials, production systems and subsystems, producer services, and product-related service systems[13]. Innovations made in one industry might have an impact in others and, as such, the boundaries of "sectors" are in continuous reconfiguration. Notably, the expansion of software and information content means that electronics and software firms are becoming a more important component and source of value capture across a range of sectors, from automotive to chemicals and medical devices[14].

Therefore, when analysing the opportunities and challenges of digitalisation in a particular manufacturing sector, it is important to recognise that digital technologies can have a wide range of applications beyond the factory level, and that they might come from outside the traditional boundaries of the sector.

2.2.2 Industrial digitalisation applications and solutions

The second core element of the framework relates to the distinction between digital platform technologies, generic digital applications and solutions, and application and solutions customised for particular manufacturing user needs.

There is a wide range of existing and emerging platform technologies (i.e. a group of technologies that are used as a base upon which other applications, processes or technologies are developed), including artificial intelligence, big data, and Internet of Things, among many others. However, *platform technologies* cannot address manufacturing user needs without first being integrated into suitable *generic applications and solutions* (e.g. a platform technology such as artificial intelligence becomes more valuable when, for example, used in combination with robotic systems to generate autonomous robots).

The integration of distinct platform technologies into suitable *generic applications and solutions* occurs through what is labelled here as *'systems integration (technology level)'*. During this integration phase, *platform technologies* are combined to create cross-cutting solutions for generic manufacturing user needs across sectors (e.g. smart sensors combined with big data analytic capabilities to enable smart supply chain scheduling solutions applicable to a range of sectors).

[13] Tassey, G. (2010). Rationales and mechanisms for revitalizing US manufacturing R&D strategies, Journal of Technology Transfer.
[14] NAE (2015). Making Value for America: Embracing the Future of Manufacturing, Technology, and Work. Committee on Foundational Best Practices for Making Value for America. National Academy of Engineering.

In order to deploy *generic applications and solutions* to address the specific needs of individual firms, it is often necessary to customise these applications and solutions to overcome integration challenges particular to those firms. This customisation is labelled here as *'systems integration (industry/process level)'*, and relates to the fact that firms have a unique combination of technologies and systems already installed in their current operations (legacy systems), which need to communicate and integrate with new digital applications and solutions. Because each firm is different, this integration phase needs to address specific firm requirements and needs.

Digital platform technologies

The universe of platform technologies is diverse and complex. A useful way to classify them is on the basis of their functionality, as illustrated in Figure 4: some technologies are used to generate and capture data from the physical world (data generation); others are used to transmit and manage this data through the network infrastructure (data transmission and management); others are employed to analyse and interpret data in real-time (sense-making); and others enable decision-making related to manufacturing operations, products and services (decision making).

In Figure 4, raw data from the outside world is at the bottom, while manufacturing related decisions occur at the top. The higher up the information is, the more valuable it is, and when it is lower down, the greater the volume of data is. Information processing occurs within each layer and communication connects both the layers and the outside world[15].

'Systems integration (technology level)' leading to 'generic digital applications and solutions'

The single most important feature of the digitalisation of manufacturing is the integration of distinct platform technologies to create applications and solutions to address the needs of the broader value chain of manufacturing activities. This is referenced as *'systems integration'* at the technology level in Figure 3.

Integrated applications and solutions range from vertical to horizontal and product lifecycle integration, including flexible, customisable and self-intelligent production systems, advanced modelling and simulation tools, autonomous robotics, smart supply chain scheduling and tracing, quality control and optimisation, and other supply chain efficiency solutions, among others.

System integration challenges at the technology level require bringing together know-how from distinct types of software / platform solutions, ICT hardware / mechatronic solutions, and data analytics / data management solutions.

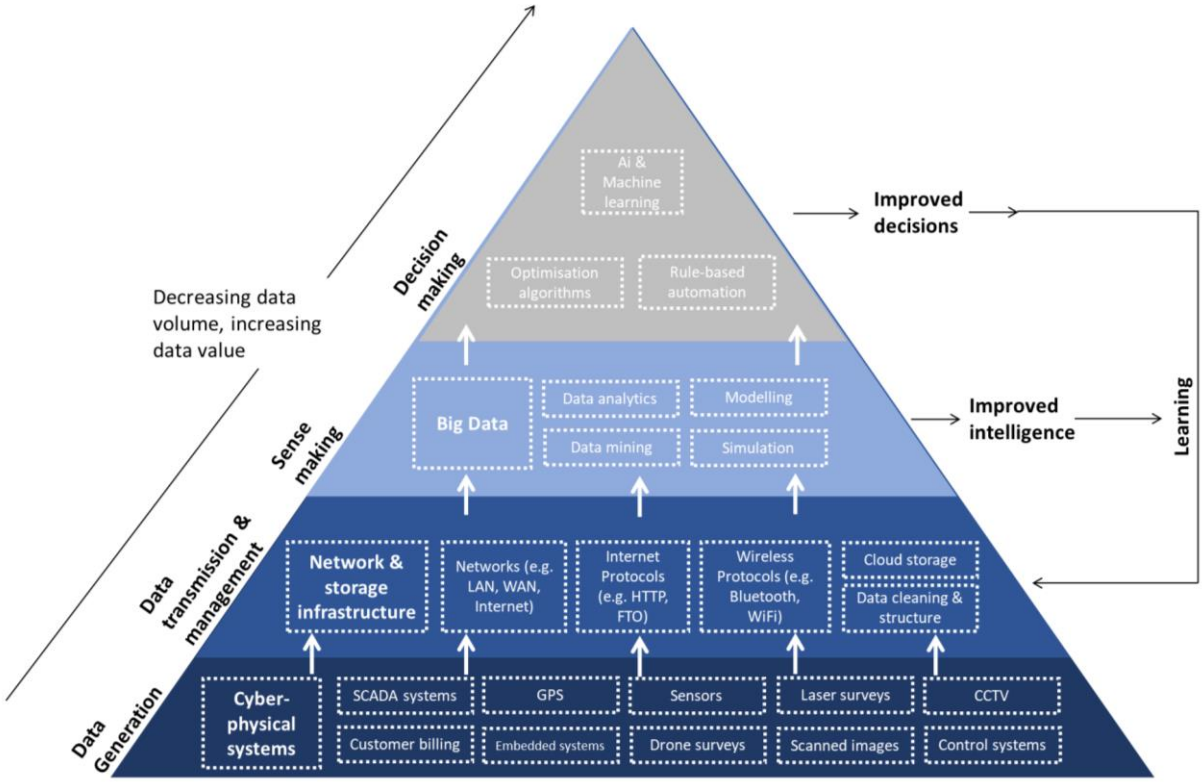
'Systems integration (industry/process level)' leading to 'digital applications and solutions addressing manufacturing user needs'

Generic digital applications and solutions are often not enough to meet manufacturers' needs. Firms have an installed base of production and ICT technologies in their current operations that would need to be integrated with newer applications and solutions to form functional digitally enabled systems. This implies another *system integration* challenge, this time at the industry/process level (Figure 3), that requires extensive

[15] Bowers, K., Buscher, V., Dentten, R., Edwards, M., England, J., Enzer, M., Parlikad, A.K., and Schooling, J. (2016). Smart Infrastructure: Getting more from strategic assets. White paper. Centre for Smart Infrastructure & Construction, University of Cambridge.

knowledge of manufacturing technology and processes together with expertise in generic digital applications and solutions.

Figure 4. Technological framework for digitalisation of manufacturing



Source: Adapted from *'Smart Infrastructure: Getting more from strategic assets. Centre for Smart Infrastructure & Construction, University of Cambridge'*

2.2.3 Policy and contextual factors

The deployment of digital technologies in manufacturing user industries occurs in the context of enabling national conditions that facilitate the development of new technologies, as well as their diffusion and absorption by industrial users. Such policy and contextual factors – including standards, R&D institutions, public R&D investments, regulations, legal system, industrial networks/consortia/clusters/collaborations, skills, infrastructure and even cultural factors – play a key role in either fostering or hindering the deployment and exploitation of digitalisation technologies into manufacturing industries.

From a policy perspective, an appropriate understanding of policy and contextual factors can inform priorities for policy action. And because digitalisation demands a particular enabling environment, this analysis can also provide further insights into where the challenges and opportunities might be for the country's manufacturing industries.

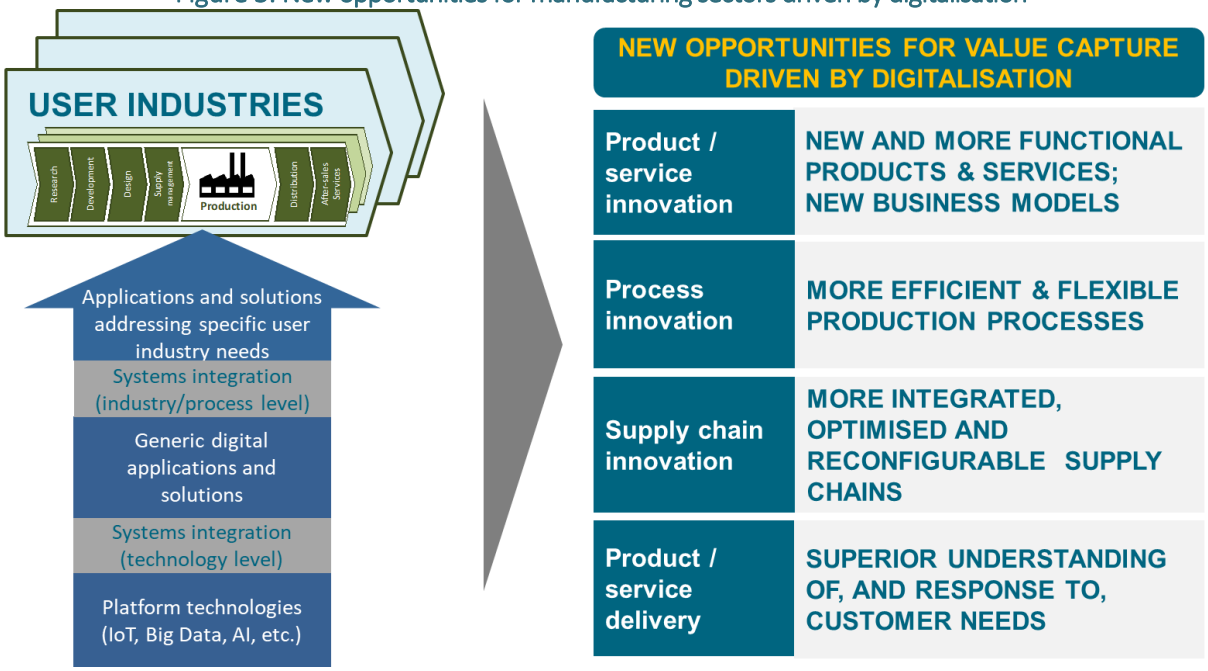
2.3 Sources of value capture for firms

Digitalisation has important implications for manufacturing firms and countries around the world. It is enabling structural change in workplaces and markets by increasing the reach and speed of communication and reducing costs, thus facilitating the flow of goods, capital, people, and information across units, organisations, and borders.

The digitalisation of manufacturing is thus driving new opportunities for value capture by enabling more flexible, customisable and self-intelligent production systems, more rapid development of new products, more efficient logistics, and more customised products and services. A useful way of cutting through this diversity of opportunities, arising from digital technology adoption, is by framing the discussion in terms of four manufacturing 'dimensions' that correspond to different types of innovation, as shown in Figure 5[16]:

- **Product / service innovation –** offering new and more functional products and services, and new business models that create value from digital data and capabilities.
- **Process innovation** – achieving higher levels of factory efficiency and more flexible production processes driven by vertical digital integration.
- **Supply chain innovation** – more integrated & optimised supply chain capabilities driven by horizontal digital integration.
- **Product / service design & delivery** – superior understanding of demand, more customer-led design and delivery using digital platforms, and higher levels of customer satisfaction.

Figure 5. New opportunities for manufacturing sectors driven by digitalisation



The universe of opportunities for value capture may take different forms for distinct industrial sectors and types of firms. To illustrate this point, Figure 6 introduces a list of generic examples of opportunities across

[16] López-Gómez, C.E, Leal-Ayala, D.R., Palladino, M. and O'Sullivan, E. (2017). Emerging trends in global advanced manufacturing: challenges, opportunities and policy responses. United Nations Industrial Development Organisation / Policy Links / IfM.

the four value capture dimensions. Similarly, the analysis of opportunities arising from the digitalisation of manufacturing in Ireland, presented in Section 3, employs the dimensions introduced in Figures 5 and 6 to classify appropriate opportunities.

Figure 6. Examples of generic value capture opportunities enabled by digital manufacturing

		EXAMPLE VALUE CAPTURE OPPORTUNITIES
Product / service innovation	NEW AND MORE FUNCTIONAL PRODUCTS & SERVICES; NEW BUSINESS MODELS	▪ New revenue streams by offering end-to-end solutions rather than just products ▪ Revenue growth through product and service customisation ▪ New revenue streams by offering data services ▪ Revenue growth from adding digital features and intelligence to average products
Process innovation	MORE EFFICIENT AND FLEXIBLE PRODUCTION PROCESSES	▪ Improved planning and budgeting ▪ Increased resource efficiency (energy and materials) ▪ Improved equipment reliability, integrity and usage ▪ Spare parts inventory reduction ▪ Higher maintenance efficiency ▪ Maximise quality and minimise production variability
Supply chain innovation	MORE INTEGRATED, OPTIMISED AND RECONFIGURABLE SUPPLY CHAINS	▪ Improved collaboration / integration with suppliers and third-party providers ▪ Improved demand forecasting for better balancing of demand & supply ▪ Ability to track and trace across supply chain ▪ Reduced inventory costs through dynamic inventory visibility and warehouse management ▪ Reduced inbound and outbound logistics costs
Product / service delivery	SUPERIOR UNDERSTANDING OF, AND RESPONSE TO, CUSTOMER NEEDS	▪ Improved business intelligence through customer needs big data ▪ Increased customer access (e.g. self-service platforms & online marketplace) ▪ Revenue growth through dynamic and flexible pricing ▪ Revenue growth through integration of sales channels ▪ Increased customer satisfaction through better design ▪ Reduced time to market

2.4 Barriers to value capture for firms

Achieving a successful deployment of digital applications and solutions addressing the needs of user industries is, however, not an easy task. Although some of the underpinning platform technologies already exist, some others are still in early stages of development. Ensuring that these technologies are successfully integrated and scaled-up into commercially available applications and solutions, represents another hurdle. Even if these applications manage to get to the market, creating awareness and demonstrating their functionality among industrial users remains a challenge. Integration into real world industrial settings would require firms to have the necessary skills to understand, implement and operate these solutions. In addition, new data-based digital applications might bring with them significant concerns about the cyber security of industrial systems and utilities.

The challenges described above are just a small sample of the many difficulties that could prevent manufacturing sectors and firms from capturing value from new industrial digitalisation trends. It can be argued that the ability to capture value from innovation in digital manufacturing is likely to require an integrated approach to:

- Develop new technologies and embed them in products
- Apply new knowledge and skills to industrial processes
- Develop adaptable and agile supply chains, and
- Deliver products and services that satisfy changing customer needs at the right time and at the right price

A helpful way of classifying the range of challenges and barriers to value capture is by framing the discussion in terms of the three fundamental stages of innovation (i.e. knowledge generation, diffusion and absorption), and by the key 'barriers' constraining such an innovation process, as shown in Figures 7 and 8:

Figure 7. The three fundamental stages of innovation applied to industrial digitalisation technologies

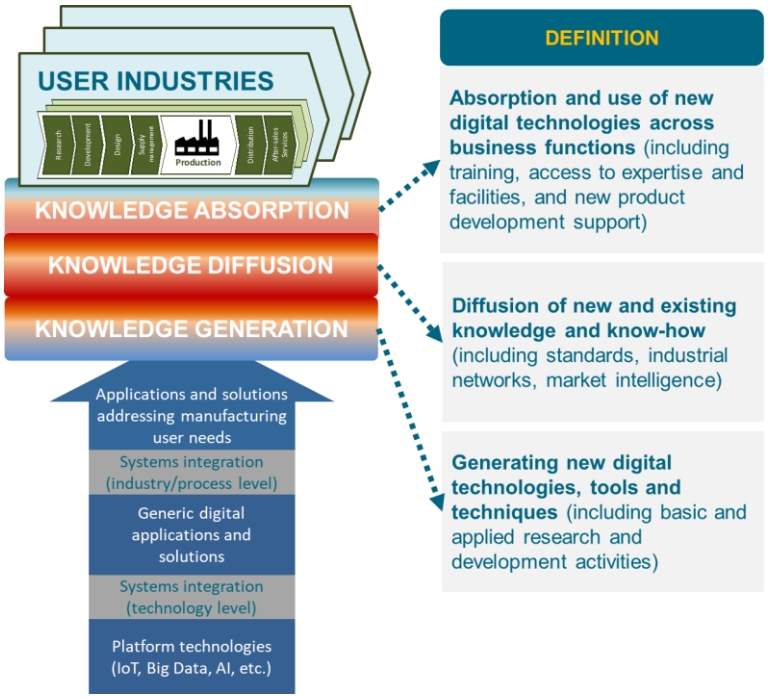
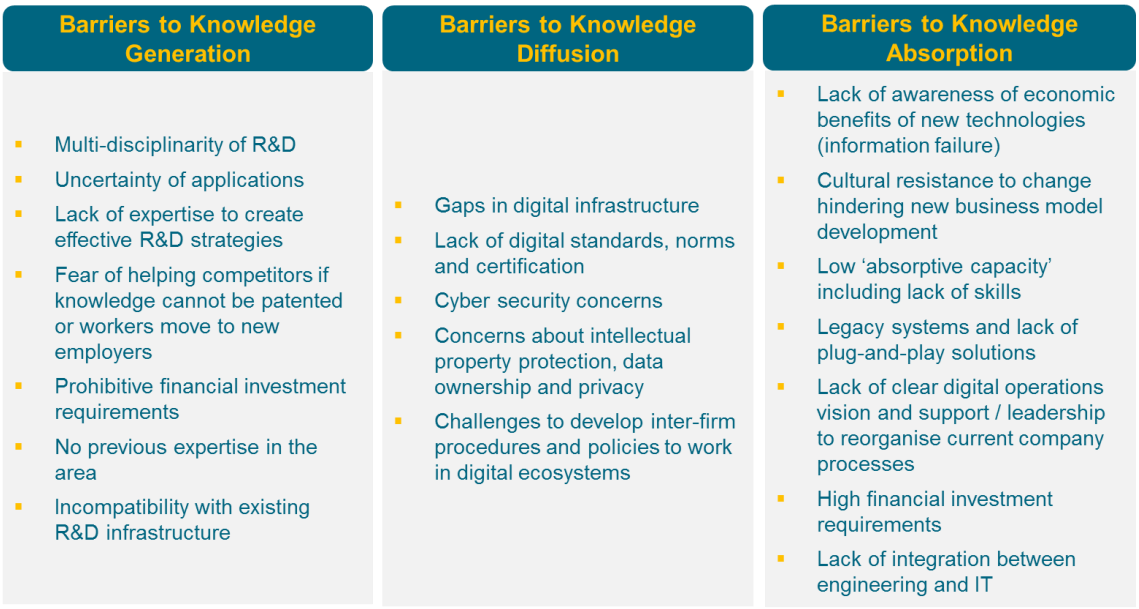


Figure 8. Example barriers constraining the development, diffusion and deployment of digital technologies



The analysis of challenges, arising from the digitalisation of manufacturing in Ireland presented in Section 3, employs the dimensions introduced in Figures 7 and 8 to classify barriers to industrial digitalisation identified during this study.

2.5 Concluding remarks

Digital manufacturing technologies can have a cross-cutting and disruptive effect across manufacturing sectors. The framework introduced in this section provides an overarching structure to deal with the complexity involved in understanding the way in which digital manufacturing technologies are developed and deployed in real-world solutions. It does so by bringing clarity regarding their potential application space within industrial value chains, by the policy and contextual factors that enable or hinder their integration and deployment, and by the new value capture opportunities they generate. Additionally, the framework provides a useful way to analyse potential barriers preventing sectors and firms from exploiting value capture opportunities from industrial digitalisation.

The framework presented in this section helped to inform the design of all research tasks in this project, including consultation exercises with local stakeholders in Ireland, and provided a foundation to structure the following sections, which deal with the identification of specific opportunities and challenges arising from the digitalisation of manufacturing in Ireland (Section 3), and potential policy options to address those challenges (Section 4).

3

Opportunities and Challenges for firms in Ireland from the Digitalisation of Manufacturing

The objective of this Section is to identify key opportunities and challenges arising for manufacturing firms in Ireland from digitalisation, particular to the Irish context. Findings from this Section provide a foundation to discuss relevant and feasible policy options that will aid manufacturing firms in Ireland in realising opportunities and addressing challenges related to digitalisation.

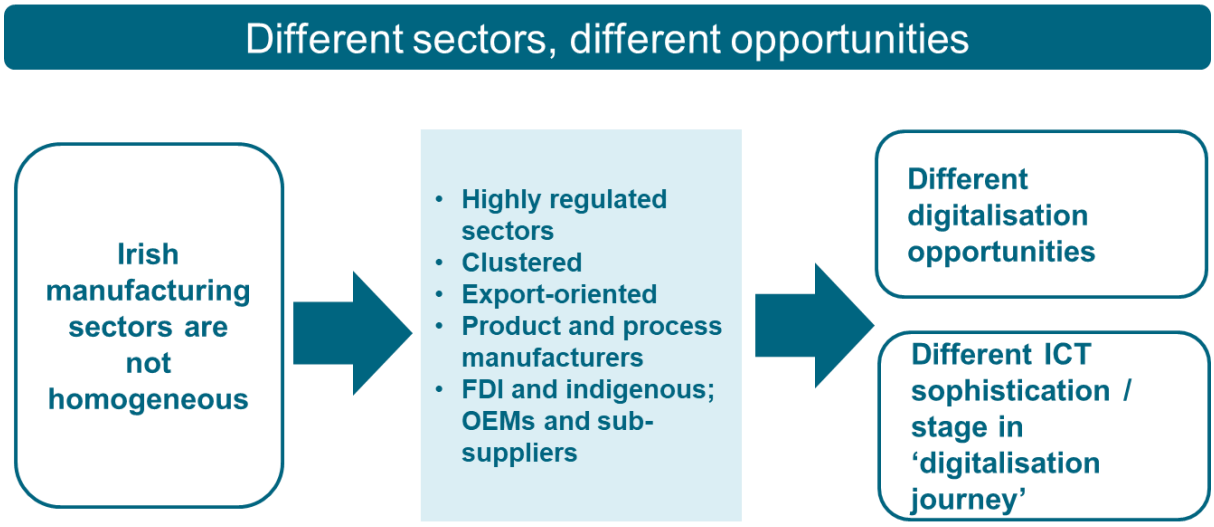
In order to help in identifying opportunities and challenges for Ireland, this Section first discusses distinctive features of its manufacturing sector and national contextual factors. It draws from economic statistics, qualitative analysis of manufacturing sub-sectors that feature highly in Ireland, and a wide stakeholder consultation. Some insights from international industry studies as well as studies on digitalisation of manufacturing are also discussed to provide a context for Ireland.

This Section also seeks to identify Ireland's position in terms of the digitalisation of manufacturing journey.

3.1 What makes Irish manufacturing distinctive?

Ireland has built strong industrial capabilities over decades, hosting some of the top global firms in some of its manufacturing sectors, as well as having world-leading software and ICT industries that add to Ireland's industrial ecosystem, and place the country in an envious starting position in the digitalisation journey. However, Irish manufacturing sub-sectors are not homogeneous and, as a result, might present distinct digitalisation contexts (Figure 9).

Figure 9. Contextualising the opportunities and challenges arising from digital manufacturing in Ireland



As such, in order to identify relevant opportunities and challenges, arising from the digitalisation of manufacturing in Ireland, it is necessary to first understand the composition and characteristics of its manufacturing sector as a whole, and to recognise the key distinctive features and national contextual factors that could promote or hinder its digitalisation journey.

3.1.1 Manufacturing in Ireland – An Overview

This sub-section introduces a series of key lessons obtained from a detailed macroeconomic analysis of the Irish manufacturing sector – presented in Appendix 3 – including its structural composition and main macroeconomic characteristics. Key observations about the characteristics of Irish manufacturing can be extracted from that analysis, as follows:

Impact of the manufacturing sector

- The manufacturing sector has a substantial impact in the Irish economy, estimated at more than 35.5% of the total valued added and 400,000 direct and indirect jobs.

SMEs and large companies

- Like other countries, the manufacturing base is mostly composed of SMEs that employ 53% of the workforce at sectoral level, although a large share of manufacturing value added (88.5%) is generated by companies with more than 250 employees that also employ 47.2% of the total manufacturing workforce.

Foreign and Irish owned firms

- A relatively small group of large foreign multinational companies (MNCs) (3.8% of total companies in manufacturing, based on 2015 data) account for more than 92% of manufacturing value added (MVA) and 45% of the manufacturing employment.
- Foreign MNCs can, on average, be classified as large companies with more than 250 employees. On the other hand, Irish-owned companies in the manufacturing sector are, on average, SMEs, though it is noted that there are also number of indigenous MNCs, most notably within the food and drinks sector.
- A feature such as this has an important implication for the definition of value chains at sectoral level that may be characterised by an Original Equipment Manufacturer (OEM), represented by a foreign owned firm, and a sub-supply value chain, composed mainly of indigenous firms.
- Irish enterprises are more concentrated in so called traditional sectors, such as basic and fabricated metal products, food and drinks and, above all, miscellaneous manufacturing, which includes activities such as wood and furniture, paper and paper printing, and repair and installation activities. Foreign owned enterprises are more equally distributed across manufacturing sub-sectors: for example, 18.8% in pharma and chemicals; 12.8% in rubber and plastics; 13.1% in medical devices; and 15.6% in miscellaneous manufacturing.

Sub-sectoral composition

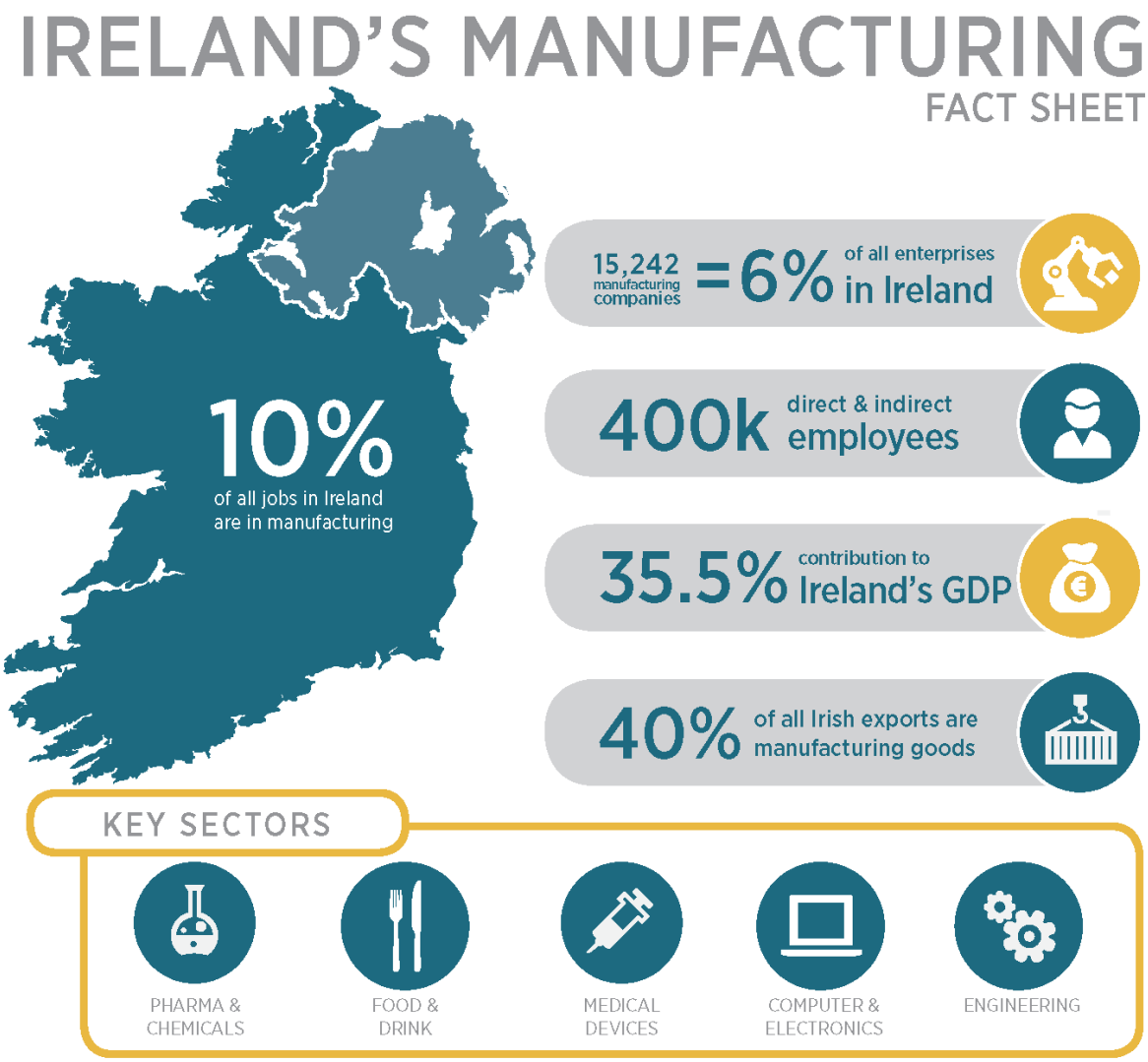
- At sub-sectoral level, manufacturing is specialised in five prominent sectors, which can be classified into two main categories:
  - **Process industries:** pharmaceuticals and chemicals (43.8% MVA)[17], and food and drinks (22.9% MVA).
  - **Product manufacturers:** medical devices technologies (13.3% MVA), computer and electronics (8.2% MVA), and the production of mechanical and electrical equipment (i.e. the engineering sector, with 7.8% MVA).

