Industry 4.0 and the Future of UK Space Manufacturing

Final Report

LE London Economics

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Executive Summary

London Economics was commissioned by Innovate UK, the UK's Innovation Agency, to undertake a study to explore the future opportunities and challenges around adoption of Industry 4.0 technologies in the UK Space Manufacturing sector. In particular, the study sought to explore the following questions:

- What Industry 4.0 technologies are relevant to UK Space Manufacturing?
- How can Industry 4.0 meet current and future challenges of the UK Space Manufacturing segment in particular, and the wider UK space industry more generally?
- What are the benefits that these technologies could bring to the sector, relative to the current way of 'doing business'?
- What are the barriers and opportunities and what needs to happen to overcome these?
- What are the potential economic benefits of adoption of Industry 4.0 technologies in UK Space Manufacturing?

For the purpose of this study, a working definition of **Industry 4.0**, based on the 2017 Made Smarter review, was adopted (presented in Box 1, below).

Box 1 Definition: Industry 4.0

Industry 4.0 refers to the next big industrial revolution, making use of digital technologies in manufacturing supply chains to enhance performance and productivity. It is the integration of digital and physical technologies, and the operation of digital technologies together (in concert). This has the potential to generate new business forms, increase speed to market, integrate and strengthen supply chains, production of customised products and generate significant productivity gains.

Source: London Economics; based on Made Smarter Review: Industrial Digitalisation 2017

The UK Space Manufacturing segment is comparatively small. The segment accounts for approximately 8% of total UK space industry income and 0.5% of the global space economy based on 2014/15 income data[1].

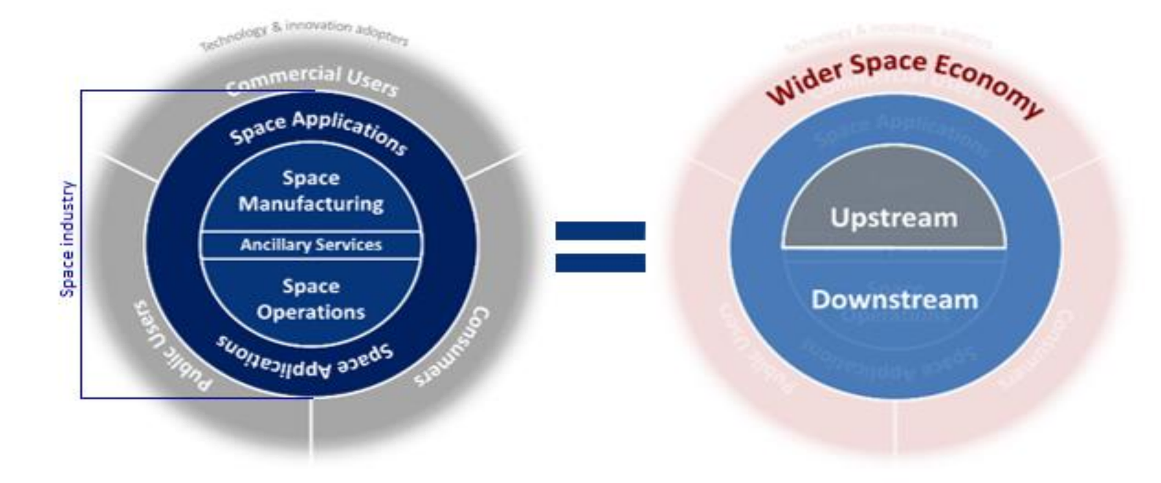
Despite this comparatively small size, wider adoption of Industry 4.0 in UK Space Manufacturing has the potential to deliver significant benefits to the UK space industry. This is because, in addition to the benefits to the UK Space Manufacturing segment itself, wider adoption of Industry 4.0 in UK Space Manufacturing is also expected to be associated with further benefits to the Space Economy as a whole.

[1] Size and Health of the UK Space Industry 2016, a report for the UK Space Agency by London Economics https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/575769/Size_and_Health_summary_report_2016.pdf and The Space Foundation (2016) *The Space Report 2016*. Overview of the report is freely available online at: http://www.spacefoundation.org/sites/default/files/downloads/The_Space_Report_2016_OVERVIEW.pdf

Box 2 Definition: The UK space economy

The UK Space Economy can be classified into upstream and downstream segments. The **upstream segment** covers activities related to sending spacecraft and satellites into space, including the manufacturing of launch vehicles or satellites (**Space Manufacturing**), while the **downstream segment** covers activities utilising space data to offer products or services (**Space Applications**) as well as ground segment operations (**Space Operations**).

Figure 1 Segmentation of the Space Economy



Note: Detailed mapping:

Upstream = **Space Manufacturing + Ancillary Services (partial)**
Downstream = **Space Operations + Space Applications + Ancillary Services (partial)**
Wider Space Economy = **Users + Non-Users (technology & innovation adopters)**

Source: London Economics

In this study we make a distinction between traditional Space Manufacturing undertaken on earth (**terrestrial Space Manufacturing**) and **in-orbit, or non-terrestrial, Space Manufacturing**. The study focuses on terrestrial Space Manufacturing.

Source: London Economics

For example, an increase in volumes in the manufacture of satellites or launch vehicles and a decrease in the time-to-space, supported by Industry 4.0 technologies, could form the basis of meeting an increased demand for space data or other services, thus opening up a range of new space applications. Similarly, increased provision of space data may foster an increased demand for end-user equipment such as flat-panel antennas. Conversely, cheaper end-user equipment may foster an increased demand for space data or other services, and thus lead to further adoption of Industry 4.0 technologies.

If the UK Space Manufacturing sector does not adopt Industry 4.0 technology, this could place the UK at a disadvantage relative to other countries that do adopt. In the medium term, this may result in a contraction of the UK Space Manufacturing sector. However, whether such a contraction will occur, and, if it does, how sizable this contraction may be is very difficult to predict. Any contraction would also be influenced by factors in addition to failure to adopt Industry 4.0.

In addition to Space Manufacturing, this study also sought to quantify economic benefits of adoption of Industry 4.0 technologies in the manufacture of ground segment equipment, such as antennas.

Unfortunately, time series data for the UK space industry was not available at this granular level. Therefore, explicit modelling of the impact on ground segment equipment was not possible. Despite these complications, this study captures the impact on the ground segment in the following way:

- Manufacture of ground-segment systems and equipment, such as larger antennas, are included in the Space Manufacturing segment (see Figure 7). As such the impact of adoption of Industry 4.0 technologies in this segment is captured.
- Manufacture of end-user terminals, such as VSATs, flat panel antennas, or receiving technologies in mobile phones, is captured in "User equipment supply", part of the Space Applications segment. As such this study captures associated downstream benefits to this segment.

Industry 4.0 technologies for Space Manufacturing

The study focused on the three overarching themes: robotics, automation, and digitalisation. In keeping with the definition of the 2017 Made Smarter Review, these are referred to collectively as digitalisation technologies throughout this study. A number of **key digitalisation concepts and technologies** were identified as part of this study, these are:

- Smart Manufacturing and The Smart Factory
- Additive manufacturing / 3D printing
- Artificial Intelligence and Machine Learning
- Augmented and Virtual Reality
- (Big) Data Analytics, Simulations and Digital Twins
- Smart Sensors and The Internet of Things
- Intelligent Robots and Cobots

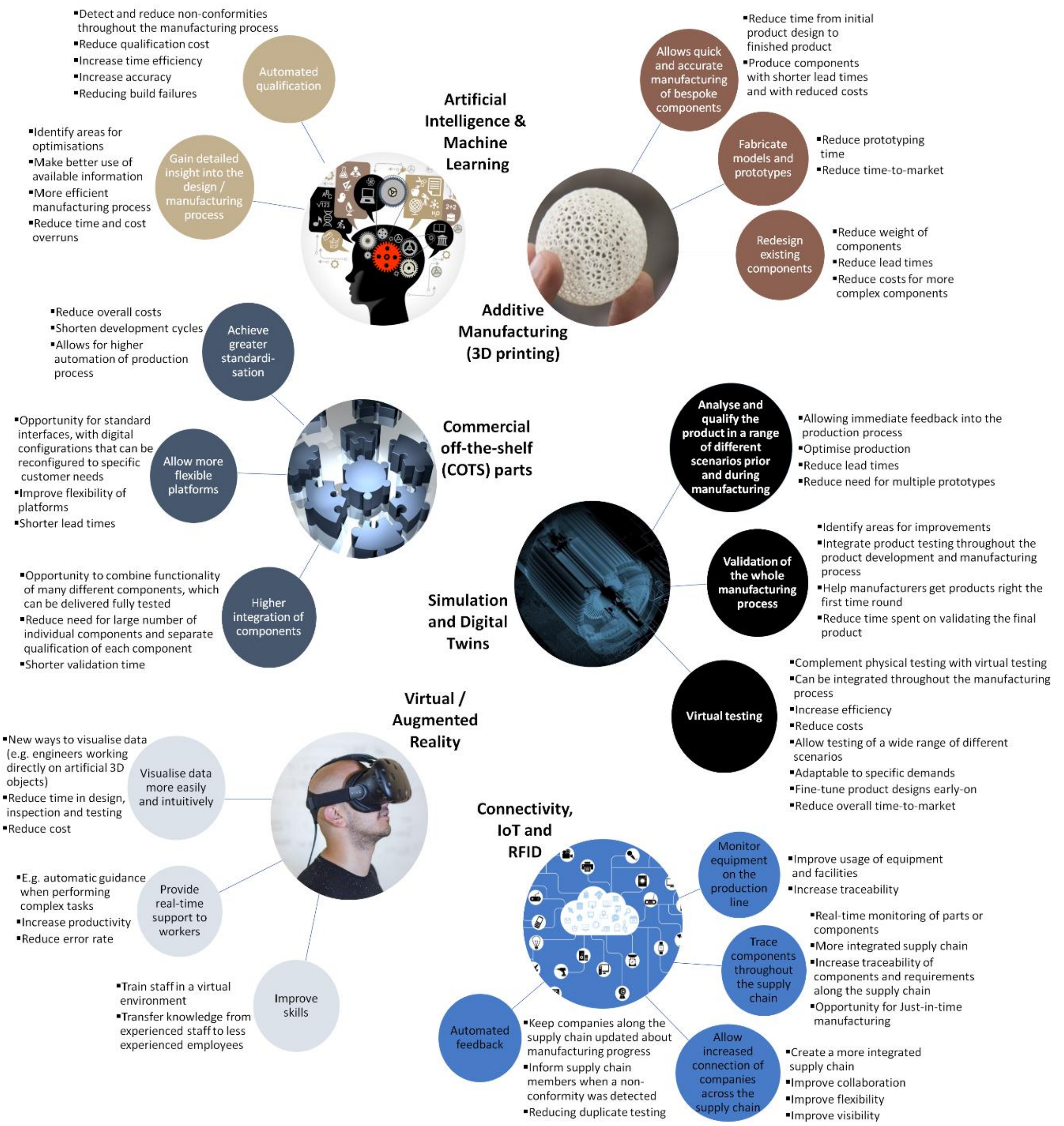
Each of these concepts and technologies is explored further in Section 4. It should be noted that the above is by no means an exhaustive list of digitalisation technologies. Indeed, technologies constituting Industry 4.0 are expected to change and evolve, as further advances in key research fields are made.

Opportunities for Industry 4.0 technologies in Space Manufacturing

Consultations with industry experts undertaken as part of this study, identified a range of **opportunities** for the use of digitalisation technologies in the Space Manufacturing sector. These opportunities are grouped into key themes around **high volumes**, **shorter lifetime** and **lower costs**, **modular and scalable design**, **optimisation of product development and manufacturing processes**, and **integrated supply chains**.

The opportunities that Industry 4.0 technologies could bring to the UK Space Manufacturing sector are explored in Section 9. Here, an overview of the opportunities specific technologies could bring to the UK Space Manufacturing sector is presented (Figure 2).

Figure 2 Potential benefits of Industry 4.0 for the Space Manufacturing sector, by technology



Note: Pictures obtained from:

- Artificial Intelligence & Machine Learning: Shutterstock – graphic by VLADGRIN accessed from https://www.shutterstock.com/image-vector/concept-education-children-generation-knowledge-103580057 [accessed 17/01/2018]
- Additive Manufacturing (3D printing): pixaby – graphic by metalurgiamontemar0 accessed from: https://pixabay.com/en/ball-3d-printing-design-597523/ [accessed 17/01/2018]
- Commercial off-the-shelf (COTS) parts: pixaby – graphic by PIRO4D accessed from https://pixabay.com/en/puzzle-kreispuzzel-platform-1713170/ [accessed 19/01/2018]
- Simulation and Digital Twins: pixaby – graphic by PIRO4D accessed from https://pixabay.com/en/motor-section-detail-copper-runner-2323189/ [accessed 19/01/2018]
- Virtual / Augmented reality: pixaby – graphic by StockSnap accessed from https://www.shutterstock.com/image-vector/concept-education-children-generation-knowledge-103580057 [accessed 17/01/2018]
- Connectivity, IoT and RFID: pixabay – graphic by jeferrb accessed from https://pixabay.com/en/network-iot-internet-of-things-782707/ [accessed 18/01/2018]

Source: London Economics; based on desk research and consultation of industry experts

Industry 4.0 economic benefits to Space Manufacturing

The **economic benefits** (see Box 3) of the adoption of Industry 4.0 in the **UK Space Manufacturing sector** were estimated using a widely used technology diffusion model, the Bass Diffusion Model. The model itself, the reasons for choosing this model, as well as a selection of recent applications are explored in detail in Annex A1.2; here a short summary of why this model was chosen is provided:

- **Wide use:** The Bass model is widely used and is backed up by a wide range of research and management applications[2].
- **Simplicity:** The Bass model is a relatively simple model, which allows estimation without the need for large amounts of data. Data available to estimate the impacts of Industry 4.0 on Space Manufacturing was found to be limited during the course of the study. While more complicated models may capture more subtleties in the innovation process, these models also require the estimation of further parameters. When data is limited, using a more complicated model adds to uncertainty in the estimations.
- **Explanatory power:** The Bass model yields a realistic adoption process that provides a good fit to the S-shaped curve[3] typical of technology adoption processes[4] and fits as well as much more complex models which are more data demanding[5].