Export orientation

- Between 2000 and 2015, the average degree of export orientation of all Agencies' client firms (i.e. both Irish and Foreign owned firms) operating in the manufacturing sector, was 83.7% (measured as total exports as a percentage of total sales).
- However, when analysing both types of firms separately during the same time period, the degree of export orientation from Irish owned manufacturing firms was 45.3%, while for foreign owned firms it was 94.6%.
- Such differences in export orientation between Irish and foreign owned firms can also be seen at sub-sectoral level. Foreign owned firms are more export oriented in every sub-sector and, on average, sectors, such as medical devices technologies and pharma and chemicals, are more export-oriented than traditional sectors, such as food and drink and basic metal production.
- ***Main trade partners:*** The United Kingdom and the USA are the main partners, for both imports and exports, when the analysis is conducted by single countries, while the European Union represents the main export market when the analysis is conducted by regions. These results

[17] The pharmaceutical and chemical sector is statistically defined as NACE codes 20 and 21, belonging to Section C – manufacturing. 'Research and experimental development on biotechnology' (NACE code 72.11) is not accounted in the statistical analysis of this report. References made to the pharmaceutical sector/pharma throughout the report include small molecule pharma and bio pharma.

can be explained by the historical close cooperation that Ireland has with the UK, and with the role that MNCs from the USA have in the country[18].



Data refer to 2015

Sources: CSO (2017) Census of Industrial Production, SBS, QHNS, National income and expenditure annual results; Comtrade (2017)

[18] During consultations, Ireland's potential to further enhance linkages with Asia was highlighted, given the country's compatible time zone to work with this region.

In order to complement the macroeconomic analysis, major messages obtained from a series of qualitative sectoral briefs[19] are reported in Boxes 1 and 2, which draw attention to important qualitative features of Ireland's manufacturing sub-sectors, such as national industrial enablers and the composition of the productive base, respectively.

Box 1. National Industrial Enablers

- **Favourable tax regime:** a distinctive feature of the Irish manufacturing sector is the existence of an advantageous tax regime that supports the presence of foreign MNCs and the development of highly innovative activities. In 2017, Ireland reported the second lowest (12.5%) corporate tax rate among OECD countries[20]. In addition, there are public instruments, such as R&D tax credits, that provide further tax relief for investments in innovation activities.
- **Skilled workforce:** the presence of a highly-qualified workforce is another characteristic that makes Ireland attractive for investment. For example, Ireland has the second highest share of a population with a tertiary education (52%) in the European Union, against an OECD average of 43.1%[21].
- **Efficient regulatory track record in highly-regulated sectors:** this is particularly true for the pharmaceuticals, medical devices and food and beverage sectors, where Ireland possesses valuable accumulated know-how and expertise in regulatory compliance matters.
- **Maturing industrial ecosystems and infrastructure:** maturing ecosystems involving domestic public institutions, and a research skills base assisting with the attraction and retention of foreign direct investment, can be observed across sectors.
- **Government support:** a number of public institutions and initiatives support key manufacturing sectors in Ireland, including a well-developed public research infrastructure (Box 3). Firms based in Ireland also benefit from advisory support provided by its State agencies and offices, which have accumulated significant relevant expertise through continuous interaction with industry.

Box 2. Composition of the Productive Base

- **Strong supply base and presence of Multi-National Companies (MNCs):** the sectoral briefs highlight a variety of configurations for the productive base depending on the sector analysed. While a strong Irish-owned supply base, and service providers composed of SMEs, are a distinctive cross-sectoral characteristic of Irish manufacturing, distinct sectors show different degrees of concentration toward multinationals, either foreign or Irish owned. Overall, foreign owned firms in Ireland account for around 80%[22] of the manufacturing value added (MVA). This represents the highest share of MVA generated by foreign-owned companies in the European Union (followed by Hungary with 70%, and against an EU 28 average of 39%).
- **Productive clusters versus dispersed production:** there are cases of well-organised productive clusters in sectors such as pharmaceuticals and medical technologies (e.g. industrial clusters in Cork and Galway), while in the food sector, for example, production is more geographically dispersed.
- **Sophisticated indigenous firms:** Ireland has a strong group of innovative indigenous firms (e.g. Computers and Electronics sector), facilitated by the joint presence of high technology multinationals and public investments in R&D. Furthermore, Irish-owned companies are engaged in either sub-supply, or in the development, manufacturing and export of their own branded products to end customers (e.g. Engineering sector vs MedTech respectively). There is also a strong presence of Irish-owned companies, both multinationals and SMEs, that are research and technology intensive (e.g. Pharma). Indigenous firms are also characterised by a high level of specialisation (e.g. Engineering and MedTech sector).

[19] Five sectoral briefs are given in Appendix 4, including the following sectors: pharmaceutical and chemicals; food and drinks; medical devices; computer & electronics; engineering sector.
[20] In 2017, among the OCED countries, Hungary presents the lowest corporate tax rate at 9%. Source: OECD (2017) OECD Tax database.
[21] In the European Union, Lithuania has the highest share of population with a tertiary education (54.9%) followed by Ireland, and the United Kingdom has the same share (52%). The indicator refers to the % of population between 25 and 34 years old who have completed a tertiary education level course. Data refer to 2016 or latest data available. Source: OECD (2017) OECD Data – Education.
[22] Source: Eurostat (2017) Structural Business Statistics - Foreign Affiliates

The sectoral briefs, presented in Appendix 4, also provide information about the Research and Development landscape for particular manufacturing sub-sectors in Ireland. Key messages from these briefs are summarised in Box 3, focusing on aspects such as the presence of research collaboration activities between industry and universities, and the presence of government sponsored centres supporting R&D activities.

Box 3. R&D and innovation landscape

- **Research collaborations**: another characteristic of Irish manufacturing, highlighted by the sectoral briefs, is the existence of a growing number of research collaborations between industry and Higher Education Institutions (HEIs), enabled by the R&D infrastructure and capacity that has been developed in Ireland. This includes partnerships between MNCs, local firms and local researchers (e.g. pharma & MedTech), as well as organised research networks (through for example Teagasc in the food sector).
- **Public research infrastructure:** the presence of government funded research centres, providing R&D support to enterprises in every sector, is a common element in Ireland's innovation landscape.
  - This includes the **14 industry-led technology centres**, which originated as a joint initiative between **Enterprise Ireland and IDA Ireland**, and which facilitate the collaboration between Irish companies and multinationals on industry defined agendas. Examples of these centres include: Pharmaceutical Manufacturing Technology Centre; Irish Manufacturing Research Technology Centre; Microelectronics Technology Centre; and the Food for Health Ireland Technology Centre[23].
  - There are also **17 Science Foundation Ireland (SFI) Research Centres**[24] which include: i-Form (advanced manufacturing research centre); Confirm (smart manufacturing); Insight (data analytics); ADAPT (digital content technology); and Lero (software research). These centres have been transformative in fostering industry-academic collaborative research in Ireland. With over 300 collaborative research agreements resulting in over €120M in co-funding from companies in their first 4 years of activity, they represent the largest public-private partnership in research and innovation in Ireland's history.
  - **Other state supported facilities and institutes** that provide R&D support to enterprises include NIBRT, Tyndall, Teagasc, ICHEC, HRB Clinical Research Co-ordination Ireland, and the Marine Institute.
  - Furthermore, **several MNCs have located their R&D facilities in Ireland (knowledge generation)**. For example, 20 of the top 30 global medical technology companies, present in Ireland, have also established R&D activities in the country.

A comparative breakdown of five prominent Irish manufacturing sub-sectors and their distinctive features is also shown in Table 1. Overall, the Irish manufacturing sector is characterised by the presence of a balanced mix between 'traditional' and 'high-tech' sectors, which includes a large number of both Irish owned and international MNCs and a thriving ecosystem of SMEs. The country has a forward-looking business environment in which the availability of skills, a favourable tax regime, and an evolving R&D and innovation landscape add to the overall attractiveness of Ireland as a high-value manufacturing destination. This is particularly true for highly regulated sectors, such as pharmaceuticals, medical devices and food and beverage, which build on Ireland's regulatory track record and stability.

[23] The full list of Ireland's technology centres is available on Enterprise Ireland's website at: https://goo.gl/AvL3qb
[24] Further details about SFI Research Centres are available on SFI's website at: http://www.sfi.ie/sfi-research-centres/

Table 1. Comparative breakdown of Irish manufacturing sub-sectors and their distinctive features[25]

	Key Macroeconomic Indicators	Distinctive Features
Process industries		
Pharmaceuticals and chemicals	▪ 43.8% of manufacturing value added ▪ 12.6% of manufacturing employment ▪ 58.7% of manufacturing exports ▪ 454 companies provide 23,833 direct jobs	▪ Mix of domestic and foreign companies ▪ Concentration toward foreign MNCs ▪ Presence of research intensive Irish-owned companies ▪ Presence of a strong base of Irish-owned firms supplying advanced services and technologies to MNCs ▪ Presence of industrial clusters in Cork and Dublin
Food and drinks	▪ 22.9% of manufacturing value added ▪ 23.9% of manufacturing employment ▪ 14.6% of manufacturing exports ▪ 1,634 companies provide 45,364 direct jobs	▪ The sector is mainly composed of small firms ▪ Geographically dispersed activities ▪ Presence of foreign and indigenous MNCs ▪ Presence of a group of companies engaged with specialised nutrition and functional foods
Product manufacturers		
Medical devices	▪ 13.3% of manufacturing value added ▪ 14.5% of manufacturing employment ▪ 9% of manufacturing exports ▪ 878 companies provide 27,469 direct jobs	▪ 18 of the world's top 25 medical technology companies are based in Ireland ▪ Irish companies represent 60% of the sector ▪ Firms in the sector are distributed along the entire medical devices value chain ▪ Presence of a strong sub-supply and service providers ▪ Sector cluster established in Galway
Computer and electronics	▪ 8.2% of manufacturing value added ▪ 8.4% of manufacturing employment ▪ 9.5% of manufacturing exports ▪ 377 companies provide 15,984 direct jobs	▪ Long established presence in the semiconductor industry ▪ Several MNCs have located manufacturing and R&D facilities in Ireland ▪ Presence of a strong group of innovative indigenous firms ▪ Presence of Tech clusters in Dublin and Cork
Engineering sector	▪ 6.1% of manufacturing value added ▪ 16.6% of manufacturing employment ▪ 4.1% of manufacturing exports ▪ 4,165 companies provide 31,531 direct jobs	▪ Irish-owned companies are engaged in either sub-supply or production of their own branded products to end customers ▪ Indigenous firms are also characterised by a high level of specialisation ▪ Many of the foreign-owned companies have been established in Ireland for over 20 years ▪ In contrast with other sectors, the engineering sector is vertically integrated in the Irish economy

[25] Extracted from sectoral briefs in Appendix 4

3.2 Where is Ireland in the digitalisation of manufacturing journey?

There is no consensus in international literature regarding best practices, methodologies or indicators that can be used to measure the industrial digitalisation readiness and/or current degree of industrial digitalisation of a country. Although some country readiness indexes have been proposed, these are not comprehensive enough to provide valid comparisons at intra and cross-sectoral level, as well as at cross-country level. Therefore, measuring the exact status of industrial digitalisation in Ireland is a difficult task.

For example, the European Commission, under the Digital Single Market Strategy, is collecting indicators for the Digital Scoreboard[26] which measures the digital performance of EU Members States in areas such as connectivity, digital skills, the digitalisation of the public sector, and the digitalisation of business. In this respect, the "Integration of Digital Technology by Enterprises" covers elements such as business digitalisation (i.e. electronic information sharing, social media, e-invoices) and eCommerce[27]. However, those indicators cover the private business sector as a whole (i.e. industry and services) and, in some cases, they are not strictly relevant to the concept of digitalisation of manufacturing.

Other digitalisation indicators, collected at sectoral level by Eurostat, also fail to provide a full picture of the actual industrial digitalisation level or readiness of a country. These indicators usually gather national data on variables such as the share of enterprises using systems for Enterprise Resource Planning; share of enterprises using systems for Customer Relationship Management (CRM); share of enterprises with automatically integrated business processes; and share of enterprises using Cloud computing services. When compared to the digitalisation definitions and frameworks presented in Section 2, it is clear that these indicators are unable to reflect the full complexity involved in the digitalisation of manufacturing in Ireland.

Perhaps the best examples of international studies that have attempted to evaluate Ireland's digitalisation readiness and stage in the digitalisation journey are from Roland Berger (2014)[28] and McKinsey (2017)[29], which employ a combination of quantitative analysis and stakeholder engagement for this purpose. The comparative study conducted by Roland Berger considers that Ireland is highly ready for industrial digitalisation, because of its existing industrial base, forward-looking business conditions and industrial technological sophistication. A Readiness Index calculated by measuring its industrial excellence (i.e. process sophistication, degree of automation, workforce readiness, and innovation intensity) and its value network (i.e. high value added, industry openness, innovation network and internet sophistication), considers Ireland as a frontrunner in industrial digitalisation readiness together with Germany, Sweden and Austria.

[26] DG Connect (2017). Digital scoreboard
[27] DG Connect (2017). Integration of Digital Technology by Enterprises.
[28] Roland Berger (2014). Industry 4.0. The new industrial revolution: How Europe will succeed
[29] McKinsey (2017). Digitally-enabled automation and artificial intelligence: Shaping the future of work in Europe's digital front-runners

Similarly, the study conducted by McKinsey considers Ireland[30] as a digitalisation front-runner in Europe, because it scores highly on digital integration, as measured by the number of public initiatives in place to boost the digital economy, the high level of digital integration in its economy, and the presence of a higher-than-average number of companies currently adopting Artificial Intelligence (AI) and automation technologies.

Despite these encouraging results, the studies and methodologies discussed above do not deal with how a country, such as Ireland, would be able to develop policies to pursue opportunities and address challenges arising from the digitalisation of manufacturing. However, these studies give valuable insights regarding Ireland's favourable starting position and enabling environment for the industrial digitalisation journey. The consultation exercise undertaken in this study provided further information about Ireland's enabling digitalisation environment, and evidenced that, although a number of challenges still exist to fully exploit the opportunities brought about by the digitalisation of manufacturing, the country certainly enjoys a potentially advantageous starting position and enabling conditions for the digital journey, as discussed next.

3.2.1 Ireland's position in the digitalisation of manufacturing: the stakeholder's view

Stakeholder consultations carried out during this project provided important insights regarding Ireland's digitalisation readiness and current state. In particular, it was suggested that Irish manufacturers (both small and large firms) are just starting to realise and exploit the benefits of digital technologies. Stakeholders suggested that distinct sectors and firms in Ireland are in different stages of the 'digitalisation journey'. Even if most sectors are dedicating resources to understand the opportunities brought about by digitalisation, some still struggle to identify the relevance of digitalisation for their organisations. The latter is particularly evident for the food and drinks sector, where both large and small firms seem to struggle to understand the value of digitalisation. However, other sectors, such as pharmaceuticals, medical devices, and computers and electronics, are certainly dedicating significant work and resources to this topic, with some firms having mature digitalisation visions and strategies in place, and actively working in the development of implementation roadmaps. While some firms might be 'ahead of the curve', consulted stakeholders perceive that there are significant opportunities for improvement in both large and small firms.

The consultation exercise also suggested that highly regulated sectors, such as pharmaceuticals, medical devices, and food and beverages, are slow to adapt to new technologies, especially when used in production, whereas other sectors tend to be more flexible and responsive in this regard, which could explain certain differences in the levels of adoption.

Overall, there was broad agreement that Irish firms will need to exploit the potential of digital technologies to remain competitive internationally. There is a concern that other countries might already be ahead in the 'digitalisation journey' and, thus, lack of action could lead to a loss of competitiveness.

[30] The other countries analysed in the McKinsey report are: Belgium, Denmark, Estonia, Finland, Luxembourg, Netherlands, Norway, and Sweden

Regarding Ireland's position in the digitalisation journey, and its readiness to pursue key opportunities and address challenges arising from the digitalisation of manufacturing, consulted stakeholders in addition also provided key insights that can be summarised as follows:

- On the one hand, Ireland is well-placed to build on existing expertise in both process industries and product manufacturing developed over decades. This includes the local ecosystem of suppliers, and the advanced regulatory and institutional framework supporting industry.
- Ireland's small size provides a potential advantage to collaborate closely and implement change quickly, and to build consortia of firms to identify common issues and potential solutions. There is the possibility, thus, to drive the digitalisation of manufacturing in Ireland, but also to develop collective expertise in the digitalisation of manufacturing that could be offered as a global service.
- Another perceived advantage for Ireland is the possibility of exploiting its close linkages with the US, which places the country in a good relative position when compared to its European competitors. Ireland's expertise on global supply chain management, and the presence of a leading ICT sector, can also be seen as unique Irish advantages in exploiting the potential of digital technologies. However, there is a perception that capabilities from the domestic ICT sector have not permeated the Irish manufacturing sector, as ICT companies have an external market orientation.
- On the other hand, Ireland's digitalisation readiness, and capability to pursue opportunities, is affected by its position as a location for international subsidiaries. There was agreement on the difficulty faced by Irish managers to influence the strategy of MNCs headquartered elsewhere. It might also be difficult for local digital solution providers to identify and influence decision makers.
- Another perceived constraint for Ireland is the increasing demand for digital skills across a number of industries, which is accentuating the difficulties faced by manufacturers to attract talent. Manufacturers compete for digital skills, not only with large multinational software firms, such as Google and Facebook established in the country, but also with other sectors such as finance, gaming and marketing.
- Finally, there were concerns about Brexit, which can particularly have an effect on Irish manufacturers with a strong UK market orientation.

In summary, although Ireland might be considered as a digital frontrunner in a number of international studies, local stakeholders consulted in this project have a more reserved opinion about Ireland's position in the industrial digitalisation journey, and its readiness to pursue opportunities and address the challenges ahead. Although the potential opportunities brought about by digitalisation are starting to be understood in Ireland, there is also a realisation that numerous challenges would need to be addressed before the country can fully exploit its own industrial digitalisation potential, and this will be discussed in the next sub-Section.

3.3 Opportunities and challenges from digitalisation in manufacturing firms in Ireland

As noted earlier, Ireland has strong manufacturing sub-sectors developed over the last few decades, made up of some major multi-national companies (MNCs), and a thriving ecosystem of indigenous SMEs. It also boosts a world-leading software and ICT industry. Under this context, this sub-Section seeks to understand the implications of the digitalisation of manufacturing for firms in Ireland, and, in particular, what are the opportunities (and challenges) from digitalisation for firms in Ireland given the country's existing manufacturing and innovation base.

Each manufacturing sector presents a unique business context that, together with emerging digital technologies and applications, drives distinct digitalisation trends, challenges and opportunities. This is exemplified by Table 2, where examples of international digitalisation trends and drivers are listed for five prominent manufacturing sectors in Ireland. These refer to global sectoral perspectives and are, therefore, not exclusive for Ireland, which means they do not provide a thorough foundation to discuss relevant and feasible policy priorities for the Irish context.

In order to identify opportunities and challenges specific to the Irish context, a stakeholder consultation was carried out involving a variety of methods that included interviews with key industrial and public body stakeholders, two roundtable discussions and one policy workshop[31]. These activities were intended to gather primary data about local perspectives on this topic and complement the desk research outputs previously shown in this Section.

It is recognised that opportunities arising from digitalisation exist for different types of companies (including foreign-owned and indigenous MNCs and SMEs), and different types of manufacturing sub-sectors. While the consultation exercise was designed to identify cross-cutting opportunities and challenges, individual sector variations were also captured to some extent. The results shown in this sub-Section are organised around the frameworks discussed in Section 2, where opportunities are classified in four main categories (Product/Service Innovation; Process Innovation; Supply Chain Innovation; Product / Service Delivery), while challenges are framed in terms of barriers to Knowledge and Technology Generation, Diffusion and Deployment. Where possible, the consultation results have been organised around two types of Irish sectors: process industries (including pharmaceuticals, chemicals and food and drinks) and product manufacturers (including medical devices, computer and electronics, and the engineering sector). Grouping manufacturing industries in these two natural groups has been used as an attempt to identify commonalities between the sub-sectors contained in those categories.

The rest of this sub-Section introduces key messages and lessons extracted from the stakeholder consultation. These set the foundation for discussing policy implications for Ireland in Section 5.

[31] Further details about the stakeholder consultation exercise can be found in Appendix 1.

Table 2. Example of international digitalisation trends and drivers in relevant Irish manufacturing sub-sectors

	Example of International Sectoral Digitalisation Trends and Drivers
Process industries	
Pharmaceuticals and chemicals	**Pharmaceuticals** ▪ Personalised healthcare driving a shift towards more targeted products ▪ Information-based medicine and innovative monitoring and delivery mechanism of therapeutics approaches being developed ▪ Flexible batch-manufacturing processes and patient data capture and analysis becoming key enablers **Chemicals** ▪ Digitalisation enabling the streamlining of complex processes and operations ▪ Development of value-added data services around chemical products (e.g. apps for providing technical recommendations to clients)
Food and drinks	▪ New digital platforms enabling consumers to engage directly with farmers and food manufacturers. Farmers and food producers are thus becoming retailers ▪ Product customisation by adapting nutrient content to particular categories of customers
Product manufacturers	
Medical devices	▪ MedTech products moving towards end-to-end solutions for better care at lower prices, including connected health and drug delivery through data capture ▪ Personalised healthcare and customisation of medical products including combination products and diagnostics
Computer and electronics	▪ Becoming a key enabling sector for digitalisation providing intermediate goods to other industrial sectors and making their products and services knowledge intensive
Engineering Sector	▪ Digitally enabled flexible batch-manufacturing processes will be required to address increased product customisation trends

3.3.1 Key Messages from Stakeholder Consultation

The consultation exercise captured a varied range of opinions regarding the digitalisation of manufacturing in Ireland. The results show that although most opportunities are cross-cutting between sectors, there are some differences in the perceived priority opportunity areas for process industries versus those of product manufacturers, as discussed below and summarised in Table 3.

Process Industries: Priority Opportunities

Of the four opportunity dimensions considered in this study (Section 2 – Product/Service Innovation; Process Innovation; Supply Chain Innovation; Product / Service Delivery), process industries are mostly concerned about process innovation, which agrees with the nature of their sector. In particular, common topics mentioned included improvements in plant utilisation, which represents a key cost driver in these industries, through better planning and forecasting including predictive maintenance. This is relevant as a number of consulted stakeholders reported low plant utilisation as a fundamental concern in their industries. Furthermore, a key theme that emerged in conversations with process industries was also the optimisation of supply chain operations and enhanced inventory management through digital integration of cross-firm operations. Similarly, increased levels of process automation and quality control through the use of real-time data was mentioned as an exciting possibility.

There was a recognition among the distinct stakeholders, consulted in this group, that process industries, due to the complexity and high capital intensity of their processes, are slightly slower and less flexible to adapt and implement new technologies. This was particularly emphasised for highly regulated sectors, such as Pharmaceuticals and Food and Drinks, where changes must be introduced without disrupting regulatory compliance. In this regard, highly-regulated sectors see opportunities for accelerated regulatory compliance processes and increased digital traceability by employing digital data gathering, management and analysis solutions.

Product Manufacturers: Priority Opportunities

Although opportunities for product manufacturers were more equally distributed across the four opportunity dimensions, there was a clear emphasis on the possibilities that digital technologies could bring for the development of new products and services. This included the addition of functional digital features, and Internet of Things capabilities, to products for better connectivity and customer data collection, as well as the provision of data services to customers, and an overall overhaul of business models, in which firms move from simply designing products into creating end-to-end solutions enabled by digital features and data analytics.

Product manufacturers also visualise opportunities for process optimisation and more efficient new process development through the use of simulation tools, modelling of virtual factories, and the use of 3D printing for prototyping. Additional perceived opportunities included improved supply chain management using digital planning and forecasting tools, and the use of digital business platforms for a more efficient delivery of products and services that could reduce the number of intermediaries involved in the chain.

Table 3. Comparative priority opportunity areas for process industries vs product manufacturers in Ireland

	Priorities for Process Industries	Priorities for Product Manufacturers
Opportunities		
Product / Service Innovation	▪ New knowledge (data) intensive services to customers	▪ Smarter products and services incorporating new digital features for better connectivity and customer data collection ▪ New knowledge (data) intensive services to customers ▪ New revenue streams through new business models in which firms move from simply designing products into creating end-to-end solutions enabled by digital features
Process Innovation	▪ Process optimisation through increased automation and real-time data availability ▪ Improved plant utilisation enabled by better planning and forecasting, including predictive maintenance capabilities ▪ Improved quality through digitally enabled quality control	▪ Process optimisation and more efficient new process development using simulation tools, modelling of virtual factories, and the use of 3D printing for prototyping (to enable offline testing of new parameters and/or designs before applying them in real world settings) ▪ Improved quality through digitally enabled quality control
Supply Chain Innovation	▪ Optimised supply chain operations and enhanced inventory management through digital integration of cross-firm operations ▪ Improved traceability of raw materials/supplies across supply chain (for example, for accelerated regulatory compliance)	▪ Improved supply chain management using digital planning and forecasting tools
Product / Service Delivery		▪ More efficient delivery of products and services using digital business platforms that could reduce the number of intermediaries involved

Cross-Cutting Opportunities: Key Themes

Even if digitalisation is regarded as a highly relevant technological trend in most sectors, a key message arising from the consultation is that there are difficulties in understanding its true value and the opportunities it could provide. As a result, responses from consulted stakeholders varied greatly when asked to identify key opportunities for Ireland. Perceptions about opportunities often depended on the level of digitalisation of the stakeholders' firms and sectors. While many Irish firms have been exposed to terms such as 'digitalisation' and 'industry 4.0', there is still a lack of clarity as to how these trends/concepts can deliver value to their businesses. There is uncertainty around the value of digitalisation in a number of dimensions: a) language, b) technical challenges to integrate digital technologies into existing manufacturing systems, and c) financial and strategic cost-benefit analyses.

As such, there was broad consensus about the need for clarity regarding the practical ways in which different types of firms can de-risk their 'digitalisation journey' and obtain tangible benefits. The need for physical demonstrators and a mechanism for firms to come together to network, collaborate and to explore the technologies, and the opportunities for themselves and for their sectors, was a clear message from the consultation.

In general, cross-cutting opportunities across process industries and product manufacturers can be classified in the following themes:

Product / Service Innovation

- New business models. Including offering equipment/products as a service and charging per outcome and/or usage. Additional opportunities include new data services to optimise customer processes. Also mentioned were more horizontal business models, in which businesses focus on connecting to a larger part of the product life cycle.
- New product functionalities. Including the addition of digital functionalities (e.g. GPS) and Internet of Things capabilities to obtain information from end users, and connect to a larger part of the product life cycle.

Process Innovation

- Improved factory productivity. Including the real-time analysis of data from sensors for enhanced process and equipment understanding and control.
- Improved factory and equipment utilisation. Through predictive maintenance, enabled by advanced data analytics and artificial intelligence, and by employing digital planning and scheduling underpinned by the use of real-time data allowing planning adjustments.
- Reduced dependency on human error and manual labour. New technologies such as Co-bots could reduce dependency on manual labour freeing people to work in more value-added areas.
- Digital Quality Management. Digitally tools could reduce dependency on manual quality control inspections by implementing digitally enabled smart quality management tools embedded in processes.
- Small batch manufacturing and customisation. To better respond to customer needs by having more connected customers.
- Reduced energy and resource use. Real time data analysis allows immediate adjustment of parameters to reduce material waste and increase energy efficiency. Opportunities also exist to employ digitally enabled communication tools that could achieve cost savings by reducing the need for paper within company operations.
- Improved training of factory workers. Reduction of human error through the support of digital tools such as virtual reality.

Supply Chain Innovation

- Improved traceability. Including digital traceability methods for raw materials/supplies across supply chains, particularly relevant to highly regulated industries, as this could translate into opportunities for accelerated regulatory compliance processes.
- Better supply chain integration and optimisation. Through real-time availability of information across distinct stages of the supply chain for better visibility, aiming to create an end-to-end supply chain and improve ability to react and minimise unknown risks.

Product / Service Delivery

- **Improved knowledge of customer needs.** Enabled by better acquisition and analysis of customer data through Internet of Things and Big Data analytics capabilities.
- **More direct interfaces with customers.** Including opportunities to use new business platforms that decrease the need for intermediaries.

Cross-Cutting Challenges and Barriers: Key Themes

Contrary to their slightly distinct views on opportunities, consulted stakeholders from process industries and product manufacturers have very similar perspectives about potential barriers to digitalisation, and the technological capabilities required to pursue opportunities. There is a wide convergence of opinions in this regard. A summary of key messages and lessons related to cross-cutting challenges, and barriers arising from the digitalisation of Irish manufacturing sectors, is shown below.

Challenges to Knowledge and Technology Generation

- **Perceived gaps in near-market business-oriented research funding and institutions**. It was suggested that there are opportunities to make research projects more business-oriented, which might require improved communication channels and collaboration mechanisms between industry and academia. It was also recognised that there is a gap in State funding and structures in Ireland in relation to nearer-to-market activity that firms looking to understand and engage in digitalisation of manufacturing can tap into
- **Disperse funding and lack of integration between industry and academia.** There were also suggestions of the need to more effectively coordinate R&D between industry and academia. The need to ensure critical mass (rather than dispersed resource allocation) to achieve impact was highlighted.

Challenges to Knowledge and Technology Diffusion

- **Lack of information and concrete examples.** As noted earlier, many companies struggle to understand how investments in digital technologies, tools and/or applications can deliver value to their businesses. There is a need to 'demystify' the use of digital technologies through, for example, tangible demonstration and diffusion of successful case studies in other sectors. Furthermore, limited dissemination of information about international practices was commonly mentioned.
- **Lack of visibility regarding where the expertise in Ireland may be.** It is difficult to identify where the expertise is nationally to help firms develop digital strategies – both from a technical and business point of view.
- **Cybersecurity and sharing concerns.** Many firms are wary about sharing internal data due to concerns about data privacy.
- **Data integrity and ownership concerns.** There are concerns regarding integrity, accuracy, safety and ownership of data, particularly when dealing with third party suppliers.
- **Lack of standards and interoperability.** Lack of standards for communication and integration between systems poses a risk of disruption for the diffusion of new digital technologies. In particular, incompatible data formats, and validation requirements for new systems and software are a concern. Furthermore, there is limited dissemination and awareness of international standards, such as those from the German Industry 4.0 initiative.

- **Lack of national digital roadmap.** It is believed that a national digital roadmap could offer a common knowledge base and reveal common opportunities, as well as address national coordination challenges and lack of government policy focus.

Challenges to Knowledge and Technology Deployment

- **Challenges to develop firm-level technology roadmaps.** Generic digital diagnostic tools could help firms to assess their current 'digitalisation status' and help direct them towards the next logical steps to develop appropriate technology roadmaps.
- **Lack of internal capability to identify opportunities and coordinate implementation.** This includes the potential lack of ability to identify and attract the skills required by firms to develop and implement digitalisation roadmaps. Beyond these skills, the lack of coordination across organisation units was suggested as a common barrier.
- **Skills gaps in the workforce.** There are concerns that there will be a generalised demand for digital skills across industries, making it difficult for manufacturers to get hold of graduates. A national 'ecosystem of skills' and a clear 'digital career path'/'digital curricula' are missing. There were suggestions that there is a disconnection between engineering and IT skills in existing curricula. In particular, it is anticipated that a set of hybrid competencies will be required by future graduates, combining ICT and data analytics skills with knowledge of manufacturing processes. Furthermore, the lack of programmes to support re-skilling and up-skilling of the existing workforce was discussed. In this respect, the ability to identify and distinguish between sector-specific skills and cross-cutting skills was mentioned as a crucial challenge to develop suitable training schemes. The lack of training facilities and centres was also mentioned as a key barrier.
- **Skills gap in board and management teams.** Board and management teams also need to be made aware about the benefits of digitalisation. There might be limited recognition of the value of data for decision making. There are concerns that this lack of skills could result in difficulties to push changes through organisations, as well as the challenges to develop appropriate business cases to gain support for digitalisation.
- **Difficulty to identify and influence decision makers.** There are also difficulties to identify the right people to talk about digitalisation within businesses, already present in Ireland, that are part of global organisations. It can be challenging to influence the strategy of the headquarters of businesses, and get approval to deviate from standard processes and designs.
- **High technology implementation costs.** Both for users and developers, a commonly suggested barrier is meeting the return of investment expectations.
- **Challenges to the adaptation of digital applications in existing processes.** Integration with legacy systems poses a significant technical challenge for implementation. Furthermore, there is uncertainty about the time and resources required for successful implementation of new technologies. Implementation in highly regulated sectors has been suggested to be time and resource intensive due to fears of disrupting compliance with stringent norms and standards.

Other

- **Other external barriers.** For example, trade uncertainty created by Brexit for Irish manufacturers with a strong UK market orientation.

Key Technological Capabilities

Similarly to previous points, the consultation exercise provided varied views regarding the technological capabilities that would be required to pursue opportunities arising from the digitalisation of manufacturing in Ireland. The same challenges that make it difficult for some stakeholders to understand the value of digitalisation exist when trying to identify technological capabilities to address potential opportunities. The following list presents a summary of the most common capabilities mentioned during the consultations:

- **Autonomous robotics.** Capable of interacting with the real world and making their own decisions.
- **Co-bots.** Robots that work in conjunction with operators to automate repetitive operations that cause strain or fatigue, where that strain or fatigue is the limiting barrier to higher through-put.
- **Data integration and format standardisation.** Including the integration of data that is already available from firms' operations.
- **Data mining and analytics.** Leverage data to bring business intelligence.
- **Digitally-enabled planning and forecasting tools.** Including simulation and dynamic optimisation models, smart inventories and predictive business planning and execution.
- **Manufacturing execution systems.** Including distributed control systems and their associated hardware items.
- **Sensors and integrated solutions.** More compact and precise for longer life and to avoid data accuracy issues.
- **Modelling tools and virtual visibility of processes and supply chains.** Including 'digital twins' of production processes and optimisation software.
- **Open source technologies.** Including applications allowing easy integration to existing systems.
- **Commodity market understanding/prediction, price interpretation algorithms.** Including big data analytics.
- **Digital tools for training.** Including virtual reality (VR) and augmented reality (AR).
- **Cybersecurity.** Including tools to enable integrity and security of data.
- **3D printing.** To enable distributed manufacturing applications and overcome geometric constraints of existing manufacturing processes.
- **Cloud computing.** To enable ubiquitous computing and communication.
- **Artificial intelligence and machine learning.** To make sense of available data and support decision making.

When asked to provide insights about their plans to access technological capabilities and skills to pursue digitalisation strategies, consulted firms mentioned three main sources:

- **Internal resources**. Some firms (particularly large MNCs) have dedicated teams and divisions offering digital solutions, which can provide advice and capability development within their operations in Ireland.
- **Third party providers and vendors.** Both in Ireland and internationally; accessible through trade shows, trade periodicals, intercompany conversations and benchmarking exercises.
- **Collaboration with academic institutions, intermediate research centres and industry associations within Ireland.** Mentioned here was leveraging the existing technology eco-system

in Ireland, beyond the academic institutions, including the presence of global software companies and industrial clusters.

Other Key Messages

- **Particular challenges for SMEs.** It is recognised, however, that SMEs face particular barriers to exploit the opportunities arising from digitalisation. SMEs tend to face more stringent constrains in terms of time, expertise, and financial resources. The challenges to understand the value of digitalisation, outlined above, are thus particularly acute for SMEs.

3.4 Concluding remarks

Digitalisation holds the promise of significant opportunities for Ireland based manufacturers. Several cross-cutting opportunities were identified during consultations with Irish stakeholders across the four dimensions of analysis (product/service innovation; process innovation; supply chain innovation; product/service delivery). In addition, distinct priority areas were also observed when comparing opportunities for process industries and product manufacturers.

For process industries (including pharmaceuticals and chemicals, and food and beverages), consulted stakeholders emphasised the opportunities to leverage digital technologies to drive improvements in plant utilisation, which represents a key cost driver for them. There was also emphasis on the potential to accelerate regulatory compliance processes by streamlining digital data gathering, management and analysis solutions.

For product manufacturers (including medical devices, computer and electronics, and the engineering sector), there was emphasis on opportunities to develop new products and related services by embedding digital capabilities for better communication and connectivity. At the same time, digital capabilities can drive an overhaul of business models by enabling firms to move from simply offering products to offering end-to-end solutions. Product manufacturers also visualise opportunities for new process development and optimisation through, for example, 3D printing and simulation tools to create virtual factories, as well as better planning and forecasting tools for supply chain management, and the use of digital technologies to implement new product and service delivery models that cut out intermediaries.

Despite these opportunities, many manufacturing firms in Ireland are still at the beginning of the digitalisation journey, and face a number of cross-cutting challenges to reap the full benefits of digitalisation, including challenges to knowledge and technology development, diffusion and deployment. A key message arising from the consultation was that there are challenges to understand the true value of industrial digitalisation and the opportunities it could provide to businesses. As such, there is a need to 'demystify' the use of digital technologies.

As discussed in this section, evidence from the stakeholder consultation indicates that Ireland is well positioned to pursue opportunities, and tackle challenges arising from the digitalisation of manufacturing, given the makeup of its manufacturing sector, and existence of ICT expertise and enabling contextual factors.

4

International Policy Approaches to Supporting the Digitalisation of Manufacturing: Common Observations and Emphases

This section provides an overview of key observations and emphases emerging from an extensive international review of national policy discussions and flagship programmes, initiatives and mechanisms aimed at supporting the digitalisation of manufacturing.

4.1 Introduction

Addressing the opportunities and challenges arising from the digitalisation of manufacturing is a top policy priority for countries around the world. As the potential of digitalisation for the global economy becomes increasingly apparent, policy makers are concerned about their country's ability to compete effectively. A number of national policy efforts focused on digitalisation have been recently established or are currently being developed[32]. This global policy landscape offers a valuable context to inform policy discussions in Ireland, as decisions that the country makes will need to be positioned in the context of international competition.

Many national policy documents, strategies and positioning papers, addressing the digitalisation of manufacturing, tend to be part of broader national digital agendas or national research, innovation and industrial strategies[33]. In addition to numerous national policy documents, high-level studies and positioning papers from international organisations such as the OECD, the World Economic Forum, the United Nations and the European Commission have placed digitalisation at the centre of international policy discussions on manufacturing[34]. Together, they provide important insights into the main challenges and opportunities identified internationally, and the main policy areas that have been prioritised for action.

In addition, specific national flagship programmes, initiatives and mechanisms provide insights into the variety of approaches to implementation chosen by countries around the world across policy areas. Selected case studies of such efforts from countries including China, Denmark, Finland, Iceland, Norway, Singapore, South Korea, Spain, Sweden, and Taiwan have been reviewed for this study and are presented in Appendix 5. While insights from these case studies are mostly referred to in this section, they have been used to inform all sections of the study.

Key common observations and emphases emerging from the review of international policy approaches include:

- The potentially disruptive impact of digitalisation in manufacturing.
- The recognition that different countries are at different stages in the digitalisation journey.
- The need for policy efforts beyond R&D in order to reap the full benefits of digitalisation.
- Particular policy emphases on: workforce skills development; standards; public-private partnerships; industry networks; technology diffusion among SMEs; and demonstration.

4.1.1 Potentially disruptive impact of digitalisation on manufacturing

While emphases can vary from country to country, reflecting national industrial structures and particular strengths, there is broad recognition of the potential of digitalisation to fundamentally change the way firms across manufacturing sectors produce and market goods and services.

There is emphasis on the potential of digitalisation to create entirely new markets based on new digitally-enabled products and services and, more generally, to bring manufacturing and innovation

[32] For an overview of national initiatives in Europe, for example, see: European Commission (2017). Digital Transformation Monitor. Key lessons from national industry 4.0 policy initiatives in Europe. DG Internal Market, Industry, Entrepreneurship and SMEs.
[33] For example, the UK's recently published 'Made Smarter Review 2017' is one of the 'sector deals' emerging from the UK national Industrial Strategy exercise. Similarly, the French 'Industrie du Future (IdF)' is part of the broader 'New Industrial France (NFI)' strategy, while the Italian 'Intelligent Factory Cluster (CFI)' is linked to the larger national 'Italian Innovation Roadmap'.
[34] These include: The OECD's Next Production Revolution studies; the World Economic Forum's Digital Transformation Initiative (DTI) and Future of Production project; the European Commission's Digitising European Industry initiative; as well as review papers commissioned by the United Nations Industrial Development Organisation (UNIDO).

closer together. There is also emphasis on digital-enabled possibilities to reduce costs, address supply constraints, increase the utilisation of global production capacity, and help ensure the sustainability of natural resources.

Estimates of the economic impact of digitalisation can vary widely. An often-cited figure is an estimated US$100 trillion of value that digitalisation could create to industry and society over the next decade, including US$1.55 trillion in logistics, US$1.28 trillion in telecommunications, US$667 billion in automotive, US$405 billion in aviation, and US$308 billion in the chemical and advanced materials industries[35]. Similarly, the European Commission reports that digitalisation could add €110 billion per year to Europe's industry[36].

A key policy concern is the effect that digitalisation may have on employment. Digitalisation is expected to reshape the skills that will be required from the workers of the future and drive significant disruptions in the labour market. Estimations of potential global job losses across the economy due to digitalisation range from 2 million to as high as 2 billion by 2030[37]. However, it is also believed that digitalisation can be a net job creator in some industries. A recent review commissioned by the UK government[38], for example, estimates that digitalisation can drive a net creation of 175,000 jobs throughout the whole UK economy over the next decade. According to some estimations, up to 6 million jobs could be worldwide by 2025[39].

Naturally, it is difficult to make a value judgement regarding the accuracy of these types of estimations, but they do reflect a commonly held view that is guiding policy priorities internationally regarding the potential large-scale impact that digitalisation can have in manufacturing in the short, medium and long terms.

4.1.2 Different countries at different stages of the digitalisation journey

It is recognised in the international policy discourse that some countries have already taken steps to respond to the digitalisation of manufacturing, and are perceived as frontrunners in the digitalisation journey. On the other hand, there is a perception that some countries face the risk of slowing down digital development by failing to modernise their policies.

Notably, Germany, the US and Japan are often presented in international and national studies as the benchmark against which others are compared. It is often mentioned that the USA is well-positioned to pursue opportunities emerging in internet platforms and big data analysis (through firms like Google and Amazon); while Germany has opportunities related to the connectivity of embedded systems, production machines and smart factories (through firms like SAP, Bosch and Siemens); and Japan is comparatively strong in advanced robotics with its government prioritising efforts to lead the world in 'robots for the Internet-of-Things era' (through firms like Fanuc, Hitachi and Softbank).

In fact, recent studies have highlighted Ireland's potential to become the international leading hub for digitalised manufacturing, citing aspects such as the country's high levels of automated manufacturing relative to its competitors. Other factors about the Irish context that have been emphasised include:

[35] World Economic Forum White Paper Digital Transformation of Industries: Societal Impacts.
[36] European Commission (2016). Digitising European Industry: Reaping the full benefits of a Digital Single Market.
[37] World Economic Forum (2016). Digital Transformation of Industries: Societal Impacts.
[38] BEIS (2017). Made Smarter Review. Independent review commissioned by the Department for Business, Energy & Industrial Strategy.
[39] World Economic Forum (2016).

- A solid industrial base, and in general, modern and forward-looking business conditions and technologies[40]
- Industrial excellence (as measured by process sophistication, degree of automation, workforce readiness, and innovation intensity), and sophisticated 'value networks' (i.e. high value added, industry openness, innovation network and internet sophistication)[41]
- The comparatively high level of adoption of digital technologies and use of robotics, machine learning and Artificial Intelligence[42]

Other countries in Europe are not staying still. In a recent study commissioned by the European Commission, new initiatives for Industry 4.0 were identified in 15 countries, including: Germany, Italy, France, Belgium, Czech Republic, Denmark, Spain, Hungary, Lithuania, Luxemburg, the Netherlands, Poland, Portugal, and Sweden[43].

4.1.3 Policy efforts beyond R&D to reap the full benefits of digitalisation

A salient observation, from the international review of policy approaches, is the broad recognition that investments in R&D and technology development are not sufficient to realise the full economic potential of digitalisation. Related to this is the fact that a range of digital technologies are already available in the market, but have not yet been integrated into manufacturing application nor have the solutions been understood by firms. And even if firms are aware of such solutions, they still need to learn to adapt them to their particular processes, and deal with the changes that relate specifically to their operations.

As observed in Table 4, while significant attention is still paid to R&D, many international initiatives and mechanisms focus on addressing barriers to the diffusion of technologies across industrial value chains, and their deployment at the factory level. It is also clear from Table 4 that government support is not limited to financial instruments, with a number of efforts taking a more 'hands-on' approach to ensure digital adoption in industry. There is recognition that firms require not only information about the potential of digitalisation, but also technical support to develop the capability to deploy digital technologies in their operations. Some of the areas where more emphasis is observed internationally are discussed in more detail below.

[40] IDA (2017). Advanced Manufacturing in Ireland.
[41] Roland Berger (2014). Industry 4.0. The new industrial revolution: How Europe will succeed.
[42] McKinsey (2017). Digitally-enabled automation and artificial intelligence: Shaping the future of work in Europe's digital front-runners
[43] European Commission (2017). Digital Transformation Monitor. Key lessons from national industry 4.0 policy initiatives in Europe. DG Internal Market, Industry, Entrepreneurship and SMEs.

Table 4 Example of initiatives and mechanisms addressing barriers to knowledge and technology generation, diffusion and deployment

Knowledge and Technology Generation		Example initiative * (See Appendix 5)
Financial incentives	▪ Direct funding, loans or subsidies for research, technology, experimental, and market development (including doctoral and postdoctoral positions) ▪ Direct funding, loans or subsidies for products, service and process development and piloting ▪ Financial support to acquire intellectual property (IP) over long periods of time ▪ Additional funding for R&D relevant to the digitalisation of manufacturing in public research centres	Denmark's Innovation Fund Denmark
Research and education support	▪ Development of new MSc and PhD programmes related to Industry 4.0 and digitalisation ▪ Revision of relevant courses in the formal education system ▪ Integration of industrial–academic exchange programs, internships and placements	Sweden's Produktion 2030 initiative
Public-private partnerships	▪ Public-private partnerships and clusters for strategic research identifying concrete solutions to industrial digitalisation challenges ▪ Research clusters offering a range of innovation functions, from contract R&D and product development to technology commercialisation services ▪ Other collaborative research environments and platforms for industry and academia	Germany's It's OWL cluster initiative
Research services	▪ Matchmaking to identify contract research opportunities between firms and universities ▪ Grant proposal writing advice for basic research ▪ Expert technological advice (technology foresight; technology roadmapping, etc.)	Finland's TEKES/DIMECC programme
Knowledge and Technology Diffusion		
Awareness generation / information provision	▪ Forums, innovation courses, seminars, workshops, conferences and international events ▪ Communication campaigns for industry ▪ Seminars offered by MNCs to provide SMEs with information about supply opportunities ▪ Matchmaking websites to match digital suppliers and buyers ▪ Online platforms for data sharing among businesses	China's Internet Plus
Technology demonstration	▪ Piloting and demonstration projects (products, services, processes) in laboratory or industrial environments ▪ Grants for pilot projects that serve as models for nationwide roll-out of new generic technologies, products and services of relevance to various industries ▪ Development of 'toolboxes' or 'toolkits' made available to consortia member firms ▪ Open Labs, presentations, case studies	Japan's Industrial Value Chain Initiative
Promotion of linkages	▪ Foreign and domestic industrial stays and study visits ▪ Specialist forums for industry and academia ▪ Personal exchange programmes where people can rotate from industry to academia or research institutes, or from academia / research institutes to industry ▪ International cooperation agreements at government level	Finland's 5th Gear Programme
Formation of industrial networks	▪ Firm networking and cluster collaboration promotion ▪ Collaboration schemes between high-tech industries and young start-ups ▪ Industrial visits, conference and workshops ▪ Support to firm networking through trade associations and chambers of commerce ▪ Support for internationalisation	Denmark's MADE initiative
Knowledge and Technology Deployment		
Workforce skills development	▪ Competency-development courses for employees and managers based on practical challenges of individual companies ▪ Business-oriented education programmes for long-term research competence building, to develop knowledge on how to implement digital technologies across the entire value chain	Norway's iKuben programme
Financial incentives	▪ Direct funding, loans or subsidies for digital products, service and process development ▪ Direct funding, loans or subsidies for companies to test new technologies and train their workforce ▪ Direct funding, loans or subsidies for tailored diagnosis of company challenges and technical assistance ▪ Grants or tax deductions for capability building and training, including overseas study trips	Spain's Connected Industry 4.0 initiative
Promotion of linkages	▪ International cooperation around standards and other technical issues ▪ Online tools for assessing digital level of companies and finding specialised consulting services ▪ Grants to partner researchers and ICT companies with manufacturing industries and their suppliers	Sweden's Process IT Innovations programme
Firm services	▪ Personalised consultancy services and access to technical expertise to address individual company challenges (e.g. process innovation, replacing old facilities, adoption of Industry 4.0 techs and solutions) ▪ Follow-up implementation advice (e.g. technology roadmapping) ▪ Access to facilities and networks of expertise located in intermediary research and technology organisations (e.g. Catapults, Fraunhofers) ▪ Promotion of technology adoption by offering packaged solutions to SMEs at accessible prices ▪ Support to develop business plans and technology investment strategy	Taiwan's Productivity 4.0 initiative

* Note: These programmes and mechanisms might address more than one policy area; they are listed across one particular area for illustration purposes. For more details on each initiative refer to Appendix 5.

** Source: Policy Links/CSTI Briefing note, based on Manufacturing Policy Portal: www.manufacturing-policy.eng.cam.ac.uk

4.1.4 Considerable policy emphasis on workforce skills development; standards; public-private partnerships; industry networks; technology diffusion among SMEs; and demonstration

The review of selected national initiatives and mechanisms reveal significant efforts across a number of policy areas as illustrated in Table 4. Some of the most prominent ones are discussed below.

Workforce skills development

Skills development and workforce training are receiving significant attention in national policy agendas. A first obvious concern is the effect that digitalisation may have on general levels of employment. However, there is no consensus on this issue. According to the World Economic Forum, estimations of potential global job losses across the economy due to digitalisation range from 2 million to as high as 2 billion by 2030[44]. However, it is also believed that digitalisation can be a net job creator in some industries[45].

A second aspect relates to the changing needs of national manufacturing workforces driven by digitalisation. There are implications not only for the level and type of skills required in the manufacturing workforce of the future across all skill levels, but also for the training of IT experts.

Workers in manufacturing are expected to require new multidisciplinary competencies combining mechanics, electronics and software. New roles in information management are emerging across the value chain. Proficiency in new computerised modelling and simulation tools and data analytics is increasingly necessary in many manufacturing design roles; the use of real-time planning tools is becoming more commonplace in operations management; and cybersecurity competencies are becoming more important in production management as processes and machines become increasingly interdependent.

Yet the challenge posed by digitalisation goes beyond the need for manufacturing workers acquiring more IT skills; fundamental changes might also be needed in the way in which IT experts are trained. Germany's Industry 4.0 initiative[46], for example, argues that the ability to identify application requirements in different industries, and partner with competent IT firms from around the world, is likely to become more important than the technological expertise itself. As such, it is argued that the digitalisation of manufacturing requires the convergence of IT and production engineering training.

Standards

The area of standards has also emerged as a key policy concern in the international policy discourse. The digitalisation of manufacturing involves networking and integration of different types of companies through value networks. Collaborative partnership in such networks will only be possible if appropriate standards are developed that ensure full interoperability in terms of data and applications.

Rather than a single rigid system, some national standardisation efforts highlight the importance of working on adaptable standard models to enable coordination and collaboration among enterprises with different types of production and IT systems[47]. The need for technical descriptions of these standards to facilitate their implementation is also recognised.

[44] World Economic Forum (2016). Digital Transformation of Industries: Societal Impacts.
[45] The UK Made Smarter review, for example, estimates a potential net gain of 175,000 jobs throughout the UK economy over the next decade.
[46] Acatech (2013). Recommendations for implementing the strategic initiative INDUSTRIE 4.0, report for the ForschungUnion 'Industry 4.0' strategic working group for New High Strategy.
[47] See for example: IVI (2016). Industrial Value Chain Reference Architecture.

Areas where standards are expected to play a crucial role include[48]:

- interoperability of data and machines
- governance in a digital environment
- performance assurance of 'digital twins' (assuring physical systems using virtual modelling)
- collaboration across enterprises and disciplines

Public-private engagements

A common feature of the initiatives reviewed is the collaboration between government, industry and academia. In some cases, initiatives are fully led by public bodies, while in others governance responsibilities are shared between actors. Occasionally, these collaborations take the shape of clusters in which academic and industrial organisations collaborate closely providing financial, infrastructural and human resources.

There is a tacit recognition that next generation digital manufacturing technologies are expensive to develop and deploy, and no one entity has all the expertise needed. Cooperative applied R&D is employed to share costs, risks, and expertise. Equally, it is recognised that where new infrastructure is required, public private partnerships (PPPs) may be able to provide a solution. A number of initiatives reviewed operate as public private partnerships.

Industry networks

Beyond government lead initiatives, one common feature of emerging digital manufacturing innovation systems, in leading countries like the US, Germany and Japan, are private sector networks that bring together stakeholders interested in the successful development and growth of the digitalisation of manufacturing.

Activities of such networks focus on creating awareness, coordinating activities and aligning priorities in the development of industrial digital technologies and infrastructure, in order to accelerate adoption by industry and reduce barriers-to-entry. Other activities include the identification, refinement and dissemination of effective practices. High-profile examples of industry networks include: the '**Industrial Internet Consortium**' in the United States, '**Plattform Industrie 4.0**' in Germany, and the '**Industrial Value Chain Initiative**' in Japan.

Technology diffusion among SMEs

Most of the international policy initiatives reviewed in this report pay particular attention to digital manufacturing, as a driver for the competitiveness of manufacturing-related SMEs. There is broad recognition that, as value chains get more connected, their competitiveness will depend on the collective capability of all firms to integrate and collaborate. Upgrading SME capability has thus become a specific concern, particularly due to their limited engagement in R&D and innovation[49].

SMEs tend to be more reluctant to undertake experimentation and risk-taking, as unsuccessful investments of their limited resources can greatly affect their financial performance and even jeopardise their survival. As a result, a number of digital manufacturing programmes and initiatives focus entirely on providing assistance to SMEs in terms of general capability development and technical assistance. Some programmes facilitate awareness and adoption of new digital technologies in SMEs by facilitating linkages with other innovation actors, such as universities and research and technology

[48] BSI (2017). Standards Outlook 2017. Delivering Digital. How Standards are Enabling the Adoption of Digital Technologies.
[49] Studies informing policy in the US, for example, estimate that only around 2% of small firms conduct R&D, compared to 14% of large firms [PCAST (2015). Supply Chain Innovation: Strengthening America's Small Manufacturers].

organisations, as well as reducing technology costs, and de-risking the technological innovation processes in general.

For example, **Denmark's MADE** initiative links SMEs and large companies with universities, other academic institutions, and advanced technology groups to promote both the development of new applications as well as SME adoption. The initiative's approach is based on 'cases stories' and a demonstration of state of the art technologies, as well as industrial visits. The initiative claims that their 'cluster project' has been particularly successful in bringing together SMEs, and in providing them with support and guidance to develop more flexible robotics solutions. This involves increasing the utilisation of robots while containing costs of restructuring production lines.

Demonstration facilities

Some countries place strong emphasis on the diffusion and deployment of existing and emerging technologies in real industrial settings. There appears to be increased funding of demonstration facilities, such as test beds, pilot lines and factory demonstrators, that aim to provide dedicated research environments with the right mix of tools and enabling technologies, and the technicians to operate them.

For example, **Finland's 5th Gear** programme funds piloting and demonstration activities focused on both novel technologies with a long time to market, as well as more mature technologies. Most recently, the *Made Smarter Review,* conducted by the UK Government sector, calls for the establishment of '*Digital Transformational Demonstrator*' programmes, to be co-funded by industry, to promote adoption of digital technologies by UK manufacturers[50]. It is recommended that these demonstrators should be organised at the regional level, and address both firm-specific as well as cross-cutting industry challenges, and provide support, catering for the particular needs of SMEs.

[50] BEIS (2017). Made Smarter Review. Independent review commissioned by the Department for Business, Energy & Industrial Strategy.

5

Addressing Challenges & Opportunities for Ireland: Thematic Policy Priorities

This section reflects on thematic policy priorities that appear to be the most relevant for Ireland in order to address challenges and opportunities arising from the digitalisation of manufacturing. These areas have been identified based on the findings from previous sections, and drawing from the various sources of information gathered during this project. The section concludes by discussing some of the cross-cutting requirements that appear to be particularly relevant in ensuring an effective policy implementation in Ireland.

5.1 Thematic policy priorities for Ireland

There is broad agreement, among the Irish industrial, research and policy communities, on the potential of digital technologies to help Irish manufacturing sectors to remain internationally competitive. There is concern that other countries might already be ahead in the 'digitalisation journey' and, thus, lack of action could mean the loss of national competitiveness. Drawing from the diverse inputs gathered throughout this investigation, five priority policy themes have been identified to support the digitalisation journey of Irish manufacturing firms. Examples of possible implementation approaches across each policy theme are presented, drawing from stakeholder consultations as well as an international review of recent policy programmes and initiatives.

This list of thematic priorities highlights the themes where collected evidence has suggested that policy action could have the most potential to address challenges and opportunities arising from the digitalisation of manufacturing for Irish manufacturing sectors. A policy-focused workshop, which brought together over 20 selected stakeholders with privileged insights into the Irish policy landscape, has been particularly useful to inform the discussions presented in this section of the report[51].

The emerging thematic policy priorities for Ireland, discussed later in this section, are listed in Table 5.

Table 5. Summary of thematic priorities for Ireland

No	Thematic Priority	Key Focus Areas
1	Awareness raising and identification of user application needs	▪ Improve understanding of the concept of digitalisation and its potential business benefits ▪ Identify and articulate nuanced digital applications and solutions of particular relevance to firms based in Ireland ▪ Increase awareness of sources of existing capabilities in Ireland
2	Demonstration of application value	▪ Showcase the value of digital applications in real industrial environments ▪ Allow decisions makers to 'see and feel' how digital technologies can drive improvements in manufacturing operations ▪ Help firms de-risk investment decisions by helping them understand potential implementation challenges and associated financial costs
3	Consortia building and application development	▪ Support the integration of digital technologies into applications and solutions that can be deployed by firms in Ireland ▪ Bring together relevant manufacturing and ICT expertise ▪ Create consortia of MNCs and SMEs, from both user industries and solution providers, and develop roadmaps for specific application development
4	Technical advisory services for application deployment	▪ Provide access to specialised digital manufacturing expertise to address technical challenges arising from implementation, thereby helping de-risk application deployment ▪ Consider the need for a variety of technical support, including R&D services, consultancy, and testing ▪ Provide support across manufacturing sectors (but differentiate support required by different types of firms)
5	Skills for digital manufacturing	▪ Support the development of digital manufacturing skills across all levels of the organisation – including factory technicians, production engineers, operation managers, and company directors ▪ Encourage ICT experts to increase their knowledge of manufacturing ▪ Support the transitioning of manufacturing workforce to new roles opened up by digitalisation

[51] This workshop was convened on 20 October in Dublin, bringing together representatives primarily from the policy community in Ireland (including representatives from key government Departments and agencies), as well as selected stakeholders from industry and research organisations. Workshop participants discussed the emerging findings of the study – in particular the challenges and opportunities for Ireland arising from the digitalisation of manufacturing – and discussed aspects of the international experience which could help inform policy design in Ireland.

In addition to these thematic priorities, a number of cross-cutting requirements appear to be particularly relevant to ensure an effective policy implementation in Ireland. These include: industry needs-oriented funding mechanisms; policy coordination, and appropriate institutional infrastructure. These are discussed at the end of this section.