Associated effects to the downstream segment are based on an econometric analysis of the past relationship between growth in the UK upstream and downstream segments using revenue data obtained from the 2016 Size and Health of the UK Space Industry 2016[6] (see Annex 1).

This historical relationship is likely to underestimate the future associated benefits. In particular, the rise of small satellites and large-scale constellations may provide significant market opportunities in the downstream segment. A detailed assessment of these downstream market opportunities was outside the scope of this study.

Following government guidance and best practice on evaluations[7], the economic benefits were estimated relative to a **business-as-usual baseline scenario.** The assumption underlying this baseline is that the UK Space Manufacturing sector continues to grow in the same way as past upstream growth trends. While actual Space Manufacturing growth is likely to differ from past trend in practice, this baseline provides a useful counterfactual which allows estimation of benefits relative to what may have happened in the absence of adoption.

As stated previously, it is possible that failure to adopt Industry 4.0 may in fact result in a contraction of the UK Space Manufacturing sector in the medium term. In order to capture this scenario we also estimate the economic benefits relative to a **no growth baseline scenario**. This scenario assumes that there is no further growth in UK Space Manufacturing (i.e. no further innovations, no large-constellations, etc). Estimated benefits for this scenario are presented in Section 7.2.3.

[2] Boyle (2010). *Some forecasts of the diffusion of e-assessment using a model*. Innovation Journal. Vol. 15:1-30

[3] Chandrasekaran and Tellis (2007). *A Critical Review of Marketing Research on Diffusion of New Products*

[4] See, for example: Golder, P. N., Mitra, G., D. (2018). *Handbook of Research on New Product Development: Edward Elgar Publishing*

[5] Golder, P. N., Mitra, G., D., (2018). *Handbook of Research on New Product Development*: Edward Elgar Publishing

[6] Size and Health of the UK Space Industry 2016, a report for the UK Space Agency by London Economics https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/575769/Size_and_Health_summary_report_2016.pdf

[7] HM Treasury (2018). *The Green Book: Central Government Guidance on Appraisal and Evaluation*

Box 3 Definition: Economic benefits

Throughout this study benefits refer to the benefits of **adoption of Industry 4.0 in terrestrial Space Manufacturing in the UK** (see Box 2 for definition). Industry 4.0 could also bring benefits for non-terrestrial Space Manufacturing, or in-orbit manufacturing - these are not covered within the scope of this study.

Economic **benefits to UK Space Manufacturing**, in this study, refer to increases in UK Space Manufacturing revenue, associated with wider adoption of Industry 4.0 in terrestrial Space Manufacturing in the UK. Revenue increases are assessed relative to a business-as-usual baseline. The business as usual baseline is a scenario in which Industry 4.0 is not adopted.

Associated downstream benefits, in this study, refer to increases in UK downstream (see Box 2 for definition) revenue, associated with adoption of Industry 4.0 in terrestrial Space Manufacturing in the UK.

In addition to the benefits presented in this report, Industry 4.0 is likely to deliver **further benefits** to the space industry through various channels, some of which are listed below. Benefits arising through these channels are outside the scope of this study, although this does not mean that they are not important or potentially sizeable.

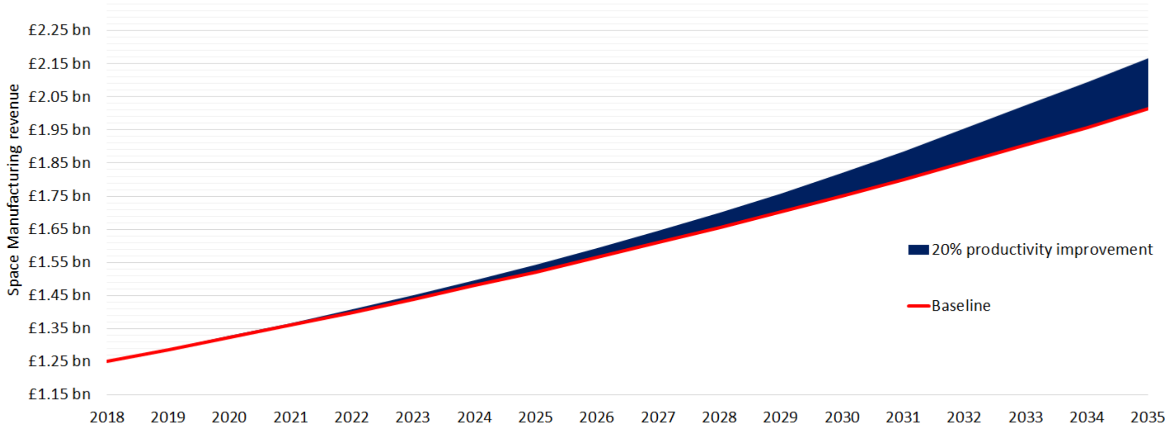
- Companies outside the UK can utilise, for example, satellites produced in the UK. Therefore, there will likely be further associated downstream effects outside the UK.
- Companies in the UK can also utilise, for example, satellites produced outside of the UK. Therefore, wider adoption of Industry 4.0 in Space Manufacturing outside of the UK will likely be associated with further downstream effects in the UK.
- Industry 4.0 technologies could also be adopted in the downstream segment, particularly in the user equipment segment (both in the UK and abroad). Adoption of Industry 4.0 technologies in the downstream segment (in addition to adoption in Space Manufacturing) would likely deliver further economic benefits to the space industry.
- Industry 4.0 technologies may also support, or in some cases enable, potential market opportunities, for example large constellations, which would likely deliver additional benefits to the space industry.
- Industry 4.0 could also bring benefits for non-terrestrial space activities, for example in-orbit manufacturing.
- While the UK already has a strong satellite manufacturing segment, the UK space industry has so far relied on foreign providers to launch satellites into Orbit. With the UK's ambitions to capture an increasing share of the launch market[8], and the first vertical launch spaceport to be built on UK soil[9], Industry 4.0 may also bring further benefits to the emerging UK launch segment.

Source: London Economics

[8] UK Space Agency (2017). *Launch UK Prospectus*.
[9] UK Government (2018). *UK Government funding for vertical launch spaceport in Sutherland*. Available at: https://www.gov.uk/government/news/uk-government-funding-for-vertical-launch-spaceport-in-sutherland

The economic benefits[10] of adoption of Industry 4.0 in the UK Space Manufacturing sector are estimated to be, approximately, **£150 million in higher revenue, annually, by 2035** (Section 7). In addition, adoption of Industry 4.0 in the UK Space Manufacturing sector is associated with further benefits to the UK downstream segment. These are estimated to be, approximately, £470 million in higher revenue, annually, by 2035.

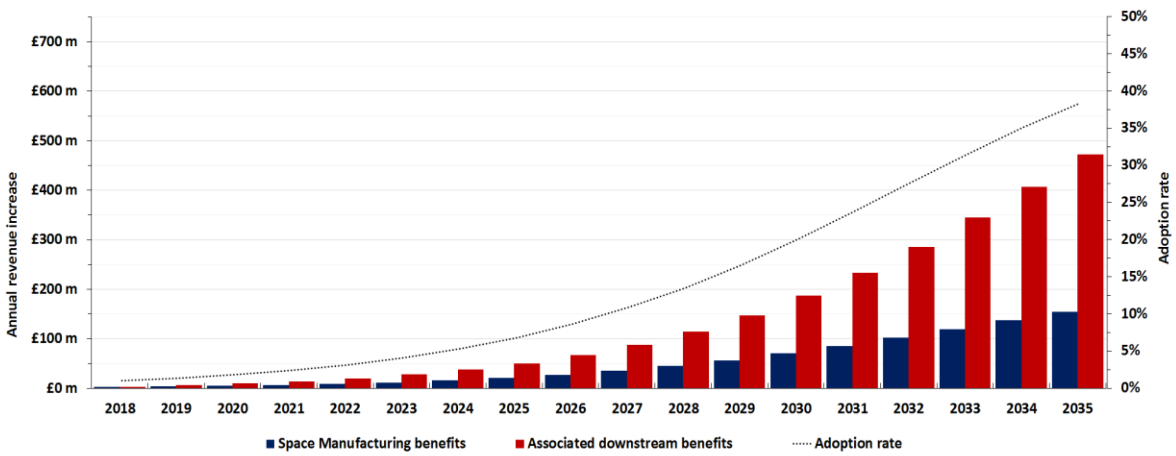
Figure 3 Estimated revenue increases, UK Space Manufacturing, relative to baseline



Note: Graph shows the estimated benefits, to the UK Space Manufacturing segment, of adoption of Industry 4.0 in terrestrial Space Manufacturing in the UK. The baseline (red line) reflects the projected Space Manufacturing revenue growth for the business-as-usual scenario; i.e. assuming that the UK Space Manufacturing sector continues to grow as indicated by past upstream trend.

Source: London Economics

Figure 4 Estimated annual revenue increases, UK Space Manufacturing and UK downstream



Note: Adoption rate refers to the estimated proportion of Space Manufacturing revenue supported by Industry 4.0 technologies. Space Manufacturing benefits refer to the benefits of adoption of Industry 4.0 in terrestrial Space Manufacturing in the UK. Associated downstream benefits refer to increases in UK downstream revenue, associated with adoption of Industry 4.0 in terrestrial Space Manufacturing in the UK. Further explanations of estimated benefits can be found in Box 3. The segmentation of the UK space industry used in this study is briefly discussed in Box 2; further details are provided in Section 2.

Source: London Economics

Over the study period (2018-2035) **cumulative benefits** to UK Space Manufacturing are estimated to be in the region of £0.9 billion in higher revenue for the UK Space Manufacturing sector. The

[10] Economic benefits reported here assume a current adoption rate of 1%, an adoption rate in 2030 of 20%, an ultimate market potential of 50% adoption, and productivity improvements of 20%. Assumptions made were based on previous experience of the UK space sector, consultations with industry experts and comparison of assumptions and the resulting adoption process with the literature (Section A1.3). Additional scenarios can be found in Section 7.2 and Annex A1.3.

majority of benefits, 78% (£0.7 billion), are estimated to accrue in the last five years of the study period (2030-2035). (See Section 7.2)

Cumulative benefits to the UK downstream segment, associated with wider adoption of Industry 4.0 in UK Space Manufacturing, are estimated to be in the region of £2.5 billion in higher revenues over the study period (2018-2035). Of these, £1.9 billion are estimated to accrue in the last five years of the study period (2030-2035).

Validation of estimated benefits

In order to validate the estimated benefits, we compared these estimates to previous studies on the impact of Industry 4.0 on UK manufacturing sectors. The estimated benefits to UK Space Manufacturing are consistent with the estimated benefits for other sectors. Benefits for UK manufacturing overall, adjusted for differences in sector size, are estimated to be approximately £0.9 billion, while benefits for aerospace and pharmaceuticals are estimated to be in the region of £0.7 billion and £1.5 billion, respectively[11]. (Table 1)

Table 1 Industry 4.0 benefits, comparison with UK manufacturing

Sector	Benefits accrued over	Benefit type	Cumulative benefits		Cumulative Space Manufacturing revenue increase, by 2035 (business-as-usual scenario)
			as reported	adjusted by sector size	
Manufacturing	10 years, by 2027	Revenue increases and cost reductions	£455.0 bn	£0.9 bn	£0.9 bn
Construction			£89.0 bn	£0.4 bn	
Food and drink			£56.0 bn	£0.6 bn	
Pharmaceuticals			£22.0 bn	£1.5 bn	
Aerospace			£18.0 bn	£0.7 bn	
Automotive	20 years, by 2035	GVA	£74.0 bn	£1.2 bn	

Note: Benefits were adjusted based on sector size using 2014/15 turnover of each sector relative to Space Manufacturing turnover. Cumulative Space Manufacturing benefits are provided for the case of 20% productivity improvements. Comparison of the low estimate for the case of 10% productivity improvements and the high estimate for the case of 30% productivity improvements are provided in Section 7.2.1.

Source: London Economics; benefits of other sectors obtained from 2017 Made Smarter Review, except for automotive, which was obtained from KPMG (2016). The Digitalisation of the UK Automotive Industry; sectoral turnover obtained from BEIS: business population estimates for the UK and regions 2015 for manufacturing, construction, food and drink, and pharmaceuticals, from ADS: Industry Facts & Figures 2016 for aerospace, from The Society of Motor Manufacturers and Traders: Motor Industry Facts 2016, and from Size and Health of the UK Space Industry 2016 for Space Manufacturing

In addition to the sectoral validation check (Table 1), we also undertook a detailed comparison of model assumptions with the literature, as well as a detailed sensitivity analysis (Section A1.6).

Applying the model to the whole UK Space sector

The main focus of this study was on the impact of Industry 4.0 on Space Manufacturing. The modelling assumptions have been built based upon literature and consultations focused on Space Manufacturing. However, in order to provide an illustration of the relative size of the estimates if the model is applied to the Space Industry as a whole, the model was run for both the upstream and downstream segments (see Annex A1.5). When this is done the benefits are in the region of £2

[11] Estimates for the period 2017-2027, obtained from the Made Smarter Review: Industrial Digitalisation 2017, adjusted for differences in relative sector size to the UK Space Manufacturing sector. See Section 7.2.1 for further details.

billion annually by 2035, and £11.7 billion over the whole study period. Much care needs to be taken in the interpretation of these estimates. As space industry characteristics differ from those of the Space Manufacturing sector, assumptions would have to be validated separately for the whole space industry. In particular, potential benefits of Industry 4.0 in non-manufacturing sectors likely differ from benefits Industry 4.0 could bring to Space Manufacturing. Therefore, estimated benefits presented here are not indicative of the potential benefits of adoption of Industry 4.0 in UK space overall (upstream + downstream). Rather, estimated benefits presented here are only illustrative of the relative size of model outputs if a different baseline (upstream + downstream) is used.

Challenges to the adoption of Industry 4.0 technologies

In order to realise these opportunities, a set of key **challenges and barriers**, were identified by industry experts (Section 8).