The thematic policy priorities outlined above recognise the importance of research and development as key innovation enablers. However, these priorities also highlight that, in order to reap the full benefits of digitalisation, efforts are also needed to address the system integration challenges involved in diffusing and deploying the application and solutions required by manufacturers to fully exploit the benefits of digitalisation.

It is important to note that the priority themes listed above are not centred around particular types of firms or sectors. In fact, it is recognised throughout the study that the pervasive nature of digitalisation demands concerted efforts by all types of firms to bring together dispersed capabilities and ensure critical mass. It is also important that firms engage effectively with relevant stakeholders in the wider national innovation system, including policy and academic stakeholders.

While many of opportunities arising from the digitalisation of manufacturing are cross-cutting, an important consideration emphasised by the study is that their exploitation requires nuanced applications and solutions to effectively respond to sector and firm-specific needs. To respond accordingly, it is widely agreed that manufacturing firms need to build their know-how of digital technologies. But, at the same time, ICT and software companies also need to better understand manufacturing processes and environments in order to support the development of sector and firm-specific solutions and their deployment in manufacturing. Both manufacturing and ICT firms need to better understand mutual business opportunities in order to incentivise engagement and cooperation.

Collaboration between MNCs and SMEs is also required to exploit the benefits that building digital capability could bring to the Irish industrial community as a whole. Support from MNCs to SMEs in their digitalisation journey can lead to positive outcomes for both types of firms. For example, a more competent local supply base does not only enhance the potential of these SMEs to pursue new supply opportunities, it can also improve the value proposition of foreign owned MNCs located in Ireland to win mandates from their headquarters located elsewhere. Exploiting clustering and the strong linkages between MNCs and SMEs throughout Ireland is thus a key step in this direction.

Finally, it is important to recognise that the starting point of firms in terms of digital capabilities (i.e. their stage in the digitalisation journey) can vary widely. As such, different types of policy support might be more relevant to different types of firms. Accounting for this diversity of needs, and ensuring flexibility in policy delivery, is critical to successfully drive the national digitalisation of manufacturing agenda forward.

5.1.1 Awareness raising and identification of user application needs

A key opportunity area identified in this study is to improve the understanding of the concept of digitalisation, the potential business benefits of digital adoption, and the sources of existing capabilities in Ireland. There is also a need to capture information about specific nuanced digital applications and solutions of particular relevance for Irish manufacturing sectors.

Stakeholder consultations revealed that many Irish manufacturers have been exposed to the concept of digitalisation and terms such as ‘Industry 4.0’ and are aware of a number of relevant digital technologies. There is still a lack of clarity among many firms, however, about how the digitalisation of

manufacturing might be relevant to them in practice. This is not only an issue related to the use of unclear technical terminology but also to the lack of specific examples regarding sector and firm-specific digital applications and solutions that can be particularly relevant for MNCs and SMEs based in Ireland.

Because digitalisation can be applied across multiple manufacturing operations in numerous ways, the range of possibilities can be daunting. There is a need to better understand what digital applications and solutions might be particularly relevant to Irish manufacturing sectors – and whether these already exists or still need to be developed.

Stakeholder consultations also suggested that it is difficult for firms to identify where the current digital capability and relevant technical expertise in Ireland may be found. Naturally, this creates barriers to the establishment of connections between relevant actors, including users and providers of digital applications. Similarly, many firms are not aware of who might be able to provide strategic and management advice to guide their efforts in digitalisation. Lack of awareness appears to be particularly challenging for SMEs, but the need to improve understanding of the opportunities enabled by digitalisation among large corporations was also identified.

As a result, there was broad consensus that raising awareness among the industrial community is a basic step in increasing the interest of users to explore the potential of digitalisation (and to reveal the market potential for solution providers).

Facilitated events, bringing together interest groups, can serve as a mechanism to capture application needs, and enable discussion of entry barriers and migration strategies among firms. The inclusion of ICT communities can help user firms articulate needs and identify where the pools of digital (technical and strategic) expertise might be found, in Ireland and abroad. Provision of cost-benefit analyses for digital adoption can also help firms address information gaps. Giving support to these type of networking activities could allow Ireland to make the best use of its tightly networked companies, researchers and policy makers. A clear goal of such initiatives is to identify and articulate the most promising applications for manufacturers based in Ireland.

Other initiatives to raise awareness and identify user application needs (identified through consultations and the review of international practices), include:

- Use of professional bodies as a diffusion and needs gathering mechanism – building on their continuous education programmes and exploiting their cross-sectoral nature.
- Activities such as seminar and workshops, site visits, site demos, study materials, etc.
- International visits
- Communication campaigns for industry
- Online platforms for best practice-sharing

Examples of implementation programmes, initiatives and institutional mechanisms

A measure that has gained prominence internationally is the compilation of digitalisation *use-cases,* often through industrial working groups. Use-cases provide in a concise manner and accessible language examples of how companies have achieved benefits by adopting digital solutions. Use-cases help visualise achievements, share best practices, and promote cooperation among businesses.

Some use-case databases have been made available online in countries including Germany (with over 310 use-cases), Japan (with over 210 use-cases) and France (with over 160 use-cases)[52]. These

[52] Consulted in early November 2017 (Japan: http://usecase.jmfrri.jp/#/; Germany: http://www.plattform-i40.de/I40/Navigation/Karte/SiteGlobals/Forms/Formulare/karte-anwendungsbeispiele-formular.html; France: http://exemples-aif.industrie-dufutur.org/)

databases provide 'long lists' of sectoral and cross-sectoral application areas have been identified by international initiatives, which could provide valuable reference information[53].

For such databases to be effective, information-gathering mechanisms need to be established to bring together firms with complementary capabilities. An example of this is Japan's **Industrial Value Chain Initiative's (IVI)**, whose bottom-up approach involving both manufacturing and ICT firms to identify digital applications with the potential to deliver value to manufacturing user firms has gained international recognition (**Box 4**). A similar activity is undertaken by the **Industrial Internet Consortium (IIC)** in the US, which identifies, assembles and promotes best practices in particular among major electrical and electronics manufacturers, semiconductor firms, and telecommunication equipment vendors[54].

In addition to their core functions, a number of R&D programmes reviewed in **Appendix 5** also support awareness raising, knowledge exchange, and industrial networking to improve communication of firms with distinct capabilities. Sweden's **Produktion2030**, for example, funds workshops, seminars and dissemination of technical solutions in particular among SMEs. Other efforts include the creation of self-diagnosis tools (for assessing the 'digital level' of firms), such as the one funded by Spain's **Connected Industry 4.0** initiative.

Box 4. Application needs and use-cases at the Industrial Value Chain Initiative (IVI) – Japan

Japan's Industrial Value Chain Initiative (IVI) is a collaborative forum with over 200 members that promotes the development and adoption of digital technologies in manufacturing. IVI brings together large and small firms in working groups to develop 'smart manufacturing scenarios', which are instances of how manufacturers can 'create value from data'. IVI emphasises the benefits of focusing on areas where firms "can naturally collaborate while keeping each company's competitive advantage untouched".

Working groups established within IVI develop bottom-up scenarios in one-year cycles. Firms identify practical ways in which the application of digital technologies can lead to improvements in common industrial operations, both within and across firms in the value chain. Use-cases are classified into broad application areas including: production process engineering; production planning and control; quality system management; and maintenance planning.

Source: *Authors' analysis based on interview with Prof. Yasuyuki Nishioka, President of IVI.*

Expected outcomes from policy interventions

Increasing awareness of the value of digital technology adoption can increase the willingness of firms to engage in digitalisation efforts. Exposing decision makers to case studies they can relate to, with insights into how digitalisation may lead to tangible benefits for firms similar to their own, can persuade them to allocate resources to exploit the possibilities opened by digitalisation. Best practice sharing can help firms de-risk their 'digitalisation journey', tackle the fear of the unknown, and address concerns about the risks inherent in innovation.

Critically, narrowing down the list of all potential digital applications and solutions to the ones of most relevance to Irish manufacturers can help focalise efforts. Needs can be segmented to identify the type of nuanced applications required by particular sectors and firm types. At the same time, understanding needs at a more disaggregated level of detail can help identify cross-cutting opportunities. All this can,

[53] The Japanese database referenced above, for example, classifies use-cases in the following categories: development process; inspection devices / tools / parts; equipment / collaboration of equipment / production control in factories; remote monitoring / collaboration of factories; supply chain / manufacturing support; customer support / manufacturing.
[54] http://www.iiconsortium.org/about-us.htm

in turn, help to clearly identify which solutions might already be available in the market (in Ireland or abroad), and which ones might still need to be developed.

5.1.2 Demonstration of application value

The need for demonstrators to showcase the value of digital applications to Irish manufacturers in real industrial environments was a clear message from stakeholder consultations. Demonstration facilities allow firms to evaluate new digital technologies and their applications, providing key insights into their potential value capture opportunities, implementation challenges, and financial cost[55].

The precise focus of any demonstrator needs to be chosen carefully, accounting for the particular needs of firms based in Ireland (as outlined in Section 4.2.1), and the different types of digital system integration challenges (as outlined in Section 2). A distinction needs to be made between demonstration activities focused on showcasing the potential of platform technologies (IoT, AI, Big Data), and those focused on the sector-specific aspects of digital applications in real industrial environments.

Given the need identified in stakeholder consultations for near-market efforts to complement the more basic technology R&D-related demonstrations already present in the country, demonstrators closer to final user applications appear more relevant to Ireland. Needless to mention, efforts are needed to ensure that any demonstration efforts in Ireland build on existing facilities in the country and complement R&D endeavours.

Another suggestion made by Irish stakeholders is that there might be value in gathering manufacturing firms into 'demonstration groups' using shared demonstration facilities. Because many of the user applications are cross-cutting, opportunities exist to bring firms from different sectors together around the work of physical demonstrators. Supporting work to ensure that the agenda of any demonstrators is linked well to the corporate technology roadmaps of the intended audience might be needed so as to ensure industrial engagement, as suggested by consulted stakeholders. Alternatively, initiatives could run in the opposite direction, using the demonstrators to drive the development of corporate technology roadmaps, especially among SMEs.

Irish stakeholders also suggested that ICT vendor firms in the country might be interested in showcasing their offering to manufacturing firms. Stakeholders also highlighted that, thanks to the country's small size, demonstration facilities could be shared among vendors to jointly demonstrate the commercial potential of digital applications. And thanks to the convenience of travel within the country, it would be comparatively easier for firms based in Ireland to convene around these demonstrators and discuss common interests and issues.

Further, the advanced regulatory framework in Ireland can place Ireland as the location of choice for testing and demonstrating new technologies. This is particularly relevant to highly regulated sectors, such as pharmaceuticals, medical devices and food & beverages. In such industries, process changes driven by the adoption of new (digital) applications might require regulatory approvals that could potentially be obtained in Ireland faster than in competitor locations.

[55] O'Sullivan, E. and López-Gómez, C. (2017). Manufacturing R&D Policies for the Next Production Revolution: An International Review of Emerging Research Priorities and Policy Approaches. In OECD (2017), The Next Production Revolution: Implications for Governments and Business, OECD Publishing, Paris.

Examples of implementation programmes, initiatives and institutional mechanisms

Examples of applied digital demonstration efforts are those undertaken by the **Digital Manufacturing and Design Innovation Institute (DMDII)** in Chicago (Box 5), which take place alongside the institute's core research functions. DMDII's the Digital Capability Center (DCC), provides a hands-on learning environment to showcase the impact of digital manufacturing and provides training on digital capabilities across the entire value chain.

Another example is Denmark's **MADE** cluster initiative, which finances small demonstration projects, and provides 'Open Labs', which include presentations, case stories, and demonstrations of the state-of-the-art technologies. Similarly, Sweden's **Produktion2030** programme supports test and demonstration projects at high levels of technology maturity, requiring high levels of industrial co-financing. Finally, Finland's **5th Gear** programme supports pilot and demonstration with a focus on the diffusion of technologies already available in the market.

Expected outcomes from policy interventions

Showcasing digital applications in action in relevant industrial environments can help demystify them, and illustrate their potential and feasibility for ordinary users. Allowing decision makers to 'see and feel' digital technologies, in a setting that they can relate to, can help them become more sophisticated customers in selecting and acquiring new capabilities. Demonstrators can be mechanisms for firms to come together to network, collaborate, and explore the technologies and the opportunities for themselves and for their sectors. They can help improve understanding of the value of digitalisation to investors, partners, the media and the public.

Box 5. Demonstration efforts at the Digital Manufacturing & Design Innovation Institute (DMDII) – USA

One of the most high-profile initiatives related to the digitalisation agenda in the United States is the Digital Manufacturing & Design Innovation Institute (DMDII) based in Chicago. DMDII is one of the new Manufacturing USA innovation institutes with a mission to develop and demonstrate new digital manufacturing and design capabilities in advanced analysis, intelligent machining and advanced manufacturing enterprise.

DMDII has 190 member companies, as well as partners from universities and other organisations and funding of $320 million ($70 million of which comes from the government). One of the functions of DMDII is to provide a space where manufacturers can see new, cutting-edge digital manufacturing products that they can put to use to improve productivity and profitability. It is also a demonstration centre where manufacturers can try out new technologies, products and equipment in a 'factory of the future'.

In partnership with McKinsey, DMDII established the Digital Capability Center (DCC) Chicago, which showcases the impact of digital manufacturing and provides training on digital capabilities across the entire value chain.

The Chicago centre is a hands-on learning environment and allows users to:

- Understand how to start, scale, and sustain their digital journey
- Interact with cutting-edge technologies in an authentic production environment
- Build capabilities at every level of their organisations through tailored workshops
- Explore 20+ experiential learning modules and leverage deep expertise to identify the technologies that are critical for their business
- Access an ecosystem of 50+ technology partners providing innovative solutions across the value chain

Source: *Authors' analysis, DMDII website*

5.1.3 Consortia building and application development

As discussed in Section 2, even when platform digital technologies are available in the market, technical challenges exist to integrate them into digital applications and solutions that can be deployed into established manufacturing systems. Developing applications with the potential to succeed in the marketplace requires combined efforts from both user industries and solution providers.

The availability of a particular digital technology does not by itself guarantee its integration with other digital technologies, or its implementation in industrial processes. Expertise from different technologies domains may need to come together to develop generic technology applications (for example, sensor technology, robotics and artificial intelligence may need to come together to develop advanced automation systems), which in turn require a combination of ICT and manufacturing expertise to ensure effective deployment in industrial processes (for example, to integrate such automation systems into production lines of firms in the engineering sector). Addressing system integration challenges require understanding of relevant standards and awareness of international developments in this area. It was highlighted during consultations, however, that Irish experts are not sufficiently involved in global standardisation activities related to emerging digital technologies and this needs to be addressed.

A potential area of action to support system integration and the development of demand-led applications is the formation of firm consortia and partnerships bringing together relevant manufacturing and ICT expertise. To ensure that all relevant expertise is available, consortia would need to include MNCs and SMEs, from both user industries and solution providers. Efforts by consortia firms would need to be brought together through, for example, technology roadmaps for specific application development.

The presence of leading ICT sectors can be seen as a potential Irish advantage, if they are able to establish linkages with the manufacturing sectors. The opportunity exists to build on these sectors' international market presence to offer new digital solutions and expertise not only to Irish manufacturers but also to the global market.

Given the particular combination of capabilities present in the country (including the ecosystem of MNCs and suppliers combined with ICT firms), and the strong regulatory framework of the country, the medical device cluster in Ireland appears particularly well positioned to take advantage of the potential of consortia building.

Support through research and development grants (with emphasis on development) was suggested as a potential mechanism to enable the development of new digital applications. However, stakeholders consulted expressed the view that current funding schemes, requiring the participation of higher education institution (HEI) researchers, are not always appropriate for this type of more industry-facing endeavours. This is not only because of the potentially time-consuming application processes that discourage industry involvement, but also due to the long-time horizons involved. Therefore, it was suggested that new or complementary funding mechanisms would be required to enable industry consortia to develop digital applications relevant to firms based in Ireland, without necessarily depending on HEI researcher involvement. It was also recommended that tapping into international knowledge in this space should be explicitly supported to accelerate outcomes.

Examples of implementation programmes, initiatives and institutional mechanisms

Examples of targeted application development and transfer efforts bringing together user firms and solutions providers, are offered by initiatives such as Germany's It's OWL initiative (Box 6). The initiative includes expert discussions to identify concrete technology interests, workshops to test technologies

and solutions in a non-binding setting, and targeted use and integration of the new technologies in production processes through collaborations between user industries and technology providers.

Valuable lessons might also be drawn from Japan's **Industrial Value Chain Initiative (IVI)**, which has established working groups of private firms to develop *"¥100,000 (~€700) IoT kits"*. These kits are developed with the aim of making a digital solution accessible to SMEs by integrating low-cost components, such as the Raspberry Pi single-board computer and cheap sensors. To disseminate the benefits of the initiative among SMEs, IVI holds seminars across the Japanese regions. Advice is made available to help SMEs adapt these kits into their particular operations.

Given the need to bring together complementary industrial expertise in standards development activities, policy support in this area might be valuable. International experience shows that funding agencies often explicitly allow (or even, where appropriate, encourage) costs associated with standards development activities as eligible items within grant applications in areas including: membership in standards developing organisations, purchase of published standards, additional travel to participate standards development workshops, and supplements to workshop grants to incorporate standards development-related sessions[56].

Box 6. Intelligent Technical Systems OstWestfalenLippe (It's OWL) – Germany

It's OWL is an alliance of over 170 businesses, universities and institutes, funded through the German Federal Ministry of Education and Research's (BMBF) Leading-Edge Cluster programme. It represents one of the largest investments associated with Germany's Industry 4.0 initiative.

It's OWL received €100M over five years, funding 46 research projects to develop intelligent technical systems, which arise from the interplay of engineering and ICT. The project aims to build on the existing manufacturing and innovation capabilities of the OstWestfalenLippe region, which has industrial strengths in mechanical engineering-related sectors and domestic appliances. In terms of research, its strengths lie on the interrelated fields of self-optimisation, cognition and industrial automation.

Solutions emerging from the consortium's research are expected to impact not only production processes, but also the development, deployment, maintenance, and life-cycle management of new products and systems. Significant efforts within It's OWL's projects are focused on developing ICT-based applications for industries with strong presence in the region, including industrial laundries, furniture and white goods.

During the second phase of its funding, the initiative places emphasis on transfer projects to make technologies and methods available to member firms, with a particular focus on SMEs.

Source: *Authors' analysis based on interviews with It's OWL management staff, It's OWL corporate reports, and the It's OWL website.*

Expected outcomes from policy interventions

The multidisciplinary nature of digitalisation places a premium on bringing together the know-how of manufacturing firms and the ICT sector. Establishing consortia of firms around digitalisation can help bring down sectoral boundaries and promote cooperation between manufacturing and ICT firms. This is a critical step to ensure that, on one hand, manufacturing firms are able to develop the required digital expertise and, on the other, ICT and software firms are able to develop a better understanding

[56] O'Sullivan, E. and Brévignon-Dodin, L. (2012). Role of Standardisation in support of Emerging Technologies. A Study for the Department of Business, Innovation & Skills (BIS) and the British Standards Institution (BSI).

of manufacturing operations. The participation of different types of firms in the development of digital applications for manufacturing can help address interoperability challenges and support the dissemination of relevant standards.

Integration of digital technologies in legacy systems poses significant technical challenges for implementation. Some solutions might be too onerous for an individual firm to undertake on its own, particularly in non-critical processes, but the case for investment may be more compelling when costs (and benefits) are shared among firms. Similarly, participation in consortia of firms might prove useful in addressing implementation challenges in highly-regulated sectors.

Irish manufacturers have the potential to develop distinctive competitive advantages if they are able to establish linkages with the world-leading software and ICT industries present in the country. The establishment of firm consortia may help articulate and communicate the growing demand for digital solutions across manufacturing sectors. This can, in turn, incentivise the engagement of ICT firms that might not be aware of opportunities in the domestic market.

5.1.4 Technical advisory services for application deployment

The 'journey' to adopt digital applications and solutions in manufacturing operations is fraught with technical challenges. Firms do not usually replace their production lines with complete new ones but instead seek to integrate new technologies into existing systems. Similarly, many digital applications are not necessarily ready to 'plug-and-play' into firms' operations and therefore their deployment represents a system integration challenge. Even when firms make efforts to upskill their workforce, they may not have the expertise necessary to address specific system integration challenges involved in the deployment of digital applications in manufacturing as they emerge.

Recognising these challenges, the consulted stakeholders highlighted the importance of ensuring access to relevant advisory technical services to support firms' digitalisation efforts. Because many of the technical challenges are essentially firm-specific, manufacturers require tailored advisory services. These would need to respond to their particular technological and organisational configurations and levels of sophistication.

Stakeholders recognised that some technical advisory services are already available to manufacturing firms in Ireland. However, it was suggested that firms would benefit from a supporting environment more specifically addressing technical challenges related to digitalisation.

Advisory services can help build digital capabilities across all firms in the manufacturing base in Ireland. However, how supports are deployed might be differentiated according to firm type. As emphasised throughout the report, and clearly illustrated in **Table 4,** support for capability building should not be limited to the funding of R&D, but should also extend to knowledge and technology deployment.

A variety of advisory services might be relevant, including: bespoke process upgrading and automation services, new process/product development and testing, standard compliance and certification, supply chain management, technology investment strategy, business model development, product delivery strategy, and firm-level technology adoption roadmapping.

For example, the importance of providing advice for digital standard adoption is often highlighted in the international experience. Timely adoption of digital standards could assist firms to integrate better into value chains, while firms that fail to adopt relevant standards might potentially be locked-out of business opportunities. As such, many countries emphasise the importance of information-sharing

efforts of national standard bodies, and the value of advisory services to support firms' digital standard adoption.

It is important to recognise that the starting point of firms in terms of digital capabilities (i.e. their stage in the digitalisation journey) can vary widely. As such, different types of support mechanisms might be more relevant to different types of firms. Accounting for this diversity of needs, and ensuring flexibility in policy delivery, is critical to successfully drive the national digitalisation of manufacturing agenda forward. It is important to recognise, for example, that the needs of MNCs and SMEs may vary widely, and therefore they might require different types of support packages. While some firms might require advice to take the first steps in the digitalisation journey, some others might already require more advanced support.

The expertise of Ireland's State agencies and offices could be leveraged to identify specific technical needs across different types of sectors and firms. Existing industrial networks and communication mechanisms, hosted by the industry associations, could also help identify such capability gaps, and capture suggestions regarding the type of services that might help in addressing them.

Finally, support provided by MNCs to SMEs can also have an important role. MNCs can help less sophisticated SMEs address application deployment challenges, which might be passed down the supply chains, as they require suppliers to integrate to new digitally-enabled systems (e.g. using new digital purchasing systems or providing real-time process line data). In the international experience, support offered by MNCs to their SME suppliers could range from information provision through to hands-on technical assistance.

Examples of implementation programmes, initiatives and institutional mechanisms

Examples from the international practice vary from more research-oriented support mechanisms, such as the UK's Advanced Manufacturing Supply Chain Initiative (AMSCI), to more process-oriented schemes, such as the ones provided by the Singapore Institute for Manufacturing Technologies (SIMTech, Box 7).

Another example is Korea's Manufacturing Innovation 3.0 initiative, which offers subsidised consulting support on manufacturing process innovation to help upgrade facilities. The programme is coordinated by the Ministry of Commerce and delivered in collaboration with industry associations. The initiative leverages the ICT know-how of MNCs such as Samsung to support SMEs' digital technology adoption.

Another relevant example is Spain's Connected Industry 4.0, which provides funding that allows SMEs and microenterprises to access specialised consulting services on 'digital enablers' provided by independent private organisations.

Expected outcomes from policy interventions

An enabling technical support environment has the potential to enhance the competitiveness of firms based in Ireland by helping them de-risk the deployment of digital applications. This can, in turn, help firms upgrade and reconfigure existing capabilities to respond to the demands of digitalisation.

Existing institutions, initiatives and firms providing advisory services might need to enhance or diversify their offering to support the needs arising from digitalisation. Some countries have chosen to establish new mechanisms focused on providing technical advisory services in support of digitalisation. Similarly, some countries have made emphasis on the need to ensure that such services are affordable for smaller

companies. While sources of funding might be made available by government, some services are often provided by private sector firms.

Stakeholders who were consulted explained that opportunities exist in Ireland to build on previous success experiences related to joint capability development in, for example, the food industry. Failing to keep up with change might lock companies out of business opportunities: international competition is expected to intensify, as digital connectivity reduces cross-boundary transaction costs even further.

Box 7. Technical advisory services at the Singapore Institute for Manufacturing Technologies (SIMTech) – Singapore

Singapore Institute of Manufacturing Technology (SIMTech) is a technology and innovation centre whose mission is to develop high-value manufacturing technology and human capital to enhance the competitiveness of Singapore's manufacturing industry.

A particularly interesting feature is SIMTech's initiatives to help firms adopt new technologies, develop new capabilities, and venture into more sophisticated industries. Dedicated initiatives have been established to help firms venture into a selected number of high growth industries by helping them build know-how in new technologies.

Advisory services typically involve a combination of joint research projects, advisory support and consultancy, and access to specialised testing equipment. Examples of advisory support and consultancy services offered by SIMTech include support to adopt new industry standards, and to develop firm-level technology roadmaps.

SIMTech has launched initiatives based on its manufacturing research expertise to develop local suppliers in aerospace, medical technology, oil and gas, complex equipment, and heat treatment industries, among others.

Source: *Authors' analysis based on interviews with SIMTech's management, and their corporate reports and website.*

5.1.5 Skills for deployment of digital applications (from factory technicians, production and ICT engineers, to company directors)

Digitalisation is driving changes in the skill profile required in the manufacturing workforce of the future. For successful integration of digital applications in manufacturing operations, manufacturing workers and managers need to acquire new ICT skills, and ICT experts need to learn more about manufacturing processes and technologies.

Ireland already has the advantage of having a relatively high-skilled workforce. The country hosts the second highest share of a population with a tertiary level of education in the European Union. Ireland's ICT Skills Action Plan represents a collaborative effort by the government, the education system and industry to meet the goal of 'making Ireland the most attractive location in the world for ICT skills availability'[57].

However, Ireland faces an increasing demand for digital skills across a number of industries, making it increasingly difficult for manufacturers to get hold of graduates. Manufacturers compete for digital skills, not only with software firms established in the country, but also with other sectors such as finance,

[57] DJEI (2014). ICT Skills Action Plan. Department of Jobs, Enterprise & Innovation.

gaming and marketing. As a result, the demand for high-level ICT skills workers in Ireland is expected to increase, with over 44,500 jobs opening forecast to arise by 2018[58].

Consultations with Irish stakeholders suggested that there is a disconnect between engineering and ICT skills in existing curricula. The need for more programmes to support the re-skilling of the existing workforce was also suggested, not only for factory technicians and engineers but also, critically, for managers and decision makers who do not always recognise the value of data for decision making. Leadership teams need to be made aware about the benefits of digitalisation, not only as an enabler of operational improvements but also as potential tools for better decision making. Exploiting the potential to establish new business models by adopting digital capabilities will require new management skills.

In the long term, the development of a national 'ecosystem of skills' and a clear 'digital career path'/'digital curricula' were also identified as important enablers. In the short term, bespoke, industry-defined modules of about two days of duration were suggested as 'quick-win' mechanisms, in particular to demonstrate immediate value in upskilling. In addition to technical skills, two sets of skills were identified as needing particular attention: i) strategy skills to embrace the wider changes needed to benefit from the deployment of digitalisation capabilities (especially for indigenous SMEs); and ii) system analysis skills[59] which are essential because of the cross-cutting and multidisciplinary nature of digitalisation. Core ICT and engineering skills, however, are still considered essential to underpin the capacity to understand the opportunities available and to appreciate the systemic nature of these opportunities.

There was a strong consensus for the need to emphasise the continuous reskilling needed in a fast-changing environment. This might be by focusing on 'the path, not just the waypoints' – so to provide an upskilling career path, potentially following an apprenticeship model and certainly with industry input to the curriculum. There were suggestions that, in previous experience, certification has been found to increase motivation for, and an uptake of training.

Higher-education programmes, such as master's degree courses, could have a valuable role to play. However, HEI structures do not always allow adaption of programmes away from a discipline focus, so as to reflect the interdisciplinary nature of digitalisation. Internships in distinct companies, and specialisations to build digital skills in graduates, were suggested as a solution. An independent industrial training offering could also help address potential gaps in the educational system. Mechanisms for dialogue between manufacturing industry and academic institutions are ever more necessary to ensure that the requirements of the digital economy are reflected in training programmes. Training partnerships between businesses and higher education institutions may also be needed.

It is important to emphasise that while it is essential that manufacturing professionals are able to develop new digital skills, changes are also required to the way IT experts are trained. The convergence between manufacturing, ICT and software training is required to develop the multidisciplinary workforce required to identify and develop application requirements in different industries. An adequately trained workforce in the area of digital security is also required to ensure the reliability of future manufacturing operations.

[58] DJEI (2014).

[59] System analysis skills refer to determining how a system should work and how changes in conditions, operations, and the environment will affect outcomes. Source: National Center for O*NET Development (2017). Systems skills. Retrieved from https://www.onetonline.org/skills/

Examples of implementation programmes, initiatives and institutional mechanisms

A number of approaches to ensuring the provision of a skilled workforce around new technologies can be found in international experience. These include the establishment of higher-education programmes linked to industry needs to produce 'industry-ready' professionals. In addition, job placements and technical apprenticeship schemes between companies and universities have been implemented in a number of countries.

One potential innovation is to upskill networks of SMEs so there is mutual support, role models and also the potential to share lessons. Upskilling programmes can be augmented with diagnostic services (as well as training needs analysis), and mentoring through early projects which deploy digitalisation and use the new skills. This suggestion is highly compatible with previous actions discussed around communities of practice, demonstration, and consortia formation.

This is the approach adopted by Denmark's KOMP-AD initiative, which paid particular attention to the need of SMEs and adopted a gradual approach to secure engagement. This included first capturing the particular needs of around 250 SMEs and, then, developing 'tailor-made' competency-development courses for employees and managers.