The industry experts identified the following challenges to wider adoption of Industry 4.0:

- Limited assistance and guidance for firms about Industry 4.0 and adoption of digitalisation technologies.
- Lack of skilled staff and access to financing.
- Lack of time to think about new technologies.
- Limited understanding of Industry 4.0 and the benefits it can bring.

Industry representatives also identified a number of risks:

- Cybersecurity threats, for example an increased risk of theft of intellectual property.
- Risk of disruption to IT infrastructure.
- Uncertainty about the impact of adoption on profitability.

In the Space Manufacturing sector, the following key sectoral characteristics were identified as additional barriers to wider adoption:

- Often low volumes, relativeto other sectors, in traditional space manufacturing
- Resistance to new technologies / materials, for some parts of the sector[12] Conservative approach to risk, for some parts of the sector
- Bespoke nature of space manufacturing
- High development costs of satellites, leading to high upfront costs to experiment with new technologies

Industry representatives also made the point that these sectoral characteristics can further create barriers to entry, preventing innovative start-ups or SMEs entering the sector.

[12] It should be noted, that there are very real economic reasons underlying the sector's conservative approach to risk and resistance to new technologies and materials such as COTS. In particular, the low volume, high cost nature of traditional space manufacturing means that component failure can have catastrophic implications: if a large satellite fails in-orbit, it is very difficult to impossible to repair or replace affected components. As such, failure could mean the loss of years of work as well as millions of pounds in manufacturing and launch costs.

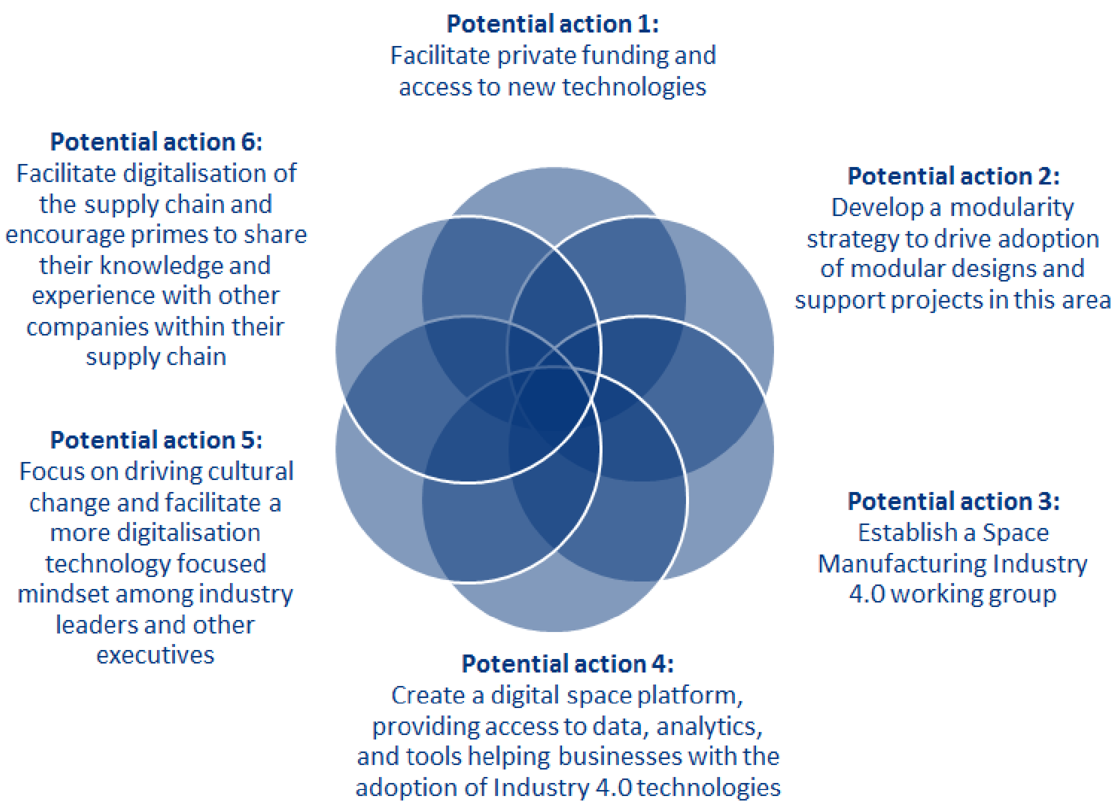
Finally, a complicated regulatory environment was also seen as a key barrier to realise identified opportunities in the Space Manufacturing sector.

It should be noted, that the identified barriers are reflections of very real economic fundamentals of the sector. In particular, the low volume, high cost nature of traditional space manufacturing means that component failure can have catastrophic implications. If a large satellite fails in-orbit, it is very difficult or impossible to repair or replace affected components. As such, failure could mean the loss of years of work as well as potentially hundreds of millions of pounds in manufacturing and launch costs. Given this, it is unsurprising, that space manufacturing firms take a cautious approach to risk.

The rise of lower cost, shorter lifetime satellites and large-constellations could thus provide a unique opportunity for overcoming these challenges and barriers. This is because the economic costs of failure are reduced significantly. If one small satellite within a constellation of, for example, 900 satellites fails, the resulting loss in capacity could be less than 1% (compared to 100% for a traditional large satellite). The economic costs of loss are also significantly reduced (thousands to hundreds-of-thousands of pounds compared to millions).

In this study, **six potential actions** to boost adoption of Industry 4.0 technologies in the Space Manufacturing sector were identified (Section 11.1). These potential actions are summarised in Figure 5 below.

Figure 5 Potential actions to boost adoption of digitalisation technologies in the Space Manufacturing sector



Source: London Economics; based on consultation of industry experts

Five further potential actions to meet the wider challenges of the Space Manufacturing sector were also identified by experts (Section 11.2):

- Encourage further development and qualification of commercial off-the-shelf (COTS) parts for the specific challenges of the space environment.
- Improve virtualisation tools to allow effective virtualisation of manufacturing integration and testing in order to be able to better replicate the real-world space environment.
- Promote a collaborative ecosystem and collate digital information from the operations of all parties so that good patterns and best practice can be identified.
- Frame a space strategy around the adoption of Industry 4.0 technologies. This strategy should aim to better market digitalisation technologies to change public perceptions; focus on developing the right skills such as data engineers, scientists and developers; create the right regulatory environment; and facilitate collaboration between large established companies and SMEs.
- Reduce time to space by reducing approval burdens and streamlining lengthy checks prior to space launches, while ensuring safety standards are met.
- Establishing a commercial launch site in the UK.

1 Introduction

Robotics and digitalisation technologies are becoming increasingly important for the UK manufacturing sector and the wider UK economy, with forecasted impacts on the UK economy of up to **£455 billion** for UK manufacturing over the next decade and delivering a net gain of **175,000** jobs.[13]

The increasing importance of advanced digital technologies is recognized by the UK Government, which, in 2017, set growing artificial intelligence (AI) and the data driven economy as one of four Grand Challenges for the UK Government and wider UK economy in the UK Industrial Strategy White Paper[14].

The UK Government aims to **put the UK at the forefront of the AI and data revolution** and embed AI across the UK in order to create jobs and drive economic growth. The Government's strategy covers four **key priorities**:

- **Make the UK a 'global centre for artificial intelligence and data-driven innovation'** by investing in AI and digitalisation technologies, providing a regulatory environment that fosters innovation, and ensuring the UK has the right talent and necessary skills.
- **Boost productivity through the use of AI and other data analytics technologies** by establishing an industry-led AI council and a government Office for AI, with the aim of improving research and innovation in, raising awareness of, stimulating demand for, and accelerating uptake of AI and other advanced digitalisation technologies across all sectors of the economy.
- **Be a world leader in the safe and ethical use of data and AI** by establishing the Centre for Data Ethics and Innovation, providing advice to the UK government on how a safe and ethical use of data can be ensured, as well as facilitating easy and secure data sharing. The UK Government further aims to reinforce the UK's position as a 'global centre for cybersecurity'.
- **Help people develop the skills needed for the jobs of the future** by investing in mathematical, digital, and technical skills education, as well as improving teaching of and participation in computer science by up-skilling computer science teachers and setting up a National Centre for Computing Education.

The UK Government has also set up the Industrial Strategy Challenge Fund with the aim to bring the research community and industry together to tackle and solve these and other major challenges. The fund will also provide funding for satellites and space technology, in particular, the fund will provide funding for a new satellite test facility, which will provide support for new launch technologies as well as manufacturing and testing capabilities for the the construction of satellites.[15]

Advanced digital technologies could also positively impact the **Space Manufacturing** sector and help the UK Government achieve its goals for the space sector, as set out in the Space Innovation and Growth Strategy 2014-30, namely, to 'grow, develop and exploit new space related opportunities'.

[13] Made Smarter Review: Industrial Digitalisation 2017
[14] HM Government (2017): Industrial Strategy White Paper
[15] Further information can be found at: https://www.gov.uk/government/collections/industrial-strategy-challenge-fund-joint-research-and-innovation. [accessed 16/03/2018]

In the 2015 update[16], the UK Government further refined these objectives and set out ten **priorities for the UK space sector**, these are:

- Developing and implementing growth roadmaps in order to address high value market opportunities for UK businesses.
- Meeting security and defence needs of the UK by increasing the use of space applications and infrastructure.
- Maximising growth of UK businesses by promoting relevant regulatory and spectrum regimes.
- Implementing the European Space Engagement Plan.
- Driving UK exports.
- Increasing investment in the National Space Growth Programme in order to access high value market opportunities.
- Encouraging SMEs and other businesses in the space sector to maximise opportunities for growth.
- Growing regional space clusters.
- Ensuring that the right skills are in place so that UK businesses are able to develop space related opportunities.
- Growing the evidence base of the economic impact of the space sector.

1.1 Objective and approach

In December 2017, Innovate UK, the UK's Innovation Agency, commissioned London Economics to undertake a study to explore the future benefits to UK Space Manufacturing of automation and Digitalisation technologies.

Space Manufacturing for the purpose of this study is defined as ground-based space manufacturing[17] activities. This includes the manufacture of satellites and spacecraft on the one hand, but also the ground segment manufacture, such as the manufacture of antennas, on the other hand.

The study comes at a time when both the cost and size of satellites have been falling substantially, bringing large cost reductions to the sector (see Section 3). Nevertheless, Space Manufacturing remains a highly bespoke and manual process, putting a downward limit on the potential future reductions.

At the same time, the rise in robotics, automation, and digitalisation technologies, known as Industry 4.0, has the potential of delivering large cost reductions and efficiency improvements across manufacturing.

This raises the question of whether, and how, UK Space Manufacturing could benefit from the vision and technological advances of Industry 4.0. In particular, this study sought to:

[16] UK Space Innovation and Growth Strategy: 2015 Update Report. Available at: http://www.ukspace.org/space-publications/space-igs/ [accessed 15/05/2018]

[17] While this study is focused on ground based manufacturing, the UK Industrial Strategy Challenge Fund also includes robotics in extreme environments including in-orbit manufacturing and debris retrieval.

- Review and identify new developments associated with Industry 4.0 and the benefits Industry 4.0 could bring to the UK economy.
- Review the current state of adoption of Industry 4.0 in the UK manufacturing sector and identify the challenges and barriers to the adoption of Industry 4.0 in UK manufacturing.
- Identify and evaluate the benefits and opportunities Industry 4.0 could bring to the UK Space Manufacturing sector as well as the challenges and barriers to adoption.
- Develop a roadmap for the future, detailing actions that could help shape and boost adoption of Industry 4.0 within the UK Space Manufacturing sector.

The study approach was multi-fold. First, a desk-based review was completed to map current Digitalisation technologies and the UK's position in terms of technology adoption across different sectors.

A series of in-depth interviews were then completed by the London Economics project team with UK and international firms operating in the Space Manufacturing sector. The depth interviews were designed to gather information on the current use of Digitalisation technologies in Space Manufacturing and the benefits derived from their adoption. Adoption barriers and drivers and what a future roadmap for the next ten years would look like were also explored.

The UK Catapult centres[18] were also engaged in the study - the Digital Catapult, the Satellite Applications Catapult, and the Manufacturing Technology Centre and Advanced Manufacturing Research Centre which are part of the High Value Manufacturing Catapult.

Two cross-sectoral workshops as well as an online survey with experts from industry and research organisations were also conducted.

1.2 Scope

Throughout this study, and in particular for the economic impact assessment, a number of important points, detailed below, regarding scope should be kept in mind.

This study focuses on the adoption of Industry 4.0 in **terrestrial Space Manufacturing in the UK**; i.e. Space Manufacturing undertaken on earth. Throughout this study, unless otherwise stated, the term Space Manufacturing will be used to refer to terrestrial Space Manufacturing in the UK. Space manufacturing covers activities related to the design and manufacture of space equipment and subsystems, including design and manufacture of: launch vehicles and systems; satellites, payloads, and spacecraft; ground segment systems and equipment; as well as related ancillary services (see Figure 7 in Section 2.1). Given this:

- Only benefits of adoption of Industry 4.0 in terrestrial Space Manufacturing in the UK are quantified. The Space Manufacturing segment accounts, based on 2014/15 income data, for approximately 8% of total UK space industry income and 0.5% of the global space economy[19].

[18] https://catapult.org.uk/

[19] Size and Health of the UK Space Industry 2016, a report for the UK Space Agency by London Economics https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/575769/Size_and_Health_summary_report_2016.pdf and The Space Foundation (2016) *The Space Report 2016*. Overview of the report is freely available online at: http://www.spacefoundation.org/sites/default/files/downloads/The_Space_Report_2016_OVERVIEW.pdf

- Industry 4.0 could also bring benefits for non-terrestrial Space Manufacturing, or in-orbit manufacturing – these are not quantified.
- While design and manufacture of launch vehicles and systems is captured in the definition of Space Manufacturing, the UK space industry has so far relied on foreign providers to launch satellites into Orbit. With the UK's ambitions to capture an increasing share of the launch market[20], and the first vertical launch spaceport to be built on UK soil[21], Industry 4.0 may also bring further benefits to the emerging UK launch segment.

In addition to the benefits to the UK Space Manufacturing segment itself, wider adoption of Industry 4.0 in UK Space Manufacturing is also expected to be associated with further benefits to the services offered by satellites.