Expected outcomes from policy interventions

Developing technical and managerial skills in the Irish workforce can help tackle critical challenges to digital knowledge and technology deployment identified in Section 3. Upskilling managers can help demystify the potential of digital technologies in manufacturing operations and, ultimately, help them develop business cases for investment with a clear vision of how implementation can be achieved. Increased digitalisation expertise among managers and leadership teams can help them identify those areas across the firm's operations where digital technologies can have the most potential to enhance competitiveness and profitability. Gaining awareness of relevant technologies can help managers better understand system integration challenges, identify capabilities missing in the organisation, and develop cost-benefit analyses.

In terms of factory technicians and production and IT engineers, new digital skills can facilitate the quick adoption and exploitation of digital applications and solutions in factory floors. Upskilling the existing manufacturing workforce with know-how on digital technologies can support employees in the transitioning to new roles.

5.1.6 Cross-cutting implementation requirements driven by the digitalisation of manufacturing

In addition to these thematic priorities, a number of cross-cutting requirements, driven by the digitalisation of manufacturing, appear particularly relevant to Ireland. These include: industry needs-oriented funding mechanisms; policy coordination; and appropriate Institutional infrastructure.

Industry needs-oriented funding mechanisms

There is broad recognition of the need to more effectively coordinate R&D between industry and academia. It was recognised that there are opportunities to make research projects more business-oriented. It was also recognised that State funding and structures in Ireland, in relation to those that are nearer to market activity, need to reflect the emerging opportunities arising from digitalisation. Further, there is a need to ensure critical mass (rather than dispersed resource allocation) to achieve impact.

Several suggestions emerged from stakeholder consultations for ways to increase the uptake and the targeting of R&D grant funding schemes. The time and effort needed to put together a robust application, and a shortfall in the skills necessary to craft compelling propositions, has created barriers to producing an application and the uptake of it. Hence, creating and providing a supporting service may help. One option might be to recognise the work already done to prepare the grant application, as a contribution of value in-kind, and therefore being explicitly part of the overall deal. A fundamentally different approach might be a bursary for skills development.

Appropriate institutional infrastructure

International experience suggests that given the particular system integration challenges associated with the development of digital applications, and the SME engagement needs required for their successful deployment, simply creating new programmes and initiatives might not be sufficient. Some countries have recognised gaps in their institutional infrastructure and have established new institutions to address such policy implementation requirements.

It is outside the scope of this study to analyse how the current Irish institutional infrastructure might be adapted to implement the digitalisation policy agenda. The focus of the investigation has been on identifying areas where policy action might have the most impact – which has not involved an assessment of whether implementation could be carried out using existing programmes and institutions.

On repeated occasions, however, Irish stakeholders mentioned the need for a different form of physical space[60] to tackle emerging manufacturing innovation challenges, such as those involved in digitalisation. Such an institution could be engaged in closer-to-market solutions, could demonstrate the technologies, and could also act as a vehicle for firm collaboration, networking, training and awareness raising.

This suggestion is associated with the call for new physical spaces, which would enable companies to come together with equipment and expertise in selected digitalisation platform technologies and applications. The scope of the services that would be offered remains an open question, but could potentially be informed by awareness raising and user application needs identification activities, outlined earlier. It is worth noting that, internationally, increased attention is being given to ensuring that manufacturing innovation institutions provide the right combinations of tools and facilities, to address the challenges and opportunities presented by the convergence of technologies[61].

Consulted stakeholders suggested that a potential new physical space used to support the digitalisation of a manufacturing agenda is envisaged to:

- Provide a demonstration suite to illustrate the scope of possibilities to manufacturing firms in Ireland
- Act as a magnet for unique Irish digital capabilities that could be used in manufacturing
- Provide ways in which manufacturers could explore how new technologies could be applied to legacy systems
- Offer specialist training based on the expertise of those working there

[60] Some stakeholders used the label 'research and technology organisation (RTO)' as an umbrella term for these kinds of spaces. It is important to note, however, that RTOs internationally provide different innovation functions, and may or may not be distributed in existing institutions (universities, public research institutes, or even private sector facilities). It is also worth highlighting that the term is not always used consistently. It is outside the scope of this report to assess and evaluate the particular institutional form required to provide the physical spaces required to drive the digitalisation agenda in Ireland forward.

[61] O'Sullivan, E. and López-Gómez, C. (2017). Manufacturing R&D Policies for the Next Production Revolution: An International Review of Emerging Research Priorities and Policy Approaches. In OECD (2017), The Next Production Revolution: Implications for Governments and Business, OECD Publishing, Paris.

- Provide demonstrators or platforms on which new sensors, new data systems, and new approaches can be tested and demonstrated
- Ideally, demonstrate credible phases of the development of digitalisation capabilities to illustrate candidate routes "on the journey"
- Provide a focal point for characterising the challenges in manufacturing firms based in Ireland which can be successfully addressed by digitalisation technologies
- Provide a clearinghouse for information and insights collected from international comparisons, benchmarking and insights

Policy coordination

An issue highlighted in the international experience around the digitalisation of manufacturing is the need to deploy instruments and mechanisms distributed across Government Departments and their associated agencies and offices in combination, in order to tackle the diverse barriers faced by companies in their digitalisation journey. Because of the wide breadth of relevant policy areas, and the pervasive effect of digitalisation across sectors, there is recognition that the digitalisation agenda poses particular coordination challenges to effective policy delivery. In principle, smaller nations, with a stable and well-connected expert policy stakeholder community like Ireland, have the potential to coordinate and align policy action more effectively.

To enhance the likelihood of success, there may be opportunities to enhance cross Government Department alignment and develop joint initiatives; thereby, building a more 'holistic' national manufacturing innovation infrastructure. Any tendency for Government Departments and their agencies and offices to work as silos will damage the awareness-raising for what is a cross-disciplinary domain.

It was emphasised that these initiatives would require coordination via the provision of a robust rationale, expressed as "a shared why". There needs also to be designed an explicit "bridging function" across State programmes. Any silo effects from too narrow a focus of capability support will inject difficulties, because companies need a range of capabilities and hence support across such capability creation.

In this respect, the definition of KPIs becomes particularly important. Traditional KPIs and metrics may not adequately incentivise efforts to enhance linkages, inter-disciplinarity and translation. Different challenges, relevant to the digitalisation of manufacturing, will require different research and innovation inputs depending on a range of factors, such as industry and technology maturity. For more effective evaluations of the success of institutions and programmes, policy makers may need to develop new indicators beyond traditional KPIs (e.g. numbers of publications and patents) in areas such as: a successful pilot line and test-bed demonstration; the development of skilled technicians and engineers; repeat consortia membership; SME participation in new supply chains; and contribution to the attraction of foreign direct investment. One-size-fits-all KPIs that do not account for the systemic nature of digitalisation should be avoided.

5.2 Concluding remarks

This section has discussed thematic priorities that appear to be most relevant for Ireland, in order to address the challenges and opportunities arising from the digitalisation of manufacturing. International examples of implementation programmes, initiatives and institutional mechanisms have been provided to stimulate discussion. Needless to mention, these programmes respond to particular national contexts and priorities, and reflect the existing institutional infrastructure.

As such, the approaches highlighted by these examples are not readily transferable to Ireland. They do, however, provide valuable reference information on what competitors are doing and, to some extent, insights into what is perceived to be effective to drive the digitalisation of manufacturing forward. It is outside the scope of this study, however, to suggest a detailed implementation plan with specific responsibilities for government departments and agencies, or to assess whether a policy agenda to drive digitalisation in Ireland forward can be implemented with existing institutions.

6

Conclusions

The objective of this study was to assess the policy implications for Ireland from the impacts, opportunities and challenges arising from the digitalisation of the manufacturing sector. For the purposes of this study, digitalisation of manufacturing is defined as the *use of digital technologies, data and applications to deliver advances in manufacturing processes, products and related services, in both established and emerging sectors*.

A number of research tasks were defined to complete this objective, including: i) defining the concept of the 'digitalisation of manufacturing' and a framework for analysis; ii) understanding the context of Irish manufacturing; iii) gathering lessons from international experience; iv) understanding the opportunities and challenges for Ireland; and v) defining policy options for Ireland. Concepts and frameworks from the academic literature have helped to inform the methodological approach, and an extensive review of international policy discussions and implementation efforts has provided a valuable context to the emerging priorities identified for Ireland. In addition, the study has drawn heavily from targeted consultations with industry, academia and government stakeholders in Ireland. Although this approach has succeeded in providing a large amount of primary data from local stakeholders, limitations exist based on the number and types of stakeholders consulted. However, the authors believe that the selection of stakeholders for consultation has been highly inclusive, in accordance with the project design, and hence has provided representative views of the Irish context.

This study has attempted to go beyond the high-level analysis of basic technologies by more carefully considering the industrial structures and technological systems underpinning the digitalisation of manufacturing. In other words, the study goes beyond considerations on R&D and knowledge generation around specific technologies, to cover issues relevant to the diffusion and deployment of those technologies in manufacturing sectors. In this respect, a framework to identify challenges and opportunities related to the digitalisation of manufacturing was developed, which outlines the interaction between three core elements: manufacturing user industries (and the possibilities for digital applications); industrial digitalisation applications and solutions; and policy and contextual factors. The interface of these elements has important implications for the creation and capture of value across manufacturing sectors. It was identified that digitalisation can drive value capture through: the development of new and more functional products and services (including new business models); more efficient and flexible production processes; more integrated and optimised supply chains; and more customer-lead products and delivery. Barriers to value capture were identified across the innovation process, by which new digital technologies are developed, diffused and deployed in the real world.

Ireland's unique position in the digitalisation journey was discussed, and the main challenges and opportunities for Ireland based manufacturing firms were elicited drawing from a wide stakeholder consultation, which included targeted interviews, roundtable discussions, and a stakeholder workshop. Although there was broad agreement that Ireland based firms will need to exploit the potential of digital technologies to remain competitive internationally, it was clear from the consultation that distinct sectors and firms find themselves in different stages of the digitalisation journey. Furthermore, a key message arising from the consultation was that there are challenges to understand the true value of industrial digitalisation and the opportunities it could provide to businesses. As such, there is a need to 'demystify' the use of digital technologies. Overall, results suggest that Irish manufacturers are just starting to realise and exploit the benefits of digital technologies. Also, Ireland is well positioned to

exploit these opportunities given the makeup of its manufacturing sector and the existence of ICT expertise and enabling contextual factors. However, a number of challenges still lie ahead.

The study suggests priority policy themes for Ireland, and identifies cross-cutting implementation enablers to address emerging challenges and opportunities. Thematic priorities included: i) awareness raising and identification of user application needs; ii) demonstration of application value; iii) consortia building and application development; iv) technical advisory services for application deployment; v) skills for the deployment of digital applications (including factory technicians; production and ICT engineers; operation managers; and company directors). In addition to these thematic priorities, a number of cross-cutting requirements, relevant to ensure effective policy implementation in Ireland, were discussed, including: i) industry needs-oriented funding mechanisms; ii) policy coordination; and iii) appropriate institutional infrastructure.

Examples from the international experience were included to stimulate discussion. They respond to particular national contexts and priorities and reflect the existing institutional infrastructure. As such, no suggestion is made that they should or could be readily transferred to Ireland. They do, however, provide valuable reference information on what competitors are doing and, to some extent, insights into what is perceived to be effective to drive the digitalisation of manufacturing forward.

Overall, the information contained in this report can help inform the design of a practical policy action plan for Ireland. The thematic priority areas that emerged from this analysis are intended to indicate areas where policy intervention could support Ireland's digitalisation efforts. It is outside the scope of this study, however, to suggest a detail implementation plan with specific responsibilities for Government departments and agencies, or to assess whether a policy agenda to drive digitalisation in Ireland forward can be implemented with existing institutions. It is recognised, however, that the success (or failure) of a particular policy programme or initiative might be determined by the quality of institutions involved in delivering them, as much as the qualities of the adopted approach.

The analysis contained in this report shows, however, that by exploiting the distinctive opportunities and national capabilities identified here, Ireland is well placed to take a leading international position in the digitalisation journey.

Appendix 1: Consultation methodology and list of stakeholders

Overview

This study draws heavily from targeted consultations with representatives from industry associations, public bodies and public research bodies. More than 50 stakeholders were consulted during the course of the study, as listed in Table A.1 at the end of this appendix.

Three consultation activities were used to engage with relevant stakeholders:

- Interviews with public bodies and public research bodies stakeholders and key businesses
- Two roundtable discussions with industry stakeholders
- One policy workshop with stakeholders representing industry associations, public bodies and public research bodies

The following sections provide further details about the objectives and approach behind each of these consultation activities.

Interviews with public body stakeholders and key businesses

Consultations with businesses and public body stakeholders were conducted during the early stages of the project. Interviews with public body stakeholders were aimed at characterising what makes Irish manufacturing sectors distinctive. Such information on sectoral 'distinctiveness' was then used to explore how manufacturing sectors might be particularly impacted by digitalisation, and what the main challenges and opportunities might be. Interviews were based on a semi-structured interview guide, in order to gather comparable information among government stakeholders.

Interviews with businesses were aimed at getting first-hand insights into how Irish manufacturing sectors might be impacted by digitalisation. This information was valuable to identify particular challenges and opportunities and inform future policy actions. Interviews with key businesses were also based on a semi-structured interview guide exploring topics, such as the relevance of digitalisation to firms and/or sectors and, from a firm perspective, the opportunities and challenges arising from digitalisation of manufacturing and the technological capabilities required to address them.

Roundtable discussions

Two industry roundtable discussions were held in Dublin to complement additional sources of information used for this project. The objectives of the roundtables were defined as follows:

- Identify cross-sectoral challenges and opportunities – both immediate and in the longer term;
- Gather views on particular digital technologies / products / solutions with the potential to address challenges and opportunities;
- Identify main national capabilities required to address challenges and opportunities (including existing capabilities and potential gaps).

Roundtables were divided between 'process industries' and 'product manufacturers', including both SMEs and large firms. The discussions during the roundtables focused on guiding questions such as 'why is there a need to act?', 'what are the opportunities for Ireland?', and 'how to exploit these opportunities?'.

Policy workshop

A policy workshop was organised in Dublin to capture the views of representatives from industry associations, public bodies and public research bodies in Ireland, complementing other desk-research and consultation activities carried out as part of the project. The workshop had the following objectives:

- Discuss findings from previous stages of the project and validate key emerging messages (in particular digitalisation opportunities and challenges for Ireland's manufacturing sectors);
- Identify national capabilities / framework conditions required to address challenges and opportunities;
- Discuss international policy efforts in the area of digitalisation of manufacturing and reflect on policy options most relevant for the Irish context.

Table A 1 Consulted stakeholders

Name	Type of organization
AMCHAM	Industry association
Ash Technologies	Company
Beta Electronics	Company
Biopharmachem Ireland (Ibec)	Industry association
Chanelle Group	Company
CONFIRM Centre	Public research body
Dawn Meats	Company
Dell Technologies	Company
Dept of Business, Enterprise and Innovation	Public body
Dept of Taoiseach- Data Protection	Public body
Eli Lilly	Company
EMC	Company
Engineers Ireland	Industry association
Enterprise Ireland	Public body
Evolve Technologies	Company
GlaxoSmithKline	Company
Hal-software	Company
Irish Manufacturing Association (Ibec)	Industry association
IDA	Public body
i-Form Centre	Public research body
Insight Centre	Public research body
Irish Manufacturing Research	Public research body
Kerry Taste & Nutrition	Company
Kuka Robotics	Company
Med Tech & Engineering (Ibec)	Industry association
Mergon	Company
Midas	Industry association
National Standards Authority of Ireland	Public body
Novartis	Company
Optel Group	Company
Pepsi Co	Company
Sanmina Ireland	Company
Sanofi	Company
Schivo	Company
Science Foundation Ireland	Public body
Seagate	Company
Siemens	Company
Synecco	Company
Takeda Ireland Limited	Company
Tomra	Company

Appendix 2: Steering Group

This project was overseen by a Steering Group. Two meetings were organized in Dublin where the study team presented the preliminary findings of the study.

Table A 2: Members of the Steering Group

Member	Organisation
Declan Hughes (Chair)	Department of Jobs, Enterprise and Innovation
Edmond Harty	Dairymaster
Tríona Garvey	2 Sisters Food Group, Green Isle Foods Ltd
Michael Phelan	DePuy Synthes
Alan Cuddihy	PCHIntl
Andrei Grigoriev	SAP
Cathal Wilson	Entrepreneur
Aidan Gaughran	Ovelle Pharmaceuticals
Brendan Sheppard	Smart Factory
Barry Kennedy	Irish Research Manufacturing
Dr Mary Shire	University of Limerick
Erik O' Donavan	Ibec
Chantelle Kiernan	IDA
Stephen O'Driscoll	Science Foundation Ireland
Tom Kelly	Enterprise Ireland
Enda McDonnell	National Standards Authority of Ireland

Appendix 3: Manufacturing in Ireland – An overview

Introduction

The objective of this appendix is to outline the structural composition of the manufacturing sector in Ireland. The following economic features of Ireland's manufacturing will be analysed:

- The contribution of manufacturing to the whole Irish economy in terms of value added, exports and employment;
- The composition of the Irish industrial structure, focusing on the role of Small and Medium Enterprises (SMEs), as well as on the role of foreign Multinational Corporations (MNCs);
- The sectoral composition of manufacturing; and
- The Irish international trade of manufacturing goods.

Methodology and data limitations

The analysis conducted in this section is based on the review of multiple primary and secondary sources of data, including the databases of Eurostat, Ireland's Central Statistics Office, surveys conducted by Irish government agencies, and industry reports.

Discrepancies across different sources of data may be found. These differences are mainly due to the fact that manufacturing sectors do not always align to the standard statistical classifications (i.e. NACE codes). This is the case, for example, of the "engineering sector", which is composed of cross-sectoral engineering activities that span from aerospace to machinery and equipment, and are also involving electronic components. Not all those sectors belong to the same statistical division. Furthermore, some activities are statistically defined as a sub-group of a sector where granular data are not always available. An example is the manufacture of medical devices, which represents a key industrial sector for Irish manufacturing. In the NACE Rev 2 statistical classification, medical devices belong to division 32 "other manufacturing" and, thus, when more granular data are not available, the data presented are not perfectly representing the sector[62].

Against this backdrop, this section will frame the current status of the manufacturing sector in Ireland, with respect to its contribution to the whole economy and main sectors of industrial activities. The analysis conducted in this section can be read together with the "sectoral briefs" (Appendix 3) that illustrate some key characteristics of the manufacturing sub-sectors, with respect to elements such as the reasons why Ireland is attractive for investments in manufacturing, the composition of the production base, and the research and development landscape at sectoral level.

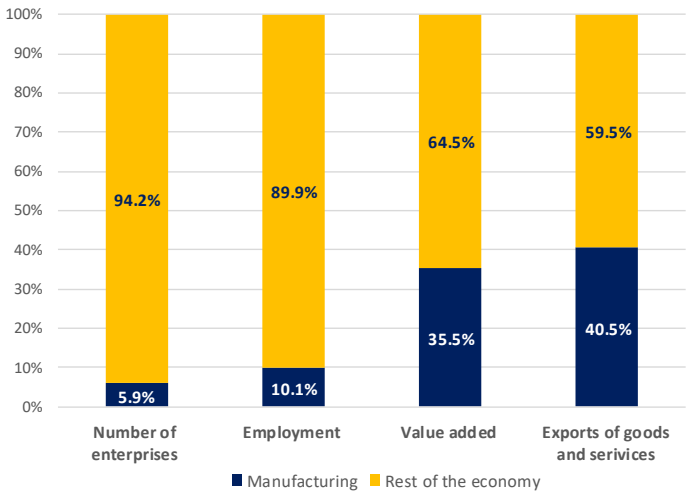
[62] Ireland's Government reports also remark on the issue of data limitation where the analysis of Ireland's manufacturing sector is concerned. Examples include: Forfás (2013, section 4). *Making it Ireland: Manufacturing 2020*; and DBEI (2017). *Overview Report and Sector Briefs.*

The contribution of the manufacturing sector to the Irish economy

The Irish manufacturing sector is composed of more than 15,000 companies directly employing 200,000 people[63], and an additional 200,000 jobs are estimated to be generated as indirect employment[64].

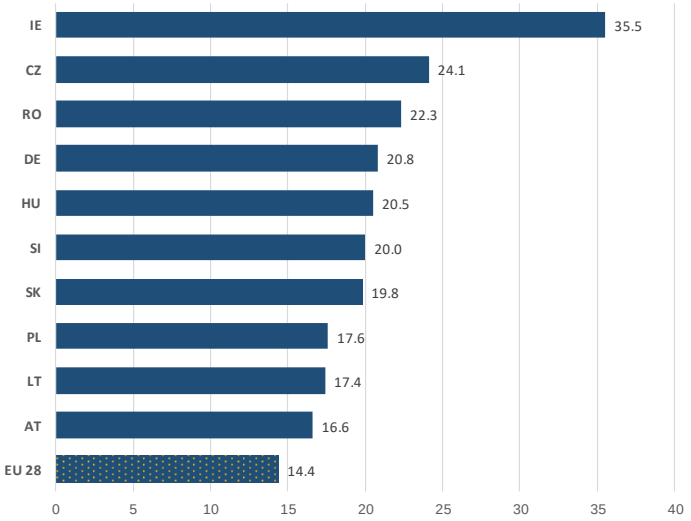
Ireland's manufacturing also provides a substantial contribution to the Irish economy, especially where the total value added and exports are concerned, as shown in Figure A.1. Manufacturing contributes 35.5% of the total economy valued added, and 40.5% to the total value of both merchandise and service exports. Furthermore, 10.1% of the total workforce in Ireland is directly employed in the manufacturing sector.

Figure A 1: Irish manufacturing contribution to the total economy, 2015



Source: CSO (2017) Census of Industrial Production, SBS, QHNS, National Income and Expenditure Annual Results; Comtrade (2017)

Figure A 2: Manufacturing value added share of GDP, 2015



Source: Eurostat (2017) – National Accounts; CSO (2017); CSO (2017) Census of Industrial Production - National Income and Expenditure Annual Results

Ireland also represents an important manufacturing-based economy in Europe. As noted, in 2015 in Ireland, the manufacturing value added (MVA), as a share of the total economy value added, is 35.5%. This is above the European Union average (14.4%)[65].

[63] Data refers to 2015. Source: CSO (2017) Census of Industrial Production

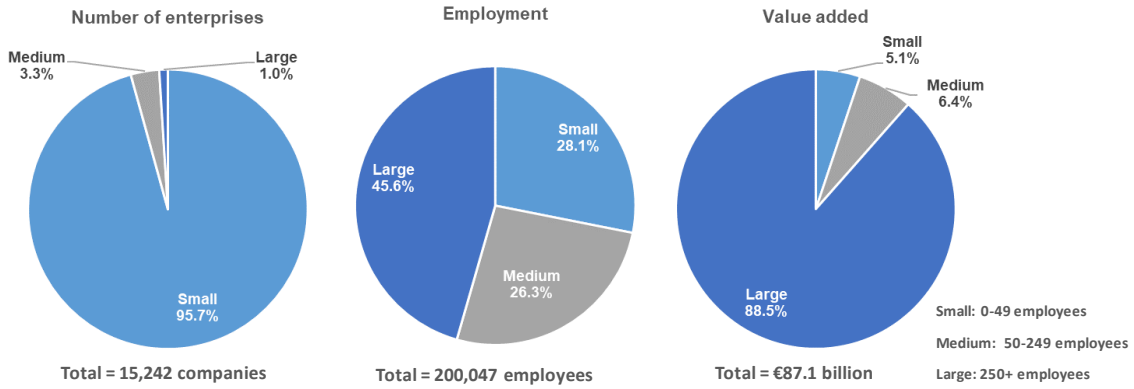
[64] Forfás (2013). Making it Ireland: Manufacturing 2020

[65] In 2014 the manufacturing value added as a share of GDP was estimated at 22% for Ireland. The dramatic increase of the MVA as a share of GDP experienced between 2014 and 2015 is mainly associated with an increase in the number of new aircraft imports for international leasing activities, and with corporate restructuring through imports of individual assets as well as through reclassifications of entire balance sheets, which led to an increase of capital assets.
According to UNIDO (2017), in 2015 Ireland's MVA as a share of GDP was 19.65%.
Source: CSO (2016). GDP increases significantly in 2015 – Explanatory note. Press State; and
UNIDO (2017). Industrial Development Report 2018 – Table B3.1.

The composition of the Irish industrial structure

Ireland's manufacturing structure is mostly composed of Small and Medium Enterprises (SMEs)[66], and is similar to other economies[67]. SMEs represent 99% of the total 15,242 companies that the sector is composed of. However, the largest proportion of manufacturing value added (88.5%) is generated by the 152 large firms in the sector that also employ 45.6% of the total manufacturing workforce.

Figure A 3: Irish manufacturing: SMEs and Large firms, 2015



Source: Eurostat (2017) - SBS

A peculiar characteristic of the Irish economy is the presence of multinational corporations (MNCs) that have established activities (including Research and Development and other high-value added activities) in the island. In 2015, foreign MNCs with activities in the country's manufacturing sector are 563, against 14,679 Irish owned companies[68].

Figure A 4: Manufacturing sector: Irish firms vs Foreign firms, 2015

Source: CSO (2017) - Census of Industrial Production

As shown in Figure A.4, foreign MNCs account for 92% of the manufacturing value added. Furthermore, 45% of the total manufacturing employment (90,000 workers) is employed in a foreign MNC. In other words, the company size of foreign MNCs is, *on average,* larger than Irish-owned companies.

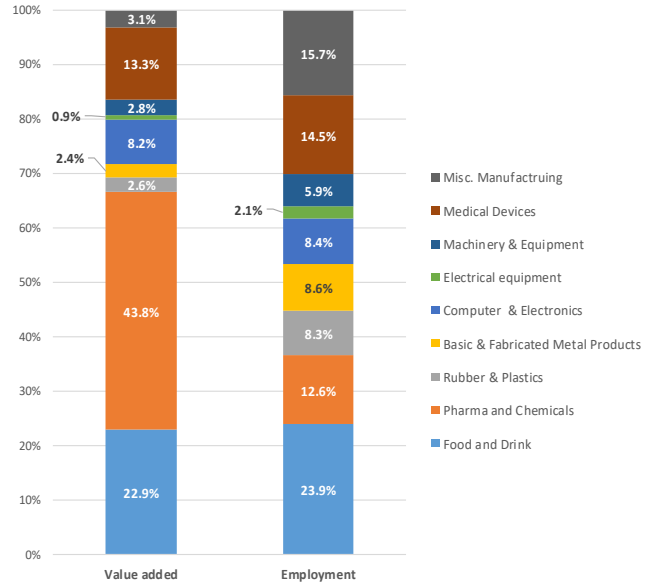
Such a condition has an important implication on the definition of the value chains at sectoral level that may be characterised by an Original Equipment Manufacturer (OEM), represented by a foreign owned firm, and a sub-supply value chain composed mainly of Irish firms.

So far, it was remarked that Ireland's manufacturing sector provides an important contribution to the whole economy in terms of value

[66] Enterprises are classified according to company size as follows: Small, firms employing up to 49 employees; Medium, firms employing between 50 and 249 employees; Large companies employing more than 250 employees.
[67] For a comparison of SMEs performance at European level, see DG GROW (2016). Annual report on European SMEs 2015/2016
[68] Source: CSO (2017) - Census of Industrial Production (Table AIA39).

added, exports and, also, employment. Furthermore, the sector is mainly composed of SMEs, and where the ownership of companies is concerned, 90% of the total manufacturing value added is generated by foreign MNCs.

Figure A 5: Ireland's manufacturing sectoral composition, 2014



Note: Miscellaneous manufacturing includes: Textile; Wood and furniture; Paper and Paper printing; Automotive; Repair and installation
Source: CSO (2017) National Income and Expenditure; Eurostat (2017) - SBS

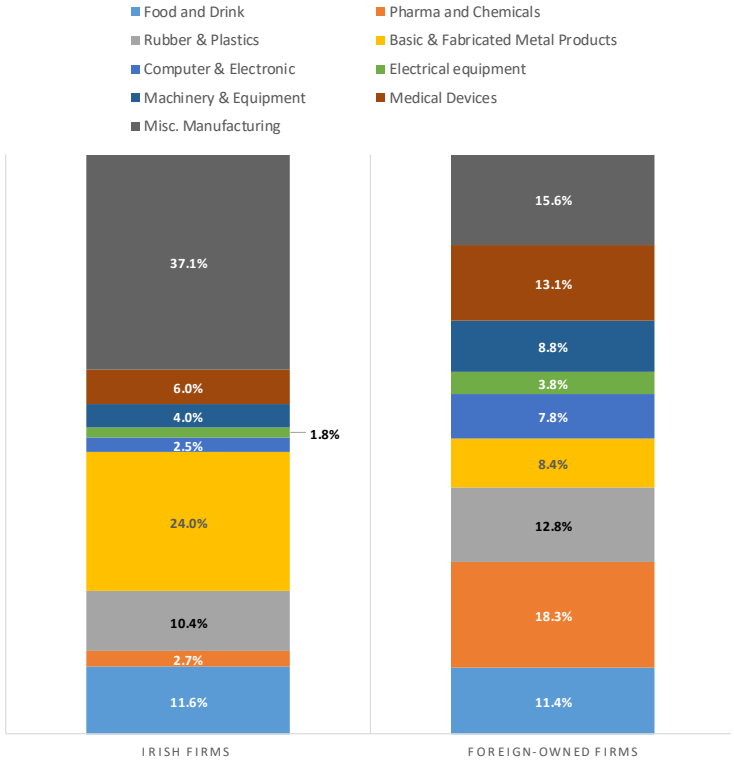
The next step of the analysis is to assess which productive activities are undertaken by companies operating within the Irish manufacturing sector.