For example, an increase in volumes in the manufacture of satellites or launch vehicles and a decrease in the time-to-space, supported by Industry 4.0 technologies, could form the basis of meeting an increased demand for space data or other services, thus opening up a range of new space applications. Similarly, increased provision of space data may foster an increased demand for end-user equipment such as flat-panel antennas. Conversely, cheaper end-user equipment may foster an increased demand for space data or other services, and thus lead to further adoption of Industry 4.0 technologies.

This study sought to also capture these associated downstream benefits. Throughout this study the term associated downstream benefits will be used to refer to benefits accruing to the UK downstream segment, associated with **adoption of Industry 4.0 in terrestrial Space Manufacturing in the UK.** The downstream segment covers activities utilising space data to offer products or services (**Space Applications**) as well as ground segment operations (**Space Operations**) - see Figure 7 in Section 2.1. Given this:

- A detailed analysis of benefits of adoption of Industry 4.0 in downstream was not carried out.[22]
- Specific market analysis on growth opportunities (including large-constellations) was not carried out as it was outside the scope of the study.
- Companies outside the UK can utilise, for example, satellites produced in the UK. Therefore, there will likely be further associated downstream effects outside the UK – these are not quantified.
- Companies in the UK can also utilise, for example, satellites produced outside of the UK. Therefore, wider adoption of Industry 4.0 in Space Manufacturing outside of the UK will likely be associated with further downstream effects in the UK – these are not quantified.

This study also sought to quantify economic benefits of adoption of Industry 4.0 technologies in the manufacture of ground segment equipment, such as antennas. Unfortunately, time series data for the UK space industry was not available at this granular level. Therefore, explicit modelling of the

[20] UK Space Agency (2017). *Launch UK Prospectus*.

[21] UK Government (2018). *UK Government funding for vertical launch spaceport in Sutherland*. Available at: https://www.gov.uk/government/news/uk-government-funding-for-vertical-launch-spaceport-in-sutherland

[22] The economic model developed for the Space Manufacturing sector was applied to the whole space industry (Annex A1.5). However, great care needs to be taken when interpreting these estimates. Estimated benefits presented in Annex A1.5 are not indicative of the potential benefits of adoption of Industry 4.0 in UK space overall (upstream + downstream). Rather, these benefits are only illustrative of the relative size of model outputs if a different baseline (upstream + downstream) is used.

impact on ground segment equipment was not possible. Despite these complications, this study captures the impact on the ground segment in the following way:

- Manufacture of ground-segment systems and equipment, such as larger antennas, are included in the Space Manufacturing segment (see Figure 7 in Section 2.1). As such the impact of adoption of Industry 4.0 technologies in this segment is covered.
- Manufacture of end-user terminals, such as VSATs, flat panel antennas, or receiving technologies in mobile phones, is captured in “User equipment supply”, part of the Space Applications segment (see Figure 7 in Section 2.1). As such this study captures associated downstream benefits to this segment.

1.3 Caveats and limitations

The research has been conducted by a team of independent professional economists with specialist knowledge of the UK Space Manufacturing sector and the wider UK space industry. Estimates of economic impacts are based on best practice and best judgement to calculate the most robust and fair estimates. The methodology used and assumptions made are described in this report in a transparent manner, with caveats noted as required. Nonetheless, the reader should bear in mind the following high-level limitations and caveats of this study throughout:

- This study estimates the impact of the adoption of Industry 4.0 technologies within the space manufacturing segment of the UK space industry *only* – both up- and down-stream segments. It does *not* include the impact of the wider adoption of such technologies across the rest of the global space industry (see previous section on scope).
- This report presents information based on publicly available information gathered via desk research, our own knowledge of the UK space industry, and information gathered through interviews and workshops with, and an online survey of industry experts. Information gathered from industry experts is presented at face-value, trusting the contact.
- Challenges, barriers, and opportunities (Section 8 and Section 9) are based on consultations and workshops with industry experts. Consultations were focused on the UK Space Manufacturing sector. Nevertheless, reported challenges, barriers, and opportunities may reflect wider phenomena of the wider UK space industry.
- Potential actions reported (Section 11) are based on suggestions from industry experts in workshops. These are therefore not recommendations of actions that should be taken, but suggestions for which actions could be taken, following further evaluation.

For the economic impact assessment, the following caveats and limitations should be noted:

- The study considered benefits of adoption relative to two baselines, a business-as-usual scenario and a no growth scenario. Baseline income for the business-as-usual scenario is based on linear extrapolation of past upstream and downstream trends, future space industry growth may differ from past trend[23]. Baseline income for the no-growth scenario is based on the assumption that UK upstream and downstream income stays constant at their 2014/15 levels. Failure of adoption of Industry 4.0 may put the UK Space Manufacturing sector at a disadvantage relative to countries that do adopt. This may result in a contraction of the UK Space Manufacturing sector. However, whether such a

[23] While actual Space Manufacturing growth is likely to differ from past trend in practice, this scenario provides a useful counterfactual which allows estimation of benefits relative to what may have happened in the absence of adoption.

contraction will occur, and, if it does, how sizable this contraction may be is very difficult to predict.

- Potential productivity improvements are based on a literature review of other sectors. Best judgment was used to select the most appropriate scenario for the Space Manufacturing sector. Selected productivity improvements were also validated via a survey with industry experts. Nevertheless, productivity benefits in Space Manufacturing may be higher or lower.
- Adoption is based on a widely used innovation diffusion model and assumptions made are based on previous experience of the UK space sector, consultations with industry experts and comparison of assumptions and the resulting adoption process with the literature. Nevertheless, actual adoption may differ.
- Associated downstream benefits are based on a statistical relationship between UK upstream and downstream sectors in the past; this relationship may not hold in the future.

2 The UK Space economy

Space is an important sector for the UK economy, directly contributing **£5.1 billion** to UK economic output (**0.27%** of UK GDP), and underpinning all nine critical infrastructures as well as supporting a broad range of other economic sectors. In 2014/15 total income of the UK space industry was **£13.7 billion**, growing at an average rate of **8.1%** per annum since 1999/00, and supporting **38,522** jobs.[24]

The space industry covers a wide range of activities and includes all organisations, which are engaged in space-related activities, including commercial businesses as well as non-commercial organisations such as universities. The Size and Health of the UK Space Industry[25] segments the UK **space industry** into the following activities:

- **Space Manufacturing**, covering activities related to the design and manufacture of space equipment and subsystems, for example satellite manufacturers;
- **Space Operations**, covering activities related to launching or operation of satellites and spacecraft, including ground segment operations and ground station networks;
- **Space Applications**, covering applications which make use of satellite signals and data to offer value-added services to end-users, for example mobile satellite communications; and,
- **Ancillary Services**, which provide support services to the space sector, for example legal or consultancy services.