Figure A.5 shows manufacturing value added and employment by sub-sector. Where manufacturing valued added is concerned the pharma-chemical sector and the food sector jointly account for more than 66% of the total value. These two sectors also account for more than 36% of the manufacturing employment. The manufacture of medical devices technologies also provides an important contribution to both value added (13.3%) and manufacturing employment (14.5%)[69]. The manufacture of computer and electronic equipment is another sub-sector that characterise Ireland's industrial structure, with 8.2% share of value added, and a contribution of 8.4% to the total manufacturing employment. Finally, the engineering sector[70] represents 7.8% of the manufacturing value added and 22.8% of the manufacturing employment.

Given their importance in the economy, it is interesting to understand which sub sectors foreign MNCs operate in, when compared with the activities conducted by Irish owned firms. In this respect, Figure A.6 shows the distribution of companies across the manufacturing sector according to their ownership.

[69] The sector of medical devices technologies is statistically defined as NACE code 32 "other manufacturing" and that also includes manufacture activities different from medical technologies. Therefore, the value in the chart may be overestimated.
[70] For statistical purposes, the engineering sector is defined as follows: Basic & Fabricated Metal Products (NACE code 24,25); Electrical equipment (NACE code 27); Machinery & Equipment (NACE code 28)

Figure A 6: Share of firms by manufacturing sub-sectors, 2014



Note: Miscellaneous manufacturing includes: Textile; Wood and furniture; Paper and Paper printing; Automotive; Repair and installation
Source: CSO (2017) - Census of Industrial Production

By comparing Irish and Foreign-owned firms, the charts show that Irish enterprises are more concentrated in the so called traditional sectors, such as basic and fabricated metal products, food and drinks and, above all, miscellaneous manufacturing. In particular, miscellaneous manufacturing include activities such as wood and furniture, paper and paper printing, and repair and installation activities. On the other hand, Foreign owned enterprises are more equally distributed across the sector.

In conclusion, the analysis of the manufacturing data shows that there are some key sub-sectors that characterise Irish manufacturing, particularly pharmaceuticals and chemicals, food and drink, medical devices technologies, computer and electronics, and the engineering sector. Foreign owned firms provide a substantial contribution (90%) to the manufacturing value added as well as to the manufacturing employment. Furthermore, Irish firms are more concentrated toward certain sectors, such as food and drink, and basic and traditional manufacturing activities, while the activities of Foreign owned firms are more evenly distributed across the manufacturing sector.

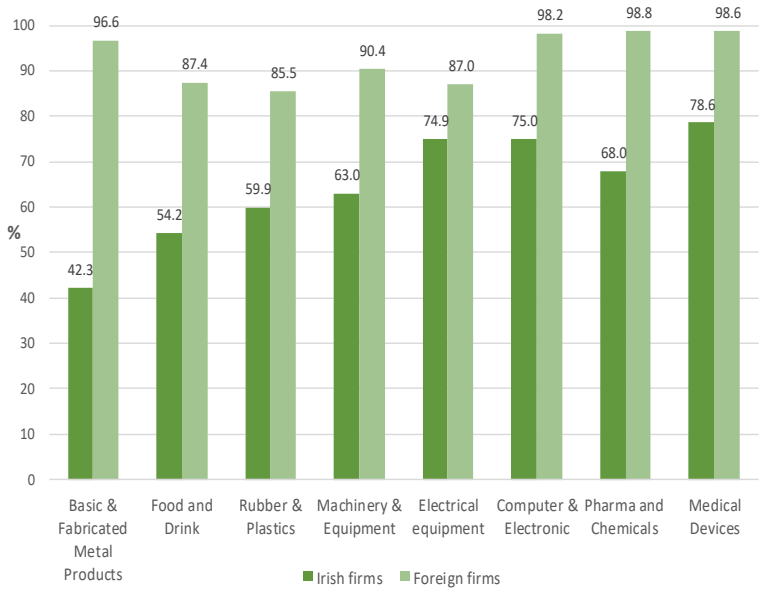
International trade in manufacturing goods

An analysis of the international trade pattern of manufacturing goods can be conducted in order to better understand the industrial structure, the relative importance of some sub-sectors, and the role of Irish and foreign owned firms.

Figure A.8 reports the total exports of manufacturing goods classified by NACE codes to ensure better consistency with the previous analysis, for the year 2014[71]. There are some key sectors that represent a substantial share of the total value of manufacturing exports. In 2014, the pharmaceutical and chemicals sector represents almost the 60% of total manufacturing exports. Processed food and drinks are the second most exported manufactured goods in Ireland, representing 14.6% of the total of manufacturing exports. Computer and electronics (9.5%) and the manufacture of medical devices technologies (9%) are the other key sectors in Ireland's manufacturing exports structure.

[71] In 2014, the share of manufacturing goods exports on the total goods and service exports is 37.7% (UN-COMTRADE data).

Figure A 7: Agencies' clients manufacturing firms- export orientation, 2015 (Total exports as a percentage of total sales, %)



Source: DJEI (2015) ABSEI

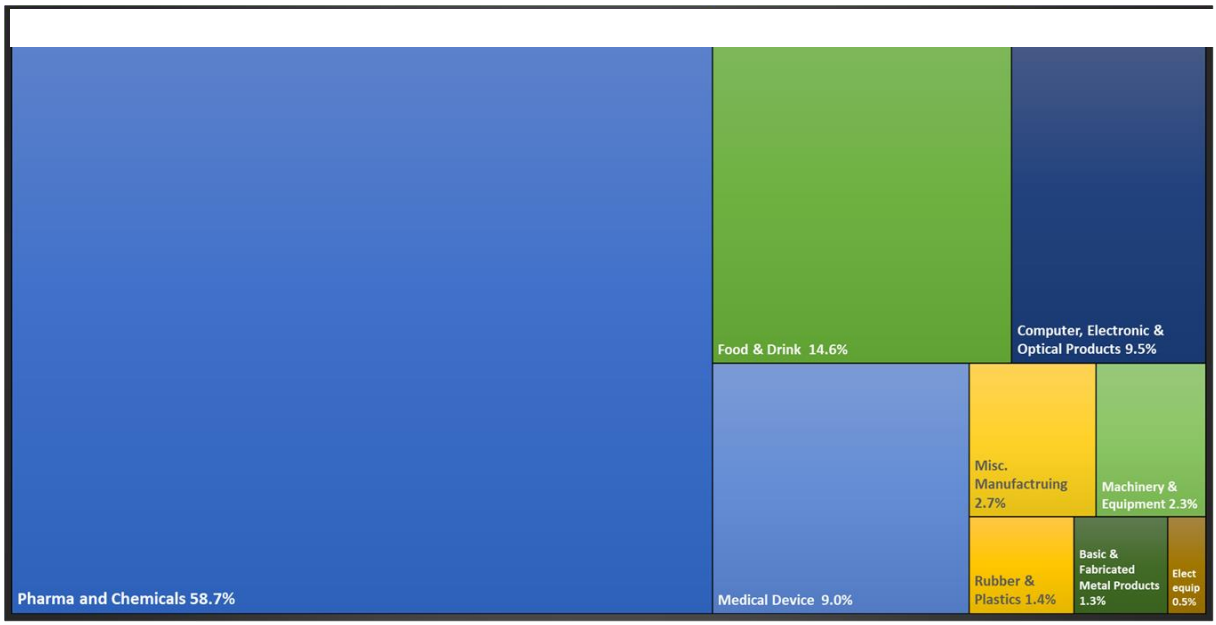
As a small economy, with a limited domestic market, a high export orientation is one of the peculiar characteristics of manufacturing companies based in Ireland. In addition, as in the previous section, the importance of foreign companies in Ireland's manufacturing sector was also remarked upon. In this respect, the presence of foreign MNCs has the effect of impacting Ireland's international trade through intra-branch trade, or just as an explicit business strategy of companies, focused on developing / producing a product in Ireland for then exporting to other countries.

As a member of the European Union, Ireland could also be seen by foreign MNCs as an easy access point to the European single market, with further effects on the country's international trade pattern. A different degree of export orientation, between Irish and foreign-owned firms, can also be seen. Based on the data of the Agencies' clients firms[72], the export orientation is measured as the share of exports on total sales. Between 2000 and 2015, the average degree of export orientation, of all of the Agencies' clients firms (i.e. both Irish and foreign-owned firms) operating in the manufacturing sector was 83.7%. However, during the same period, Irish manufacturing firms presented a degree of export orientation of 45.3%, against an export orientation degree of 94.6% of the foreign owned firms with activities in Ireland's manufacturing. Such a difference in export orientation between Irish and Foreign owned firms can also be seen at sub-sectoral level in Figure A.7. Foreign firms are more export oriented in every sub-sector and, on average, sectors such as medical devices technologies and pharma and chemicals are more export-oriented than traditional sectors, such as food and drink, and basic metal production.

Finally, Figure A.9 shows the main international trade partners of Ireland. The United Kingdom and the USA are the main partners, for both imports and exports, when the analysis is conducted by single countries. These results can be explained by the historical close cooperation that Ireland has with the UK, and with the role that MNCs from the USA have in the country.

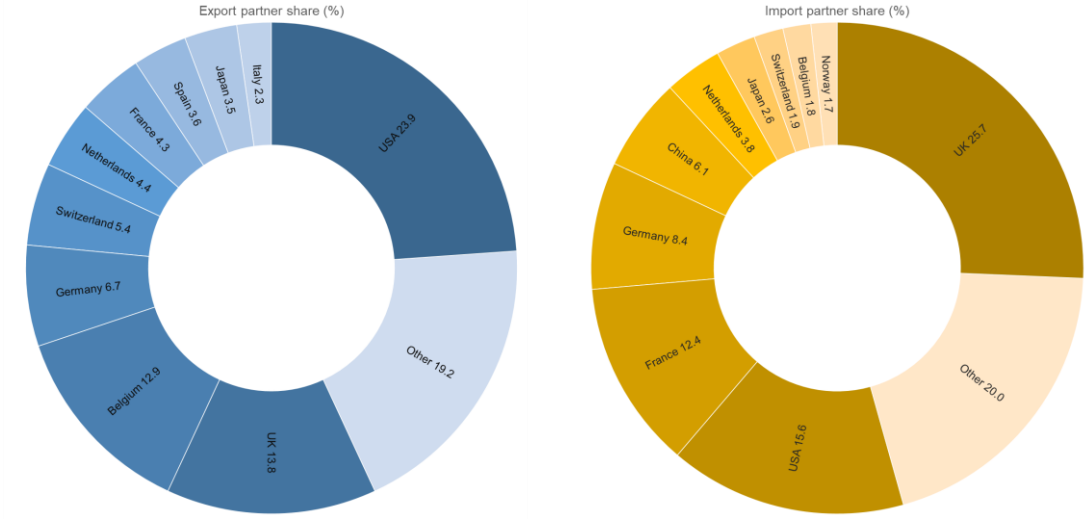
[72] The analysis refers to data collected in the Annual Business Survey of Economic Impact (ABSEI), which is a survey conducted on the universe of client companies (with more than ten employees) of the Agencies Enterprise Ireland, IDA Ireland, and Údarás na Gaeltachta. In 2015: a) firms with less than 10 employees represented 0.9% of the MVA and 8.6% of manufacturing employment; b) the ABSEI database represents 15.3% of the total employment in Ireland, 56.8% of the total value added, and 77.2% of total exports.
DJEI (2017). Annual Business Survey of Economic Impact - 2015 (ABSEI)

Figure A 8: Ireland' exports of manufacturing goods classified by NACE codes - 2014



Source: Eurostat (2017) Comext; COMTRADE (2017)

Figure A 9: Ireland's main international trade partners, by single country



Source: World Bank (2017). World Integrated Trade Solution

Concluding remarks

The macroeconomic analysis conducted in this section highlights some key features of the manufacturing sector in Ireland that can be summarised as follows:

- The manufacturing sector provides a substantial impact to the Irish economy, estimated in 35.5% of the GDP in 2015, and with 400,000 direct and indirect jobs;
- Like other countries, the sector is mostly composed of SMEs that employ 54.4% of the workforce in manufacturing, although the large share of manufacturing value added (88.5%) is generated by companies with more than 250 employees;
- In the sector, in 2015 foreign MNCs represent 3.8% of total companies in manufacturing, accounting for 92% of the MVA and 45% of manufacturing employment;
- At sub-sectoral level, manufacturing is specialised into the following sectors: pharmaceuticals and chemicals, food and drinks, computer and electronics, medical devices technologies, and the production of mechanical and electrical equipment (i.e. the engineering sector);
- Irish owned companies are more concentrated in the so called traditional sectors, while foreign owned companies are more evenly distributed across all the manufacturing subsectors;
- Ireland's manufacturing presents a high degree of export orientation, with two further distinctions: by ownership of firms, because foreign owned companies are relatively more export-oriented than Irish owned firms; and by sectors, because pharmaceuticals, and medical devices technologies are more export oriented than, for example, food and drinks.

Appendix 4: Sectoral briefs

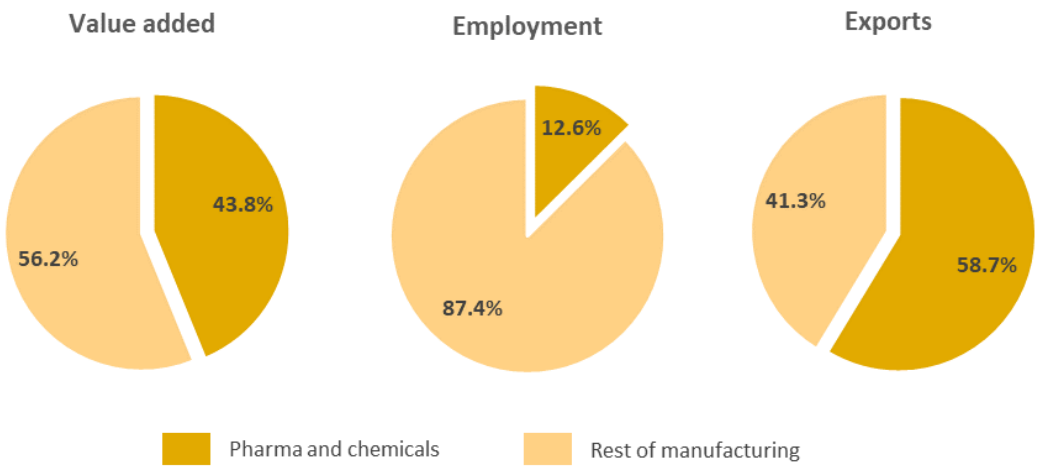
In this appendix, qualitative features of Ireland's manufacturing are described in order to complement the macroeconomic analysis.

For these purposes, sectoral briefs were developed for the following sectors:

- Pharmaceutical and chemicals
- Food and Drink
- Medical Devices
- Computer & Electronics
- Engineering

In order to facilitate a cross-sector comparison, sectoral briefs present the same structure, consisting of key data about the sectors, and an overview outlining the main production segments or production activities that characterise the sector. Reasons why Ireland is attractive in terms of investment at the sectoral level are then described. Peculiar features, regarding the composition of the productive base, are also reported in order to have a better idea on how the sectoral value chains could be depicted. The final section concerned with the R&D landscape, focusing on innovation activities generated through industry - higher education institution collaborations and the availability of public support programmes.

Pharmaceuticals and Chemicals – sectoral brief



Note: Data refer to 2014
Source: *CSO (2017) for Value added data; Eurostat -SBS (2017) for employment, Eurostat – Comext (2017) and COMTRADE (2017) for Trade data*

Overview

- In 2014, 454 companies were operating in the Irish pharma and chemicals sector[i], providing direct employment to 23,833 people[ii]
- Composed of a mix of domestic and foreign companies, the sector also includes ten of the largest pharmaceuticals companies in the world[iii]
- The business of most of the companies in the sector has to do with either Active Pharmaceutical Ingredients (API) and/or dosage form manufacturing[iv]

Why Ireland is attractive[v,vi]

- Qualified workforce and presence of core engineering skills
- Advantageous tax regime, including the Knowledge Development Box (2016), a Corporate Tax relief that applies to income from qualifying patents, computer programmes and, for smaller companies, certain other certified intellectual property (IP)
- An efficient regulatory track record
- An established biopharma ecosystem and infrastructure, involving domestic public institutions, as well as a research skill base assisting the attraction and retention of foreign direct investment

The productive base[iv,v]

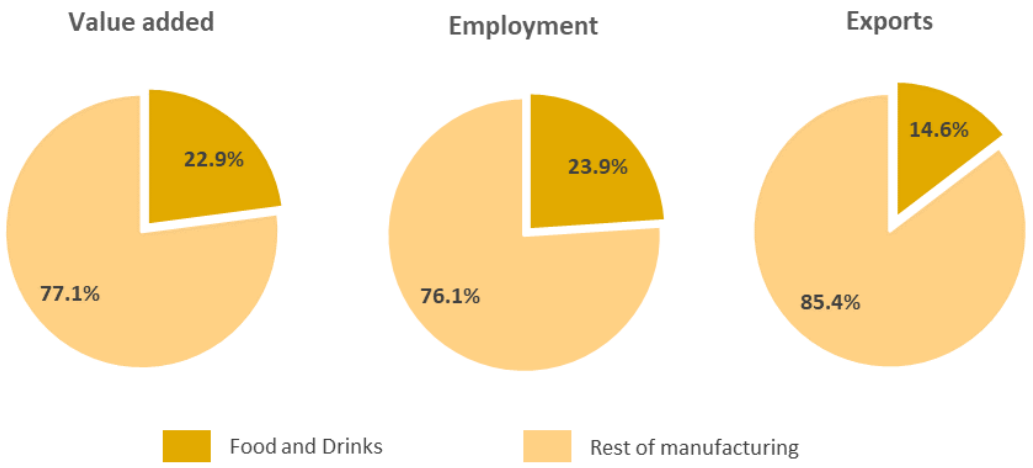
- The sector is concentrated toward foreign multinational corporations
- Presence of Irish-owned companies, both multinationals and SMEs that are research/technology intensive
- Presence of a strong base of Irish-owned firms supplying advanced services and technologies to MNCs
- Presence of industrial clusters (i.e. API plants in Cork; Dublin)

Research and development landscape[vii]

- Ireland invested to develop R&D capacity. Examples of research centres established include the National Institute for Bioprocess Research and Training (NIBRT); Pharmaceutical Manufacturing Technology Centre (PMTC); the Solid State Pharmaceutical Cluster (SSPC); the Applied Polymer Technologies (APT); and the Pharmaceutical and Molecular Biotechnology Research Centre (PMBRC)

[i] *The pharmaceutical and chemical sector is statistically defined as NACE codes 20 and 21. "Research and experimental development on biotechnology" (NACE code 72.11) is outside the scope of this report.*
[ii] *Eurostat (2017) Structural Business Statistics*
[iii] *IPHA (2017) Industry overview*
[iv] *Cefic (2017) Landscape of the European Chemical Industry 2017 – Ireland*
[v] *IPHA (2014) Bringing Health and Growth to Ireland*
[vi] *EGFSN (2016) Future Skills Needs of the Biopharma Industry in Ireland*
[vii] *DBEI (2017) Overview Report and Sector Briefs*

Food and Drinks – sectoral brief



Note: Data refer to 2014
Source: *CSO (2017) for Value added data; Eurostat -SBS (2017) for employment, Eurostat – Comext (2017) and COMTRADE (2017) for Trade data*

Overview

- In 2014, the Food and Drinks sector employed 45,364 people in 1,634 companies[i]
- The most important product segments include meat (i.e. beef), dairy, processed food, beverages and fish[ii]

Why Ireland is attractive[iii]

- Leading cohort of food, marine and biopharmaceutical companies with their related manufacturing and technological competencies
- Potential to further develop a seafood industry
- Several public initiatives supporting the agri-food and beverages sector
- Research expertise
- Favourable tax treatment for young farmers
- Measures to encourage the long-term leasing of land and improve productivity
- Establishment of knowledge transfer groups at farm level to deliver technology adoption programmes

The productive base[iv]

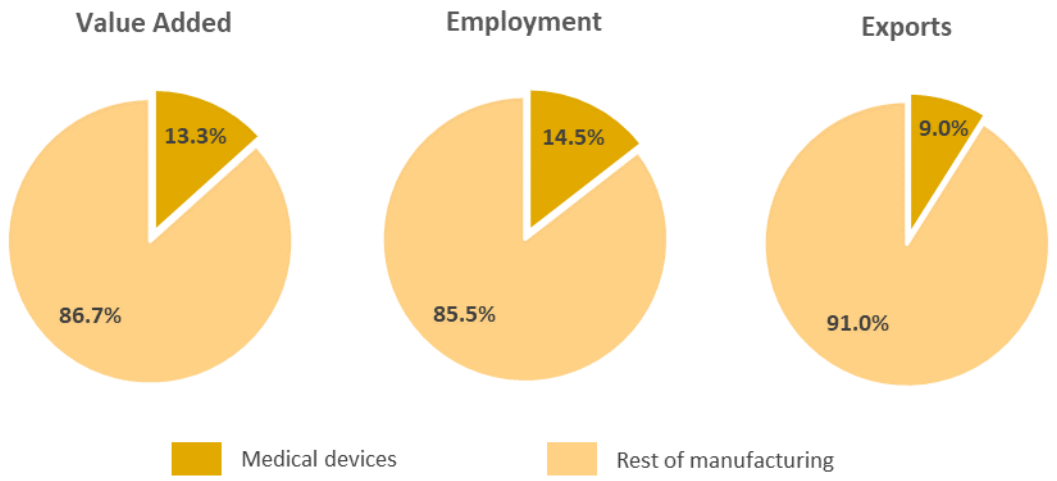
- This sector has a strong set of Ireland - originating MNCs, and has a relatively significant base of micro and SME Irish-owned firms.
- The sector is geographically dispersed
- The sector is mainly composed of small firms, though a number of companies of significant scale have developed through both continuous growth and mergers/acquisitions[iii]
- Presence of foreign multinational companies operating in Ireland
- Presence of a group of companies engaged with specialised nutrition and functional foods (i.e. any food substance that provides medical or health benefits, over and above its basic nutritional composition)

Research and development landscape[iii]

- In Ireland, there are 14 Technology Centres, and joint initiatives between Enterprise Ireland and IDA Ireland, led by industry. The mission of three of those centres (– Food for Health Ireland; DPTC Diary Processing Technology Centre; MTC Meat Technology centre)[v] is specifically the food industry
- Presence of a national organisation for agriculture and food research - Teagasc – in charge of providing research and specialist commercial services to both foreign and Irish-owned companies
- Presence of University-Industry programmes of research for common research interests (i.e. the Dairy Processing Technology Centre)

[i] *Eurostat (2017) Structural Business Statistics*
[ii] *Bord Bia (2016). Export Performance and Prospects 2015-2016*
[iii] *DBEI (2017) Overview Report and Sector Briefs*
[iv] *Minister for Agriculture, Food and the Marine (2015). Food Wise 2025*
[v] *The full list of the 14 Ireland's technology centres is available at the following link:* https://goo.gl/wAUv9A

Medical Device Technologies – sectoral brief



Note: Data refer to 2014
Source: *CSO (2017) for Value added data; Eurostat -SBS (2017) for employment, Eurostat – Comext (2017) and COMTRADE (2017) for Trade data*

Overview[i]

- The Irish MedTech sector represents one of the leading manufacturing producers of medical devices at global level
- In 2014, there were 878 companies in the sector providing 27,469 direct jobs[ii]
- Product segments include: diagnostic, ophthalmic, cardiovascular, orthopaedic, hospital and/or homecare products and health software
- Examples of leading products are: injectable devices to treat diabetes; contact lenses; stent; orthopaedic knee[iii]

Why Ireland is attractive[iii,vi]

- Regulatory track record and efficient CE approval
- Advantageous tax regime, including the Knowledge Development Box (2016), a Corporate Tax relief that applies to income from qualifying patents, computer programmes and, for smaller companies, certain other certified intellectual property (IP)
- Good investment climate: 12.5% Corporate tax rate; high-skilled workforce; access to the EU markets (for non-EU companies); strong supply base

The productive base[iv,v]

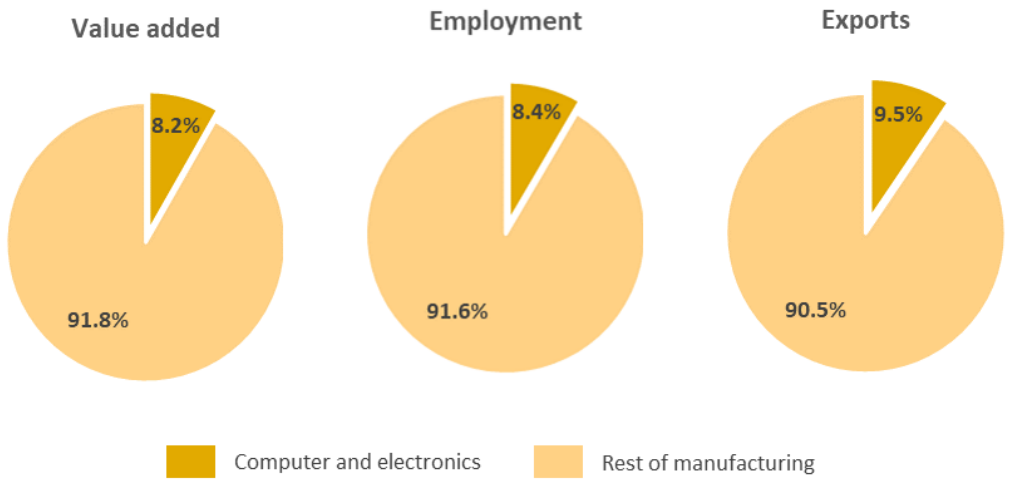
- 18 of the world's top 25 medical technology companies are based in Ireland
- Irish owned companies represent 60% of the sector
- The sector is composed of SMEs or Start-up companies (up to 80%)
- Firms in the sector are distributed along the medical devices value chain, to include activities such as: R&D; clinical trials; design and/or manufacture of products and solutions; management of global business services; sub-supply and services specific to the sector
- Presence of a strong sub-supply and service providers in segments such as clinical trial management, health analytics, contract manufacturing, packaging, and contract assembly
- Increasing collaboration among foreign MNCs, local companies and research centres

Research and development landscape[iv]

- Presence of the National Health Innovation Hub (NHIH), supported by Enterprise Ireland and the Department of Health, aimed at promoting the collaboration between industry and the national health system
- Increasing industry collaboration in R&D activities in areas such as microelectronics, biomaterials, and medical engineering
- Activities and collaboration supported by the public agencies, Irish Medical Devices Association (IMDA) and the Irish Medical and Surgical Trade Association.

[i] *The sector of medical devices technologies is statistically defined as NACE code 32 "other manufacturing" that also includes manufacture activities different from medical technologies. Therefore, the value in the chart may be overestimated.*
[ii] *Eurostat (2017) Structural Business Statistics*
[iii] *Irish MedTech Association (2016) The Global MedTech Hub*
[iv] *DBEI (2017) Overview Report and Sector Briefs*
[v] *Irish MedTech Association (2016) MedTech Rising*
[vi] *EGFSN (2008) Future Skills Needs of the Irish Medical Devices Sector*

Computer and electronics – sectoral brief



Note: Data refer to 2014
Source: *CSO (2017) for Value added data; Eurostat -SBS (2017) for employment, Eurostat – Comext (2017) and COMTRADE (2017) for Trade data*

Overview

- The manufacturing of computer and electronic equipment provides 15,984 direct jobs, employed in 377 companies[i]
- Ireland is a leading country, supplying around 20% of EU electronics' output, primarily in semi-conductor components and data processing equipment[ii]
- The sector is export-driven, with an indigenous sector dominated by exporters providing leading-edge technology products to global niche markets[ii]

Why Ireland is attractive[ii,iii]

- Long established presence in the semiconductor industry
- R&D infrastructure and capacity
- Quality logistics infrastructure
- Low corporate tax rate
- High skill workforce

The productive base[iii]

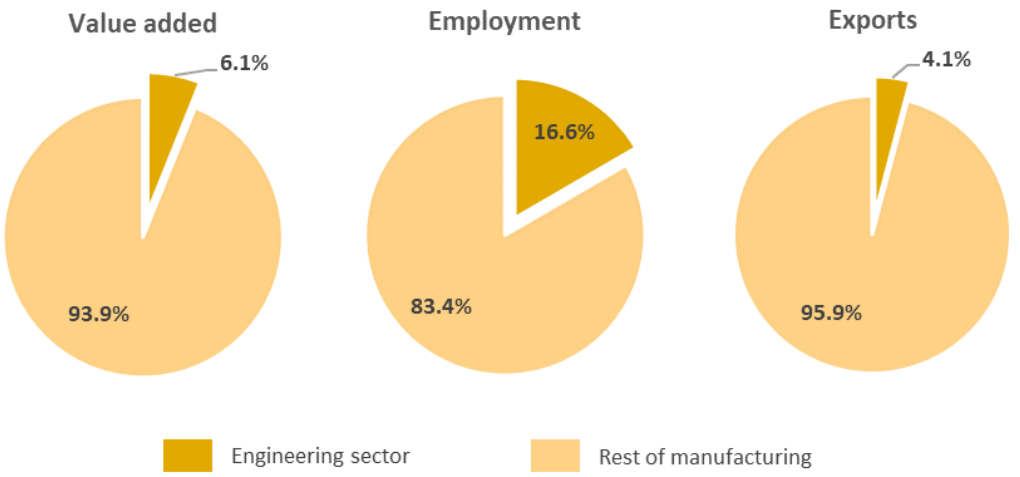
- Several MNCs have located manufacturing and R&D facilities in Ireland
- As a part of a global trend, the sector is characterised by a high level of mergers and acquisitions driven by market leaders, trying to expand their core business and entering new markets
- Presence of Tech clusters in Dublin and Cork
- Presence of a strong group of innovative indigenous firms that has been facilitated by the joint presence of high technology multinationals and public investments in R&D in the electronics sector

Research and development landscape[ii,iii]

- The sector is characterised by state-supported industry clusters working with research centres on the development of next generation technologies
- State supported centres in the areas of microelectronics, sensors, ambient technologies, nanoelectronics and photonics, including the Tyndall National Institute, Microelectronics Circuits Centre Ireland, and Centre for Research on Adaptive Nanostructures and Nanodevices
- Interaction with other sectors of the economies, particularly international construction firms with a track record in the design and build of complex manufacturing, clean room and data centre facilities

[i] *Eurostat (2017) Structural Business Statistics, data referring to 2014*
[ii] *Enterprise Ireland (2016). Electronics. Sector profile.*
[iii] *DBEI (2017) Overview Report and Sector Briefs*
[iv] *IDA Ireland (2017). Ireland's Technology Sector.*

Engineering sector– sectoral brief



Note: Data refer to 2014
Source: *CSO (2017) for Value added data; Eurostat -SBS (2017) for employment, Eurostat – Comext (2017) and COMTRADE (2017) for Trade data*

Overview

- The engineering sectors encompasses a variety of manufacturing activities, spanning from mechanic, automotive to the production of electrical components[i]
- In 2014, the sector employed 31,531 people in 4,165 companies[ii]
- Production segments include: manufacturing and communications infrastructure, energy production and distribution, agricultural machinery, and some consumer goods[iii]

Why Ireland is attractive[iv]

- Highly educated and trained engineering workforce
- Advantageous tax regime
- Presence of a strong supply capability
- Regulatory stability

The productive base[v,vi]

- In the sector, Irish-owned companies are engaged in either sub-supply or in the development, manufacturing and export of their own branded products to end customers
- Indigenous firms are also characterised by a high level of specialisation
- Many of the foreign-owned companies have been established in Ireland for over 20 years, and they produce products for their parent corporations
- In contrast with other sectors, the engineering sector is vertically integrated in the Irish economy. Both foreign-owned and indigenous companies source a large proportion of their inputs and services in Ireland
- Engineering companies are important suppliers to large indigenous and multinational companies in areas such as construction, ICT, and pharmaceuticals

Research and development landscape[iii,vi]

- Presence of Industry-led technology centres, such as the Materials Surface Science Institute in Limerick, providing transversal services to the entire manufacturing sector
- Higher education institutes have specific expertise or centres dedicated to manufacturing, to include: the BioInnovate forum; the Centre for Advanced Manufacturing and Management Systems in CIT; the Enterprise Research Centre and U Learning programme in University of Limerick; UCD-Trinity Innovation Partnership; and Sligo/Athlone Institutes of Technology/Skillnets distance learning offering in Polymer Engineering
- Some of the world's largest engineering companies have deepened or widened their investment in the Irish economy's R&D expertise

[i] *For statistical purposes, the engineering sector is defined as composed by the following sub-sectors: Basic & Fabricated Metal Products (NACE code 24,25); Electrical equipment (NACE code 27); Machinery & Equipment (NACE code 28)*
[ii] *Eurostat (2017) Structural Business Statistics*
[iii] *Enterprise Ireland (2010) Engineering - Sector profile*
[iv] *IDA (2017) Engineering & Industrial Technologies Industry in Ireland*
[v] *Irish Engineering Enterprises Federation (2004). Engineering in Ireland: Economic assessment and strategic issues.*
[vi] *DBEI (2017) Overview Report and Sector Briefs*

Appendix 5: International Policy Initiatives - Case Studies

This annex presents a review of selected programmes and initiatives in major countries addressing challenges arising from the digitalisation of manufacturing. The focus of the case studies presented in this annex has been on the identification and classification of practical instruments deployed as part of industrial digitalisation programmes and initiatives. They provide valuable insights into the major challenges and opportunities arising from the digitalisation of manufacturing identified internationally, and the variety of practical initiatives, programmes and instruments deployed. While it is difficult to represent the full breadth of policy efforts in each particular country, representative examples have been chosen that highlight some key national priorities and some important flagship initiatives.

It is important to note that the focus of the review has been on policy efforts particularly focused on manufacturing, rather than generic or economy-wide instruments. Thus, the review does not include generic tax incentives that apply to all firms in the economy; generic export promotion or overseas business development programmes; generic foreign direct investment promotion programmes; or start-up promotion programmes/university accelerators.

The choice of national case studies cannot be comprehensive due to time limitations, and given that many 'experiments' are still in development in countries around the world. However, the choice of cases (and in general the whole study) has benefited from international reviews already conducted by, for example, the European Commission through their Digitising European Industry initiative[73], the OECD[74], and the United Nations[75].

In order to facilitate a cross-comparison, after information has been given about a program's name and country, case studies are presented by following the same structure: summary, mission, focus, approach, budget, governance, examples of successful cases, impact indicators of the programmes (where available), and references.

[73] Including the study European Commission (2017) Digital Transformation Monitor: Key lessons from national industry 4.0 policy initiatives in Europe
[74] Including the review of policy approaches as part of the Next Production Revolution.
[75] Including commissioned papers on international policy approaches.

Every case study will also include a "summary table" similar to the following:

		Minor emphasis	Some emphasis	Primary emphasis
FOCUS OF THE PROGRAMME	**Knowledge generation** (basic and applied R&D)	○	○	○
	Knowledge diffusion (linkages & institutions)	○	○	○
	Knowledge use (firm capability)	○	○	○
POLICY DELIVERY MECHANISMS	**Funding agency**	○	○	○
	RTO / Technology Centre / Institution	○	○	○
	R&D Institution	○	○	○
	Cluster organisation	○	○	○
	Education / training institution	○	○	○
	Industry associations / trade unions	○	○	○
	Industry/Economy government entity	○	○	○

The first part of the summary table reports information about the focus of the programme in terms of knowledge generation, diffusion, and use, where:

- 'Knowledge generation' includes basic and applied research and development activities related to new technologies, tools and techniques.
- 'Knowledge diffusion' includes activities to facilitate the diffusion of knowledge and know-how (including standard development, creation of industrial networks, and industrial and market intelligence gathering).
- 'Knowledge use' includes activities to support firm access and application of new technological knowledge (including training, access to expertise & facilities, and new product development support).

The second part of the summary table focuses on policy delivery mechanisms, such as funding agency, cluster organisation, Industry associations/trade unions and so on. For every category, the level of emphasis was qualitatively assessed based on the literature review, benchmarking and expert judgment.

List of case studies	
Name of the programme	Country
Internet Plus	China
Competence Track for Automation and Digitalisation in SMEs (KOMP-AD)	Denmark
Innovation fund Denmark	Denmark
Production in Denmark	Denmark
Vaekstløft	Denmark
Manufacturing Academy of Denmark (MADE)	Denmark
5th Gear programme	Finland
TEKES/DIMECC	Finland
Team Finland Industrial Internet Programme	Finland
Icelandic Institute for Intelligent Machines	Iceland
iKuben: Manufacturing Network 4.0	Norway
Industry Transformation Programme	Singapore
National Robotics Program	Singapore
Manufacturing Innovation 3.0	South Korea
Connected industry 4.0	Spain
Process IT Innovations	Sweden
Produktion2030	Sweden
STREAM	Sweden
Taiwan Productivity 4.0	Taiwan

Internet Plus – China

Summary

The Internet Plus initiative was launched in 2015, seeking to better integrate the Internet with industry. The action plan integrates the mobile Internet, cloud computing, big data and the Internet of Things with modern manufacturing, to encourage the development of e-commerce, industrial networks, and Internet banking, and to help Internet companies increase their international presence. Internet Plus promotes digitalisation in 11 sectors: entrepreneurship and innovation, synchronised manufacturing, modern agriculture, intelligent energy, inclusive financing, welfare services, efficient logistics, e-commerce, transportation, green ecology and artificial intelligence.

		Minor emphasis	Some emphasis	Primary emphasis
FOCUS OF THE PROGRAMME	**Knowledge generation** (basic and applied R&D)	○	○	○
	Knowledge diffusion (linkages & institutions)	○	○	●
	Knowledge use (firm capability)	○	○	●
POLICY DELIVERY MECHANISMS	**Funding agency**	○	○	○
	RTO / Technology Centre / Institution	○	○	○
	R&D Institution	○	○	○
	Cluster organisation	○	○	○
	Education / training institution	○	○	○
	Industry associations / trade unions	○	○	○
	Industry/Economy government entity	○	○	●

Mission

To boost, transform and upgrade traditional industries and business models by leveraging Internet and digital technologies.

Focus

- Value chain activity: All.
- Technology: big data analytics, cloud computing, information infrastructure, core chips, high-end servers, IoT
- Sectors / research fields: entrepreneurship and innovation; synchronised manufacturing, modern agriculture, intelligent energy, inclusive financing, welfare services, efficient logistics, e-commerce, transportation, green ecology and artificial intelligence
- Level of digitalisation and automation: Knowledge diffusion and use

Approach

- Pilot project to publish data on government and public services, and encourage national innovation platforms to open up to enterprises, especially SMEs
- Lower the eligibility requirements for relevant products and services
- Finance support and tax references to key projects; in addition to encouraging local governments' support
- Maintain cyber and information security
- Pilot and innovation zones, such as Zhongguancun, the Chinese version of Silicon Valley

Budget

Internet Investment Fund (2017): CNY 100 billion (~EUR 12.8 billion). The Cyberspace Administration of China and
Ministry of Finance oversee the fund. The fund supports Internet companies and the Internet Plus Action Plan via equity investment. In addition, the Industrial and Commercial Bank of China (ICBC), together with the China Development Bank and the Agricultural Bank of China, will provide financial services and CNY 150 billion (~EUR 19.2 billion) of credit to selected enterprises.
In 2016, a CNY 200 billion (~EUR 25.6 billion) state-controlled venture capital fund was launched. This was financed by China Construction Bank Corporation, China Reform Holdings Corporation Ltd. (CRHC), the Postal Savings Bank of China and Shenzhen Investment Holding Co. Ltd, to support innovation and technology upgrading in centrally-administered state firms.

Governance

The State Council coordinates Internet Plus, and the National Development and Reform Commission (NDRC) is responsible for implementing the strategy

References

Dai, Qian (2017), "China and the next production revolution", in *The Next Production Revolution: Implications for Governments and Business*, OECD Publishing, Paris.
OPENGOV (2017). *Chinese government sets up US$ 14.6 billion Internet Investment Fund.*
The State Council. The People's Republic of China (2015). *Internet Plus.*
Wübbeke et al. (2016). *Made in China 2025. The making of a high-tech superpower and consequences for industrial countries.* MERICS.

Competence Track for Automation and Digitalisation in SMEs (KOMP-AD) – Denmark

Summary

Competence Track for Automation and Digitalisation in SMEs (KOMP-AD) was an education programme that worked between 2013 and 2015. It addressed the lack of knowledge and practical competencies in the field of automation and digitalisation. KOMP-AD was a collaboration of 15 Danish vocational schools and colleges, 250 SMEs, business associations and public actors within business support.

Mission

Improve SMEs' productivity and growth, by increasing their use of digital and automated solutions in products and services.

		Minor emphasis	Some emphasis	Primary emphasis
FOCUS OF THE PROGRAMME	**Knowledge generation** (basic and applied R&D)	○	○	○
	Knowledge diffusion (linkages & institutions)	○	○	○
	Knowledge use (firm capability)	○	○	●
POLICY DELIVERY MECHANISMS	**Funding agency**	○	○	○
	RTO / Technology Centre / Institution	○	○	○
	R&D Institution	○	○	○
	Cluster organisation	○	○	○
	Education / training institution	○	○	●
	Industry associations / trade unions	●	○	○
	Industry/Economy government entity	●	○	○

Focus

- Value chain activity: production.
- Technology: automation and digitalisation.
- Level of digitalisation and automation: Knowledge use.

Approach

The courses consisted of three phases:

- Recruitment and screening of SMEs to identify companies with potentials and challenges within automation and digitalisation.
- Initial problem identification and dialogue with the SMEs.
- "Tailor-made" competency-development courses for employees and managers in the SMEs based on the practical challenges of the individual company.

Budget

The total budget of this project was EUR 5,697,400; from this, the European Social Funded contributed with EUR 3,981,790.

Governance

Actors involved: Vocational schools and colleges, SMEs, business associations, the Ministry of Business and Denmark's Growth Council.

Success cases

VVS Løsning. This company collaborated with Learnmark Horsens to digitise the workflow. The company chose to invest in iPads for all employees, and to implement its cloud base -ready time- and case management program for craftsmen "Ordrestyring.dk".

Impact indicators

From the participating companies (250 companies, from January 2013 to June 2015):

- 72% have experienced some productivity improvement.
- 41% have experienced a revenues increase.
- 55% have experienced an increase on profits.

References

European Social Fund (2017). Projects. *Technical training streamlines for success*.

Iris Group (2015). *Digitalisation and automation in the Nordic manufacturing sector. Status, potentials and barriers*. Nordic Council of Ministers.

Iris Group (2015). *Evaluering af KOMP-AD*.

Innovation Fund Denmark – Denmark

Summary

The Innovation Fund Denmark (IFD) was established in April 2014 consolidating three existing national funding bodies (Danish Council for Strategic Research; Danish Council for Technology and Innovation; Danish National Advanced Technology Foundation) within a single new entity. IFD finances up to 75% of the costs of projects focused on research, technology, experimental development and market development. This funding agency also supports the development of research capacities of PhD and Postdoc candidates.

		Minor emphasis	Some emphasis	Primary emphasis
FOCUS OF THE PROGRAMME	**Knowledge generation** (basic and applied R&D)	○	○	●
	Knowledge diffusion (linkages & institutions)	○	●	○
	Knowledge use (firm capability)	○	○	○
POLICY DELIVERY MECHANISMS	**Funding agency**	○	○	●
	RTO / Technology Centre / Institution	○	●	○
	R&D Institution	○	●	○
	Cluster organisation	○	○	○
	Education / training institution	○	○	○
	Industry associations / trade unions	○	○	○
	Industry/Economy government entity	○	○	○

Mission

'Innovation Fund Denmark invests in cultivating and translating ideas, knowledge and technology for the benefit of Danish Society'.

Focus

- Value chain activity: research and development
- Sectors / research fields: bio-resources, food and lifestyle; trade, service and society; energy, climate and environment; production, materials, digitalisation and ICT; infrastructure, transport and construction; biotech, medico and health
- Technology: digitalisation and ICT
- Company size: Industrial researchers, entrepreneurs, SMEs and large companies
- Level of digitalisation and automation: Knowledge generation

Approach

- IFD finances up to 75% of the project's total budget
- Three programmes:
  - Grand Solutions. For substantial investments (over DKK 5 million - ~EUR 670,000) and long-term projects/partnerships where the focus is on research, technology, experimental development and market development. For these projects, there are three types of calls: thematic calls, open calls and societal innovation partnerships.
  - InnoBooster. For small and medium-sized enterprises (with fewer than 250 employees) which aim to develop a new product, a new service or to improve a process. Finance up to DKK 5 million (~EUR 670,000)
  - Talents. This programme involves two schemes: "Industrial PhD / Postdoc", which supports the development of research capacities in collaboration with enterprises and research institutions; and "Entrepreneurial Pilot", financial support for recent graduates.

Budget

In 2014, DKK 1,580.5 million (~€212,000) was allocated to IFD.

Governance

The IFD is a public funding agency where the Board of Directors has overall decision-making authority. The Board is formed by 9 appointed members with research and industry expertise

Success cases

Earplugs for diagnosing sleeping disorders:

- Investment: Total budget, DKK 26 million (~EUR 3.5 million); fund investment, DKK 15.8 million (~EUR 2.1 million)
- Duration of the project: 4 years.
- Actors involved: UNEEG medical A/S; Aarhus University, Department of Engineering; Aarhus University Hospital, Neurophysiology Department; Sjælland University Hospital.

PACE project (Proactive care for elder citizens with dementia). System to connect existing sensor technology to improve the quality of elderly people with dementia, without interfering with their privacy:

- Investment: Total budget, DKK 8.6 million (~EUR 1.1 million); fund investment 6.4 million (~EUR 860,000)
- Duration of the project: 4 years.
- Actors involved: Technical University of Denmark (DTU); Aalborg University Copenhagen (AAU CPH); Kullegaard; Care Center Skovhuset; SIF Group; Væksthus Hovedstadsregionen

References

IFD (2015). Innovation Fund Denmark 2015 Strategy
IFD Website. https://innovationsfonden.dk/en
Innovationsfonden (2015). *Årsrapport 2014.*
Iris Group (2015). *Digitalisation and automation in the Nordic manufacturing sector. Status, potentials and barriers*. Nordic Council of Ministers.

Production in Denmark – Denmark

Summary

Production in Denmark is a completed project that ran between 2013 and 2016. This project targeted SMEs. Its aim was to strengthen employment, productivity and competitiveness, by exploiting the growth potential of existing state-of-the art technologies and through exchange of knowledge in cluster activities. Production in Denmark involved innovation courses, seminars, open labs and foreign stays.

		Minor emphasis	Some emphasis	Primary emphasis
FOCUS OF THE PROGRAMME	**Knowledge generation** (basic and applied R&D)	○	○	○
	Knowledge diffusion (linkages & institutions)	○	○	●
	Knowledge use (firm capability)	○	●	○
POLICY DELIVERY MECHANISMS	**Funding agency**	○	○	○
	RTO / Technology Centre / Institution	○	○	●
	R&D Institution	○	○	●
	Cluster organisation	○	○	○
	Education / training institution	○	○	●
	Industry associations / trade unions	○	○	○
	Industry/Economy government entity	○	○	○

Mission

'Optimize and develop production through knowledge of new production technologies and development processes'.

Focus

- Value chain activity: Production
- Sectors / research fields: Laser welding processes; advanced material and process technology, including micro and nanotechnology; digitisation and automation; digitised documentation and quality; resource productivity; the human aspects of production systems
- Company size: SMEs
- Level of digitalisation and automation: Knowledge diffusion

Approach

Innovation courses, seminars, workshops, open labs, demonstration projects, foreign stays, networking and cluster collaboration.

Governance

Actors involved: FORCE Technology, the Danish Technological Institute, the Board of Research and Innovation; and the Ministry of Education.

Success cases

Applications of ICT scanning technologies in small companies (with guidance of the *Teknologisk Institut*):

- *Vaavud*. Established in 2013, this company produces the world's first hand-held anemometer. Industrial CT scanning shows information on material defects as air gaps and disparities.
- *Stensved Form Tool*. Founded in 1970 and employing 22 people. This toolmaker company used ICT scanning to show material defects and geometric measurements. Data from the scan can be visualised in 3D images and colour maps that show the material distribution.

References

Force Technology. *Production in Denmark.*
Institute of Technology. *Production in Denmark*
Iris Group (2015). *Digitalisation and automation in the Nordic manufacturing sector. Status, potentials and barriers*. Nordic Council of Ministers

Vaekstløft – Denmark

Summary

Vækstløft is an initiative established in collaboration between the Danish Business Authority and the six Regional Growth Forums. It is administered by the so-called Growth Houses that are specialised in business support for companies with high growth potential. This programme emphasises the potential of digitalisation and automation to strengthen companies' productivity and competitiveness. The goal is to strengthen the productivity and competitiveness of 1,000 SMEs.

		Minor emphasis	Some emphasis	Primary emphasis
FOCUS OF THE PROGRAMME	**Knowledge generation** (basic and applied R&D)	○	○	○
	Knowledge diffusion (linkages & institutions)	○	●	○
	Knowledge use (firm capability)	○	○	●
POLICY DELIVERY MECHANISMS	**Funding agency**	○	○	○
	RTO / Technology Centre / Institution	○	○	○
	R&D Institution	○	○	○
	Cluster organisation	○	○	○
	Education / training institution	○	○	○
	Industry associations / trade unions	○	○	○
	Industry/Economy government entity	○	○	●

Mission

'Strengthen the company's productivity, competitiveness and support development and growth'.

Focus

- Value chain activity: Production
- Sectors / research fields: Manufacturing
- Technology: Digitalisation and automation
- Company size: SMEs
- Level of digitalisation and automation: Knowledge diffusion and use.

Approach

- Private consultancy services to address individual growth potentials and challenges of companies
- A Growth Check Action Plan is jointly developed by the private consultant and the SME. Then follow up advice is provided to implement the plan. The process includes a final Growth Plan for how the further growth of projects is realised and what investments and effects these entail.

Budget

The program is co-financed by the EU Regional Fund with DKK 6 million (~EUR 800,000) for the region Sjælland and DKK 23.5 million (~EUR 3.2 million), for the rest of the country.

Governance

Actors involved: Danish Business Authority and the six Regional Growth Forums.

Success cases

Start-up: Romani:

- Core activity: hardware and software that monitors environmental engineering solutions in buildings.
- Number of employees: 23
- Type of support received: Capital coaching, patent advice and funding.

References

Iris Group (2015). *Digitalisation and automation in the Nordic manufacturing sector. Status, potentials and barriers*. Nordic Council of Ministers.

Væksthus Midtjylland (2017b). *Vækstprogram for små og mellemstore produktionsvirksomheder*.

Væksthus Midtjylland (2017a). *Annual report 2016.*

Manufacturing Academy of Denmark (MADE) – Denmark

Summary

Manufacturing Academy of Denmark (MADE) is a cluster initiative. Among MADE members are large, medium and small companies; universities; academic institutions and advanced technology groups. The main activity of MADE lies in facilitating a number of collaborative research and innovation projects aimed at various aspects of automation and digitalisation in SMEs. Moreover, MADE facilitates knowledge exchange and matchmaking through open workshops, site-visits and demonstration projects. The core of MADE consists of more than 30 PhD students.

		Minor emphasis	Some emphasis	Primary emphasis
FOCUS OF THE PROGRAMME	**Knowledge generation** (basic and applied R&D)	○	○	●
	Knowledge diffusion (linkages & institutions)	○	●	○
	Knowledge use (firm capability)	○	○	○
POLICY DELIVERY MECHANISMS	**Funding agency**	○	●	○
	RTO / Technology Centre / Institution	○	●	○
	R&D Institution	○	●	○
	Cluster organisation	○	○	●
	Education / training institution	●	○	○
	Industry associations / trade unions	●	○	○
	Industry/Economy government entity	○	○	○

Mission

'Applying research, driving innovation and strengthening education to improve the competitiveness of Danish manufacturing'.

Focus

- Value chain activity: From research and development to distribution
- Sectors / research fields: high speed product development; modular production platforms for high speed ramp-up; 3D print and new production processes; model based supply chain development; digitalisation of supply chains; lifelong product customisation; the "new" manufacturing paradigm; hyper flexible automation; and sensors and quality control
- Level of digitalisation and automation: Knowledge generation and diffusion.

Approach

- Open Lab. Short presentations, case stories and demonstrations of the state-of-the-art technologies.
- Demonstration projects. Finance (up to DKK 92,000 - ~EUR (12,300) and knowledge-based support. This scheme targets industrial MADE's members with less than 250 employees.
- Industrial visits, MADE Innovation Conference and workshops.
- The Strategic Platform for Innovation and Research (SPIR). Provides funding to initiatives that strengthen the link between strategic research and innovation.

Budget

The Danish Council for Strategic Research and The Danish Council for Technology and Innovation allocated in the end of 2013, a grant of DKK 64 million to the Strategic Platform for Innovation and Research (SPIR). This grant is now administered by Innovation Fund Denmark. The grant is co-financed with additional resources from participating companies, universities, the Association of Industrial Employers (IAK) and Future Food Innovation (FFI).

Governance

Actors involved: Companies, universities and GTS institutes (technological service providers). MADE's board consists of five industrial representatives, three university representatives, and one representative from the GTS institutes.

Success cases

MADE: Demonstration projects for testing new technology or solving a specific challenge in production:

- CCM Electronic Engineering. This company will develop and set up a new type of scanner and software from the manufacturer SICK in Danmark. The setup of sensors and software can help a robot identify issues that are cluttered in a box and must be collected one by one.
- Other actors involved: Technological Institute; the robot manufacturer KUKA.

MADE: Cluster project for small and medium-sized companies that share a particular challenge or want to become better within a particular technology:

- Aim of the project: Help companies who need support and guidance to develop more flexible robot solutions. Such solutions reduce the risk of unemployed robots or ongoing costs of major restructuring of production lines.
- Actors involved: four industrial companies, Danish Technological Institute, University of Southern Denmark, Aalborg University, Danfoss and Danish Crown.

References

Iris Group (2015). *Digitalisation and automation in the Nordic manufacturing sector. Status, potentials and barriers*. Nordic Council of Ministers.

MADE (2017). MADE Website. http://made.dk/om-made/made-i-detaljer/

5th Gear programme – Finland

Summary

The 5thGear programme funds projects that aim to solve challenges related to the next generation wireless data communications, by creating new business models, and making Finland the leading target for international investments. The programme also offers networking through events and excursions and foreign market data. Gear runs in the time period 2014–2019.

		Minor emphasis	Some emphasis	Primary emphasis
FOCUS OF THE PROGRAMME	**Knowledge generation** (basic and applied R&D)	○	○	●
	Knowledge diffusion (linkages & institutions)	○	●	○
	Knowledge use (firm capability)	○	○	○
POLICY DELIVERY MECHANISMS	**Funding agency**	○	○	●
	RTO / Technology Centre / Institution	○	○	○
	R&D Institution	○	○	○
	Cluster organisation	○	○	○
	Education / training institution	○	○	○
	Industry associations / trade unions	○	○	○
	Industry/Economy government entity	○	○	○

Mission

'Finland to be the innovation leader in digitalisation and to attract international investments by means of wireless communications excellence'.

Focus

- Value chain activity: research and development
- Technology: 5G-technology
- Company size: The program targets companies of various sizes and research institutions
- Level of digitalisation and automation: Knowledge generation and diffusion.

Approach

In addition to supporting research of novel technologies with a long time to market, this program also covers more mature technologies and a broader range of businesses, including the diffusion of existing technologies. The activities include:

- Piloting and demonstration driven world-class 5G research
- Cross-industry collaboration, innovation and utilisation
- Global competiveness, new business opportunities and international.

Budget

The total budget for the five-year programme is approximately EUR 100 million, of which Tekes funds approximately EUR 50 million.

Governance

The 5thGear programme is managed by TEKES.

Success cases

5G Test Network Finland. 5GTNF coordinates the integration of 5thGear testbed projects and facilitates the cooperative creation of an open national innovation platform for 5G technology and concept verification and application development. This is a joint effort from industry and academia with global manufacturers such as Nokia, Ericsson, Huawei, Coriant and Intel, as well as internationally recognised research organisations like VTT, University of Oulu, University of Helsinki, Tampere University of Technology and Aalto University.

References

Iris Group (2015). *Digitalisation and automation in the Nordic manufacturing sector. Status, potentials and barriers*. Nordic Council of Ministers.
Tekes (2017). 5thGear.

TEKES/DIMECC – Finland

Summary

The Finnish National Agency for Technology and Innovation (Tekes) is the most important publicly funded organisation for financing research, development and innovation in Finland. Tekes promotes a broad-based view on innovation: besides funding technological breakthroughs, Tekes emphasises the significance of service-related, design, business and social innovations. TEKES' support is centred on a number of strategic focal areas, including 'Digitalism renewing business and industry'. In practice, the area is addressed by stimulating the development of clusters that carry out joint research and innovation projects.

		Minor emphasis	Some emphasis	Primary emphasis
FOCUS OF THE PROGRAMME	**Knowledge generation** (basic and applied R&D)	○	○	●
	Knowledge diffusion (linkages & institutions)	○	○	○
	Knowledge use (firm capability)	○	○	○
POLICY DELIVERY MECHANISMS	**Funding agency**	○	○	●
	RTO / Technology Centre / Institution	○	○	○
	R&D Institution	●	○	○
	Cluster organisation	○	○	●
	Education / training institution	○	○	○
	Industry associations / trade unions	○	○	○
	Industry/Economy government entity	○	○	○

Mission

Sponsored by Tekes, DIMECC - Digital, Internet, Materials & Engineering Co-Creation - 'connect manufacturing and ICT-industries and drive the digital transformation with the most efficient and holistic manner'.

Focus

- Value chain activity: All.
- Technology (DIMECC):
  - Enabling technologies: materials, connectivity, data utilisation, augmented/virtual reality, cognitive robotics, sensors, software.
  - Technology cross-utilisation: industrial internet & IoT applications, autonomous systems of systems, co-creative intelligence.
  - Business: outcome economy, digital enterprise, smart design & production.
- Level of digitalisation and automation: Knowledge generation.

Approach

- Strategic Centres for Science, Technology and Innovation (SHOKs). Companies and research units work in close cooperation and carry out research that has been jointly defined (Tekes stopped funding SHOKs in 2016).
- DIMECC is a co-creation platform for digital transformations. Their network consists of 2,000+ R&D&I professionals, 400+ organisations, 69 shareholders and 10+ co-creation facilitators. DIMECC's services include:
  - LIFEX. The projects supported by this scheme are developing methods for efficient virtual and augmented product information usage and new innovative vibration management solutions.
  - Post Docs in Companies (PoDoCo). Matchmaking program supporting strategic renewal of companies and employment of young doctors in the private sector.
  - DEMOBOOSTER. Innovation service for rapid commercialisation.

Budget

EUR 50 million in 2016.

Governance

Public-private partnership.

Success cases

- Solita. IT company specialised in data analytics, and developed a method where the magazine sales are forecasted based on other similar magazines in similar magazine sales points.
- Ericsson (and partners) Capillary Data Fusion. This is a platform to combine technologies. The Capillary Network uses short range radio access to services, storage, and applications that are in the cloud.

Impact indicators

Results in 2016:

- EUR 50 million research portfolio.
- Demobooster: 6 demo days, 34 companies, 69 solutions, 20 demos.
- 42 PoDoCo scholarships by private foundations.

References

DIMECC (2017). *DIMECC in brief*.
DIMECC (2016). *DIMECC. The most effective innovation in Europe*.
DIMECC (2016). *What is DIMECC?*
DIMECC (2017). *Annual report 2016.*
Embassy of Finland (2015). *Tekes – the Finnish Funding Agency for Technology and Innovation.*
Iris Group (2015). *Digitalisation and automation in the Nordic manufacturing sector. Status, potentials and barriers*. Nordic Council of Ministers.

Team Finland Industrial Internet Programme - Finland

Summary

Industrial Internet is a research and innovation programme focusing on the refinement of big data-technologies in terms of machine-to-machine communication and real-time service and production processes. The program also supports the development of new technological solutions (with long time to market), required in digital business, as well as related research. The program covers the period 2014–2019.

		Minor emphasis	Some emphasis	Primary emphasis
FOCUS OF THE PROGRAMME	**Knowledge generation** (basic and applied R&D)	○	○	●
	Knowledge diffusion (linkages & institutions)	○	○	○
	Knowledge use (firm capability)	○	○	○
POLICY DELIVERY MECHANISMS	**Funding agency**	○	○	●
	RTO / Technology Centre / Institution	○	○	○
	R&D Institution	○	○	○
	Cluster organisation	○	○	○
	Education / training institution	○	○	○
	Industry associations / trade unions	○	○	○
	Industry/Economy government entity	○	○	○

Mission

'Support Finnish companies in business development and innovation as well as in achieving a global forerunner status in developing and utilising IoT solutions'.

Focus

- Value chain activity: research and development.
- Technology: data analytics.
- Level of digitalisation and automation: Knowledge generation.

Approach

- Innovation funding for developing and piloting products and services for global markets.
- Companies can apply for co-funding under the program if they meet the following criteria:
  - The project helps renew business processes and services using industrial Internet technologies. It has considerable volume to ensure impact.
  - It features cross-industry collaboration.
  - It features pilots and demonstrations with active industrial participation.
- Level of digitalisation and automation: Knowledge generation, diffusion and use.

Budget

The total budget for the five-year program is approximately EUR 100 million out of which TEKES funds account for approximately EUR 50 million.

Governance

Team Finland Industrial Internet Programme is managed by TEKES.

Success cases

- Pesmel. Founded in Kauhajoki In 1978, the family-owned company Pesmel manufactures highly automated logistics, packaging and storage systems. Its customers are mainly from the metal and paper industry, as well as the general cargo industry in Finland. In their Industrial Internet project the company developed a software for remote machine control. The company has experienced an increase in sales of about 20%.
- Servicepoint Kuopio. Their Internet of Things project involves developing its business based on the serialisation of medication packaging. During the serialisation process, a serial number will be assigned to the medication packaging at the end of the production process, enabling each package to be uniquely identified, tracked and verified. The objective is to prevent falsified and counterfeit medical products from entering the market.

References

Iris Group (2015). *Digitalisation and automation in the Nordic manufacturing sector. Status, potentials and barriers*. Nordic Council of Ministers.
Tekes (2017). Team Finland Industrial Internet Programme.

Icelandic Institute for Intelligent Machines – Iceland

Summary

The Icelandic Institute for Intelligent Machines (IIIM / Vitvélastofnun Íslands) is a non-profit research institute founded in 2009. The Institute develops software tools, methods and systems within areas of artificial intelligence, robotics and simulation that are applicable in a wide range of areas, including manufacturing. Their collaboration takes many forms, including contract work, grant proposal writing, prototyping and basic research.

		Minor emphasis	Some emphasis	Primary emphasis
FOCUS OF THE PROGRAMME	**Knowledge generation** (basic and applied R&D)	○	○	●
	Knowledge diffusion (linkages & institutions)	○	○	●
	Knowledge use (firm capability)	○	○	○
POLICY DELIVERY MECHANISMS	**Funding agency**	○	○	○
	RTO / Technology Centre / Institution	○	○	●
	R&D Institution	●	○	○
	Cluster organisation	○	○	○
	Education / training institution	●	○	○
	Industry associations / trade unions	●	○	○
	Industry/Economy government entity	○	●	○

Mission

'IIIM strives to optimise the match between academic and industry needs, resources and goals, relieving members from the need to be on the outlook for opportunities, technologies, projects, students and resources'.

Focus

- Value chain activity: research and development.
- Technology: software design, big data, artificial intelligence and complex systems simulations.
- Level of digitalisation and automation: Knowledge generation and diffusion.

Approach

- IIIM is a bridge between academia and industry, enabling academia to better relate to industrial needs, and at the same time allowing industry to benefit sooner from academic results. The 3-year horizon of most product development in industry ("3", left-hand side) is met with IIIM's 3-9 year horizon, connecting with the most advanced products on the industrial side with the further-reaching horizon of academic projects ("9", right-hand side), at one decade or more into the future.
- For start-up companies IIIM offers two comprehensive start-up programs:
  - High-Tech Highway. Provides quick access to IIIM's network of experts.
  - Accelerator. Collaboration method for high-tech industry and young start-ups.

Governance

The institute was founded in collaboration with industrial and academic institutions. These are Center for Analysis and Design of Intelligent Agents (CADIA), Reykjavik University School of Computer Science and CCP. Industrial members provide challenging practical questions, while universities provide doctoral students, postdoctoral associates, and a research faculty.

Success cases

- Threadneedle. This project involves an Agent Based Economic Simulation Framework based on a full implementation of the double entry book keeping transactions on which all modern credit/debt financing is based. It is intended as a tool for creating realistic economic simulations, allowing it to explore the systemic behaviour of the economic constructs that we inhabit.
- CoCoMaps. This project expands on an existing implementation of an architecture approach called Cognitive Maps, originally built to enable the Honda robot ASIMO to learn from and interact with its environment. The technology will allow robots (or computers) to communicate with multiple parties

References

IIIM. About IIIM.

IIIM (2015). Featured projects.

Iris Group (2015). *Digitalisation and automation in the Nordic manufacturing sector. Status, potentials and barriers*. Nordic Council of Ministers.

iKuben: Manufacturing Network 4.0 – Norway

Summary

The broad industrial cluster organisation iKuben launched the research project Manufacturing Network 4.0 in 2015. This project is carried out in collaboration with the Norwegian University of Science and Technology, Molde University College, and a number of other research institutions and manufacturing companies from different sectors.

		Minor emphasis	Some emphasis	Primary emphasis
FOCUS OF THE PROGRAMME	**Knowledge generation** (basic and applied R&D)	○	○	○
	Knowledge diffusion (linkages & institutions)	○	○	●
	Knowledge use (firm capability)	○	○	●
POLICY DELIVERY MECHANISMS	**Funding agency**	○	○	○
	RTO / Technology Centre / Institution	○	○	○
	R&D Institution	○	●	○
	Cluster organisation	○	○	●
	Education / training institution	○	○	○
	Industry associations / trade unions	○	○	○
	Industry/Economy government entity	○	○	○

Mission

Strengthen the competitiveness of Norwegian companies struggling with high production costs, through the developing of knowledge on how to implement ICT across the entire value chain.

Focus

- Value chain activity: All
- Sectors / research fields: Value chain design and localisation; innovation through production networks; future forms of production; use of ICT to increase effectiveness
- Technology: ICT
- Level of digitalisation and automation: Knowledge diffusion and use.

Approach

Business-oriented research education and long-term competence building in Norwegian research environments, within topics that are of major importance for the development of business in Norway.

Budget

Manufacturing Network 4.0 is funded with NOK 20 million (~EUR 2 million) from The Research Council of Norway and NOK 5.6 million (EUR 570,000) from companies.

Governance

Actors involved: Research institutes and manufacturing companies.

References

Iris Group (2015). *Digitalisation and automation in the Nordic manufacturing sector. Status, potentials and barriers*. Nordic Council of Ministers.
Panorama (2017). Livet i Dødens dal.

Industry Transformation Programme – Singapore

Summary

The Industry Transformation (IT) Programme launched in 2016 integrates different restructuring efforts, taking a targeted and industry-focused approach to address issues, and deepen partnerships between government, firms, industries, trade associations and chambers. The IT Programme involves three strategy levels: transformation of enterprises, transformation of industries and transformation through innovation. Under the IT programme, there are Industry Transformation Maps (ITMs) developed for 23 industries under 6 clusters, covering over 80% of Singapore GDP.

		Minor emphasis	Some emphasis	Primary emphasis
FOCUS OF THE PROGRAMME	**Knowledge generation** (basic and applied R&D)	○	●	○
	Knowledge diffusion (linkages & institutions)	○	○	●
	Knowledge use (firm capability)	○	○	●
POLICY DELIVERY MECHANISMS	**Funding agency**	○	○	○
	RTO / Technology Centre / Institution	○	●	○
	R&D Institution	○	○	○
	Cluster organisation	○	○	○
	Education / training institution	○	●	○
	Industry associations / trade unions	○	●	○
	Industry/Economy government entity	○	○	●

Mission

Create new value and drive growth in four ways:

- Integrating different restructuring efforts
- A more targeted and sector-focused approach to better meet the needs of firms in each sector
- Deepen partnerships between government and the industry, and among industry players to identify challenges, and develop solutions to support transformation
- A stronger emphasis on technology adoption and innovation

Focus

- Sectors / research fields: Manufacturing; Built Environment; Trade and Connectivity; Essential Domestic Services; Professional Services and Lifestyle
- Level of digitalisation and automation: Knowledge generation, diffusion and use

Approach

Transforming enterprises:

- Business Grants Portal. Portal organised along core business needs of capability building, training and international expansion
- Automation Support Package (grant scheme)
- Financing and tax incentives to support scale-ups
- Support for internationalisation (Advice and funding).

Transforming Industries:

- National Trade Platform. It will enable electronic data sharing among businesses and government.
- Leveraging new technologies, such as robotics.
- Increasing outreach through trade associations and chambers.

Transforming through Innovation

- Additional investment in innovation and R&D funds.
- Allow businesses the flexibility to write down the cost of acquiring IP over different periods of 5, 10 or 15 years (instead of the current 5 years only).
- SG-Innovate. Network support that will match entrepreneurs with mentors, introduce them to venture capital firms, help them to access talent in research institutes, and open up new markets. SG-Innovate will build on what has been done by the Infocomm Investments Private Limited (IIPL), and work with SPRING and EDB to expand the accelerator programmes to new and emerging sectors, such as Smart Energy, Digital Manufacturing, Fintech, Digital Health, and Internet-of-Things.
- The Jurong Innovation District.
- Industry Transformation Roadmaps (ITMs). The Future Economy Council (FEC) will take overall responsibility for the implementation of the ITMs. To do so the FEC has 6 sub-committees, with each sub-committee overseeing a group of ITMs within the same broad cluster of industries.

Budget

SGD 4.5 billion (~EUR 2.8 billion) (2016).

Governance

Actors involved: Government (SPRING, Singapore Economic Development Board, Future Economy Council); industry associations; education and training providers; productivity and innovation centres; and companies.

References

Ministry of Trade and Industry Singapore, MIT (2016). *Industry Transformation Maps.*

Singapore Government (2015). *Budget 2016.*

National Robotics Program – Singapore

Summary

The National Robotics Programme (NRP) is an initiative to develop and enable the adoption of robotics technologies. It is coordinated by the Agency for Science, Technology and Research in collaboration with other government organisations (Singapore EDB, Ministry of Health, National Environment Agency, Ministry of Home Affairs; Ministry of Transport; National Research Foundation) and local universities. It responds to challenges in both the demand and supply sides, such as: high opportunity costs, unattractive return on investment and lack of resources to expand operations.

		Minor emphasis	Some emphasis	Primary emphasis
FOCUS OF THE PROGRAMME	**Knowledge generation** (basic and applied R&D)	○	●	○
	Knowledge diffusion (linkages & institutions)	○	●	○
	Knowledge use (firm capability)	○	○	●
POLICY DELIVERY MECHANISMS	**Funding agency**	○	○	○
	RTO / Technology Centre / Institution	○	○	○
	R&D Institution	○	○	●
	Cluster organisation	○	○	○
	Education / training institution	○	○	○
	Industry associations / trade unions	○	○	○
	Industry/Economy government entity	○	●	○

Mission

'Aims to improve manufacturing productivity and develop next-generation robotics with enhanced capabilities for human-machine interaction and skill-based operations'.

Focus

- Value chain activity: Production
- Technology: Robotics
- Level of digitalisation and automation: Knowledge generation, diffusion and use

Approach

- Support for technologies adoption: offer packaged solutions to small and medium-sized enterprises (SMEs) at a reasonable cost
- Build in-house robotics capabilities among selected companies to design and support integration of solutions
- Build up delivery capacity and capabilities to support local demand for robotics solutions.

Budget

Over SGD 450 million (~EUR 283 million) to be spent during the period 2016-2018.

Governance

It is coordinated by the Agency for Science, Technology and Research in collaboration with other government organisations (EDB, NRF) and local universities.

Success cases

ABB Regional Robotics Packaging Application Hub

- Company core activity: Manufacturing of industrial robots and robot systems
- Project description: Workshop features demo units for picking, packing and palletizing processes to allow end customers, channel partners and ABB to run trials with actual products, assemble robotics systems and conduct factory acceptance tests before delivery. The hub is an innovation platform to develop novel robotics manufacturing solutions in hardware and software to benefit growing industries, such as food and beverage, pharmaceutical, consumer electronics, and solar photovoltaics.

References

Agency for Science, Technology and Research (2017). *Engineering.*

Kok Kiang (2016). *The Importance of Industry 4.0 in Singapore's Push into Advanced Manufacturing.*

Singapore EDB.

Manufacturing Innovation 3.0 – South Korea

Summary

Manufacturing Innovation 3.0. This strategy is part of the five year (2013-2017) Korean Creative Economy policy that aims to strengthen manufacturing industry through IoT, 3D printing and Big Data. The strategy plans to set up 10,000 smart factories by 2020 to facilitate convergence between software and hardware technologies.

Mission

Create new value and obtain competitiveness in manufacturing sectors by converging factory and IT to accelerate the smart factory system.

Focus

- Value chain activity: Production
- Technology: IoT, 3D printing and Big Data
- Sectors / research fields: Manufacturing
- Level of digitalisation and automation: Knowledge use.

Approach

- Subsidised consulting support on manufacturing process innovation and replacing old facilities
- The main analysis and consulting tool is the Korea Production System (KPS) developed by the Korea Productivity Center (KPC)
- The KPC also offers know-how on project performance management and management for innovation tasks
- About 75% of the fund is allocated to SMEs supplying their products to large, medium-sized, and public companies that also participated in the programme. The remaining 25% of the fund is allocated to SMEs with no linkage to contributing companies.

Budget

KRW 1 trillion (EUR 765 million)

Governance

The programme is coordinated by the Ministry of Commerce and Industry in collaboration with industry associations.

Success cases

Establishment of the Creative Economy Innovation Center:

- Samsung is providing their IT know-how to the small and medium sized enterprises (SMEs) for the improvement of the productivity and reduction of defects.
- ENA, a Korean SME, supplies automotive components to 3 major US automotive companies. However, they have been facing difficulties to grow due to the high defect rates.

		Minor emphasis	Some emphasis	Primary emphasis
FOCUS OF THE PROGRAMME	**Knowledge generation** (basic and applied R&D)	○	○	○
	Knowledge diffusion (linkages & institutions)	○	○	○
	Knowledge use (firm capability)	○	○	●
POLICY DELIVERY MECHANISMS	**Funding agency**	○	○	○
	RTO / Technology Centre / Institution	○	○	○
	R&D Institution	○	○	○
	Cluster organisation	○	○	○
	Education / training institution	○	●	○
	Industry associations / trade unions	○	●	○
	Industry/Economy government entity	○	○	●

In order to solve this problem, Samsung Electronics formed a task force team in the ENA Industry to improve the productivity and environment of working conditions. They have managed to reduce the defect rate from 12% to 1.8%.

References

Eun Ha (2015). *Smart Industry in Korea.* Rijksdienst voor Ondernemend Nederland.

Kallio, J. (2016). *Digital Disruption of Industry: case Korea. Digital Disruption of Industry.* Disruption Brief No. 6. Korea Productivity Center International Cooperation - Sang Yong Han (2014). *Industry Innovation 3.0.* APO News. July – August 2014.

Connected Industry 4.0 – Spain

Summary

Connected Industry 4.0 is an initiative launched by the Spanish Ministry of Industry and Competitiveness, aiming to increase industrial added value and skilled employment; develop the local supply of digital differential solutions; develop competitive levers to favour the Spanish industry and to boost Spanish exports. The programme focus is enterprises with industrial activity, in particular SMEs and micro-enterprises. Industry 4.0 is complemented by two broader policies: the Digital Agenda and the Agenda for the Strengthening of the Industrial Sector.

		Minor emphasis	Some emphasis	Primary emphasis
FOCUS OF THE PROGRAMME	**Knowledge generation** (basic and applied R&D)	○	●	○
	Knowledge diffusion (linkages & institutions)	○	●	○
	Knowledge use (firm capability)	○	○	●
POLICY DELIVERY MECHANISMS	**Funding agency**	○	○	○
	RTO / Technology Centre / Institution	○	○	○
	R&D Institution	○	○	○
	Cluster organisation	○	○	○
	Education / training institution	○	○	○
	Industry associations / trade unions	○	○	○
	Industry/Economy government entity	○	○	●

Mission

'Support the digital transformation of the Spanish industry through public and private joint efforts'.

Focus

- Value chain activity: Production
- Technology: Digital enablers
- Sectors / research fields: Manufacturing
- Level of digitalisation and automation: Knowledge generation, diffusion and use
- Company size: SMEs and micro-enterprises.

Approach

Key strategies:

- Development of knowledge and competences 4.0
- Multidisciplinary collaboration
- Development of digital enablers supply
- Promote the development of Industry 4.0

Connected Industry 4.0 also involves two digital diagnostic tools:

- HADA (Advanced Digital Self-diagnosis Tool). On-line tool for assessing the digital level of the companies
- ACTIVA INDUSTRIA 4.0. Personal and specialised consulting services on digital enablers.

Budget

EUR 97.5 million for project calls in 2016; EUR 78 million from additional related programmes.

Governance

- Public-private partnership
- Companies involved: Indra (technological solutions), Santander (financing) and Telefónica (telecommunications)
- Connected Industry 4.0 is managed by the Ministry of Industry and Competitiveness
- Funding: loan and direct aid based system to ensure participation of the private sector

Success cases

ASTI. Founded in 1982, the core activity of this company is automated driving systems. Type of support from Connected Industry 4.0: Diagnosis. Opportunity areas identified:

- Improvement of data analysis within the value chain context.
- Cybersecurity.
- Human development.

References

Escuela de Organización Industrial (2017). *Programa Activa Industria 4.0.*

Klitou et al. (2017). *Key lessons from national industry 4.0 policy initiatives in Europe*. European Commission. Digital Transformation Monitor.

Ministerio de Economía, Industria y Competitividad. *Industria Conectada 4.0*.

Ministerio de Economía, Industria y Competitividad (2017). Anuncios. Boletín Oficial de Estado, p. 62836, No. 215.

Process IT Innovations – Sweden

Summary

Process IT Innovations is a business accelerator for industrial IT and an innovation hub for the regional innovation and growth system; established as a research centre at Luleå University of Technology and Umeå University, Northern Sweden. The region faces a number of developmental challenges (e.g. emigration) and is dominated by traditional businesses within the primary sectors (forestry, mining etc.). However, the region also features an emerging ICT cluster around Luleå and Umeå. For example, Luleå is the location of Facebook's Nordic data centre. The strategic concept of ProcessIT Innovations is to bring together the functional process and engineering industry in the region with ICT services in universities and industry. Process IT's vision is to establish a leading European R&D centre in ICT for primary industry.

		Minor emphasis	Some emphasis	Primary emphasis
FOCUS OF THE PROGRAMME	**Knowledge generation** (basic and applied R&D)	○	○	○
	Knowledge diffusion (linkages & institutions)	○	○	●
	Knowledge use (firm capability)	○	○	●
POLICY DELIVERY MECHANISMS	**Funding agency**	○	○	●
	RTO / Technology Centre / Institution	○	○	○
	R&D Institution	○	●	○
	Cluster organisation	○	○	○
	Education / training institution	○	○	○
	Industry associations / trade unions	○	●	○
	Industry/Economy government entity	○	○	○

Mission

'Reinforce existing primary industries and develop the region's ICT-industry to an internationally competitive position'.

Focus

- Value chain activity: Production
- Technology: ICT
- Sectors / research fields: Manufacturing with an emphasis on the primary sector
- Level of digitalisation and automation: Knowledge diffusion and use

Approach

- Bringing researchers and ICT companies together with manufacturing industries and their suppliers
- Identify concrete solutions to challenges regarding digitalisation and automation in manufacturing and in primary sectors.

Budget

Process IT Innovation has a combined budget, including industrial co-funding, of approximately SEK 65 million (~EUR 6.5 million) in 2016.

Governance

- Actors involved: VINNOVA, universities, regional industry, ICT companies, four coastal municipalities and the county administrative boards of Västerbotten and Norrbotten
- Organisation: The board of directors at ProcessIT Innovations includes representatives from the process and engineering industries, international suppliers to industry, ICT companies, the universities of Luleå and Umeå and the county administrative board.
- Funding: VINNOVA, the Swedish Innovation Agency funds this initiative.

Success cases

Arrowhead:

- Aim: This project aims to bring about autonomous collaborative automation systems. This has been dealt with by resolving the interoperability and integrability of IoT to build IoT/SoS automation systems.
- Results: Industrial partners have assessed and verified Arrowhead Framework in 26 commercially based demonstrators. 15 companies already have products on the market that contain results of Arrowhead. Four start-up companies have been created.
- Partners: SKF, LKAB, Boliden, BnearIT, Abelko, Noda, EISTEC, LTU and 70 partners from 15 countries. Project manager Jerker Delsing, Luleå University of Technology.

Impact indicators

Results in 2016:

- 46 new prototypes.
- 4 new companies.
- 26 new products.
- 14 new processes.
- 2 new patents.

References

Iris Group (2015). *Digitalisation and automation in the Nordic manufacturing sector. Status, potentials and barriers*. Nordic Council of Ministers.
Process IT Innovations (2017). *Annual report 2016.*

Produktion2030 – Sweden

Summary

Produktion2030 is an open innovation programme where the project consortia, consisting of researchers and companies, can apply for funding of research and development projects lasting up to a maximum of five months. The program particularly targets innovative SMEs within manufacturing. The projects can apply for a maximum of SEK 500,000, and government support must not exceed 67 per cent of the project's total budget. Projects with particular high potential have the opportunity to apply for additional funding. The fund calls for proposals once-twice a year.

		Minor emphasis	Some emphasis	Primary emphasis
FOCUS OF THE PROGRAMME	**Knowledge generation** (basic and applied R&D)	○	○	●
	Knowledge diffusion (linkages & institutions)	○	○	●
	Knowledge use (firm capability)	○	●	○
POLICY DELIVERY MECHANISMS	**Funding agency**	○	○	●
	RTO / Technology Centre / Institution	○	●	○
	R&D Institution	○	●	○
	Cluster organisation	○	○	○
	Education / training institution	○	○	○
	Industry associations / trade unions	○	●	○
	Industry/Economy government entity	○	○	○

Mission

'Translate industry challenges to relevant and innovative solutions for the industry; build and strengthen networks and cooperation, both in Sweden and internationally; and link ideas, actors and funding opportunities to create valuable solutions for the future manufacturing industry'.

Focus

- Value chain activity: production
- Sectors / research fields: resource-efficient production; flexible manufacturing processes; virtual production development; human-centred production systems; circular production systems and maintenance; integrated product and production development
- Level of digitalisation and automation: Knowledge generation, diffusion and use.

Approach

Produktion20130 involves five instruments:

- Calls for projects on:
  - Research and innovation. Co-financing from companies must amount to at least 50%.
- Test and demonstration. These projects should result in a high level of technology maturity. The industrial co-financing should therefore be high, at least 60%.
- Workshops, seminars, dissemination of results and tests of new technical solutions for SMEs.
- Education. A national PhD School in production is organised since 2014.
- Mobility:
  - Personal exchange projects. People can rotate from industry to academia or research institutes, or from academia/research institutes to industry.
  - Study visits. For groups within industry, academia and institutes. The aim of these visits is to give the participants knowledge and insight in ongoing investments.
- International networking and business intelligence.

Budget

The most recent call (08/Sep/2017) considers a budget of SEK 10 million (~EUR 1 million).

Governance

- Actors involved: Innovation Agency VINNOVA, the Swedish Energy Agency, the Research Council Formas, Association of Swedish Engineering Industries, The Swedish Production Academy and the Swedish research institutes.
- Organisation: Technology companies manage Produktion2030 through a programme office. Production2030 has appointed a Research and Innovation Council with representatives from industry, academy and institutes of technology.
- Financing: Public funding and co- financing from industry - typically required to finance around 50% of project costs in research projects.

Success cases

3D SILVER - Decision support based on layout visualisation and ergonomics simulation. This project provides decision makers in manufacturing industries with better virtual layout planning, ergonomics and workplace design tools. Researchers in this project have previously created a simulation program that connects ergonomics with advanced mathematical modelling to analyse and create a better working environment.

Impact indicators

- 30 projects funded.
- Over 150 businesses involved.
- 50% industry co-financing.

References

Iris Group (2015). *Digitalisation and automation in the Nordic manufacturing sector. Status, potentials and barriers*. Nordic Council of Ministers

STREAM – Sweden

Summary

This initiative 'Innovations for Sustainable, Smart, and Efficient Automation' (STREAM) emerged in 2012 with the aim to create new and competitive solutions within automation through collaborative projects with the participation of industrial companies. Researchers have worked in collaboration with the industry in developing automation solutions. These were created through integration and further development of current technologies for automated condition monitoring, diagnosis, planning and optimisation in existing systems. STREAM covers the period 2012–2017. This project is funded by VINNOVA, the Swedish Innovation Agency that funds this initiative.

		Minor emphasis	Some emphasis	Primary emphasis
FOCUS OF THE PROGRAMME	**Knowledge generation** (basic and applied R&D)	○	●	○
	Knowledge diffusion (linkages & institutions)	○	○	●
	Knowledge use (firm capability)	○	○	○
POLICY DELIVERY MECHANISMS	**Funding agency**	○	○	●
	RTO / Technology Centre / Institution	○	○	○
	R&D Institution	○	●	○
	Cluster organisation	○	○	○
	Education / training institution	○	○	○
	Industry associations / trade unions	○	●	○
	Industry/Economy government entity	○	○	○

Mission

'The innovations in the STREAM project contribute to increased competitiveness through technical solutions that are translated into new products and services'.

Focus

- Value chain activity: Research, development and design
- Technology: automation, data analytics
- Sectors / research fields: Manufacturing
- Level of digitalisation and automation: Knowledge generation and diffusion.

Approach

- Researchers from SICS (the Swedish ICT organisation working on areas such as big data analytics, automation, security, and internet-of-things) in collaboration with the industry, have created new and competitive automation solutions based on advanced IT and customised business models. The automation solutions were created through integration and further development of current technologies for automated condition monitoring, diagnosis, planning and optimisation in existing systems.
- The new products and services are generic, meaning that they can be used in several industries and will be available to stakeholders outside the project.
- The results from the case studies build the so-called toolbox, which consists of tools and algorithms that, with some adjustment, can be used in other production environments.

Governance

- Actors involved: Research centres, universities and companies (SICS, Mälardalen University, ABB - the mining business unit, Addiva, Atlas Copco, Blue Institute, Bombardier, Eduro, Mälarenergi, Prevas, Trafikverket and Volvo CE).
- Funding: VINNOVA, the Swedish Innovation Agency funds this initiative.

Budget

VINNOVA has supported the project with SEK 20.5 million.

Success cases

Smarter ways to drive trains. Given parameters like scheduling, track profile, load or traffic lights along the way it can be energetically advantageous to pull up or slow down at different times. The results from STREAM will be used to produce energy optimal motion profiles for drivers as well as for automatic control systems. This knowledge will also increase the possibility of replacing diesel trains with battery-operated trains on non-electrified sections of track. Companies involved: Bombardier and Addiva.

References

Iris Group (2015). *Digitalisation and automation in the Nordic manufacturing sector. Status, potentials and barriers*. Nordic Council of Ministers.
RISE SICS. STREAM.

Taiwan Productivity 4.0 – Taiwan

Summary

Taiwan Productivity 4.0 is a policy for developing smart manufacturing via three connections: connecting to the local (fully utilising the resources in Taiwan), connecting to the future (adding value to products, especially new technologies), and connecting to the world (cooperating with other countries and introducing foreign professionals to Taiwan). The aim of this policy is to raise the GDP per capita of manufacturing industry to NTD10 million in 2024.

Mission

Increase manufacturing productivity through the optimisation of the smart supply chain eco-system of 5 leading industries: electronics and information, metal transportation, machine tools, food, and textile.

Focus

- Value chain activity: production
- Technology: precision machinery and ICT technologies (IoT, Big Data, lean management, robotics, CPS, 3D printing and sensors)
- Sectors / research fields: electronics and information, metal transportation, machine tools, food, and textile
- Level of digitalisation and automation: Knowledge use.

Approach

- International cooperation reinforcement (particular focus on Germany), e.g. the 2016 Taiwan-Germany Productivity/Industry 4.0 Forum.
- Technological capability enhancement.
    - Introducing Industry 4.0 and experienced experts to help Taiwan's companies, in particular SMEs, adopt Productivity 4.0 and corresponding solutions or platforms for higher productivity.
    - Revision of relevant courses in the formal education system.
    - Integration of the industrial–academic-institute system.
    - Reactivate the A-Team model (a former model for industry wide, connected entrepreneurship).
- New venture incubation and technology localisation-manufacturing.

Budget

TWD 45 billion (~EUR 1.2 billion) (2016-2014).

		Minor emphasis	Some emphasis	Primary emphasis
FOCUS OF THE PROGRAMME	**Knowledge generation** (basic and applied R&D)	○	○	○
	Knowledge diffusion (linkages & institutions)	○	○	○
	Knowledge use (firm capability)	○	○	●
POLICY DELIVERY MECHANISMS	**Funding agency**	○	○	○
	RTO / Technology Centre / Institution	○	○	○
	R&D Institution	○	○	○
	Cluster organisation	○	○	○
	Education / training institution	○	○	○
	Industry associations / trade unions	○	○	○
	Industry/Economy government entity	○	○	●

Governance

This policy is coordinated by the Industrial Development Bureau under the Ministry of Economic Affairs, R.O.C.

Success cases

Siemens-Productivity 4.0 Promotion Office Cooperation:

- Introduction of Siemens' aerospace controller and driver technologies, as well as value-added machine tools.
- CPS training courses to cultivate talent on site or in Taiwan.

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