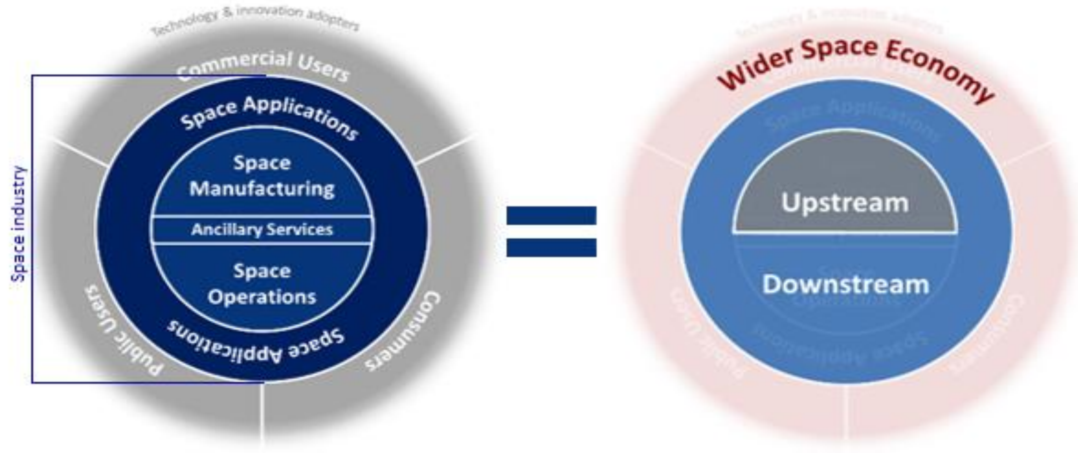
The space related activities described above can also be classified into **upstream** and **downstream** segments. The upstream segment covers activities related to sending spacecraft and satellites into space, including the manufacturing of launch vehicles or satellites, while the downstream segment covers activities utilising space data to offer products or services (space applications) as well as ground segment operations (space operations).

In addition to the space industry, **users** not directly engaged in space related activities also derive benefit from space services, for example, online map providers, weather forecasts, or disaster

[24] Size and Health of the UK Space Industry 2016, a report for the UK Space Agency by London Economics https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/575769/Size_and_Health_summary_report_2016.pdf
[25] Size and Health of the UK Space Industry 2016, a report for the UK Space Agency by London Economics https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/575769/Size_and_Health_summary_report_2016.pdf

response. Users of space services include commercial and public users as well as consumers, forming, together with the space related activities described above, the **wider space economy.**

Figure 6 Segmentation of the Space Economy



Note: Detailed mapping:

Upstream = **Space Manufacturing + Ancillary Services (partial)**
Downstream = **Space Operations + Space Applications + Ancillary Services (partial)**
Wider Space Economy = **Users + Non-Users (technology & innovation adopters)**

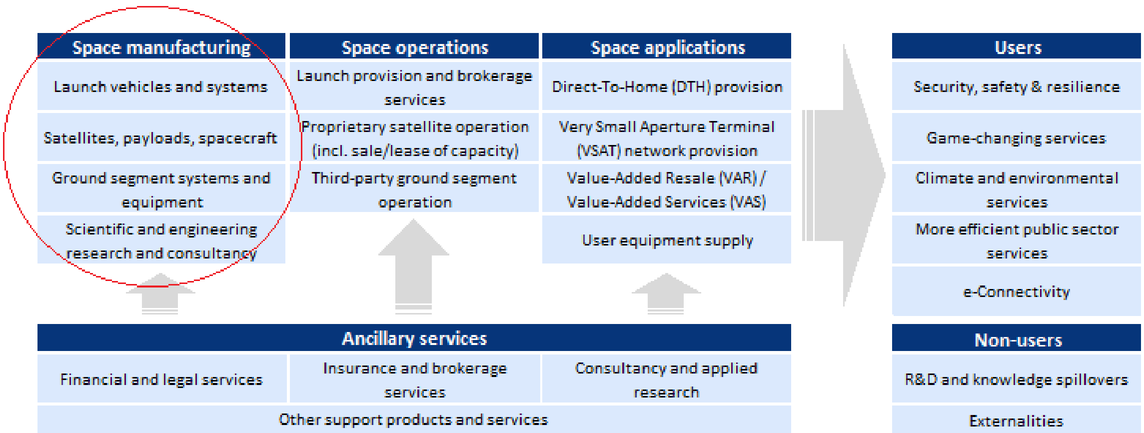
Source: London Economics

2.1 Space economy value chain

The focus of this study is the use of Digitalisation Technologies in terrestrial Space Manufacturing activities, with some consideration of the downstream segment such as antennas.

Space Manufacturing includes activities related to the manufacture of satellites and spacecraft, including subsystems, launching vehicles and systems, ground segment systems and equipment manufacturers and scientific and engineering research and consultancy services.

Figure 7 Segmentation of the space sector



Source: London Economics 2015

Manufacture of ground segment equipment, such as antennas, fits into this segmentation in the following way:

- Manufacture of ground-segment systems and equipment, such as larger antennas, are included in the Space Manufacturing segment.
- Manufacture of end-user terminals, such as VSATs, flat panel antennas, or receiving technologies in mobile phones, is captured in "User equipment supply", part of the Space Applications segment.

Space Applications is the most dominant segment with an income, in 2014/15, of around **£10.1 billion**, making up **73.7%** of total space industry income, as reported in the Size and Health of the UK Space Industry 2016[26], contributing around **£3.7 billion** (**71.6%**) to the UK economy and employing around **26,710** (**69.3%**) staff.

Space Operations is the second largest segment with an income of approximately **£2.1 billion** (**15.1%**) in 2014/15, contributing around **£0.6 billion** (**12.7%**) to the UK economy, and employing around **6,840** (**17.8%**) staff.

The third largest segment is **Space Manufacturing** with an income, in 2014/15, of around **£1.2 billion** accounting for **8.4%** of total space industry income, contributing around **£0.5 billion** (**10.1%**) to the UK economy, and employing around **3,230** (**8.4%**) staff.

Ancillary Services is the smallest space segment with an income of around **£0.4 billion** (**2.9%**) in 2014/15, a contribution of around **£0.3 billion** (**5.5%**) to the UK economy, and employing around **1,740** (**4.5%**) staff.

Table 2 UK space industry income, contribution to GVA, and # of employees by segment 2014/15

Segment	Income (£m)	Contribution to GVA (£m)	# of employees
Space Applications	10,092	3,676	26,711
Space Operations	2,066	653	6,841
Space Manufacturing	1,151	520	3,235
Ancillary Services	392	284	1,735
Total	**13,702**	**5,132**	**38,522**

Source: London Economics 2016

Within the Space Manufacturing segment, the **manufacture of satellites, payloads, spacecraft and subsystems is the largest activity** accounting for nearly half (**49.2%**) of total Space Manufacturing income. Scientific instruments, ground segment systems and equipment, and suppliers of materials and components together account, approximately, for a further one third (**36.7%**) of total Space Manufacturing income, while fundamental and applied research, scientific and engineering support, and launch vehicles and subsystem account for approximately one seventh (**14.1%**) of total Space Manufacturing income.

Table 3 Space Manufacturing income by activity 2014/15

Space Manufacturing activity	£m
Launch vehicles and subsystems	34

[26] Size and Health of the UK Space Industry 2016, a report for the UK Space Agency by London Economics https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/575769/Size_and_Health_summary_report_2016.pdf

Space Manufacturing activity	£m
Satellites/payloads/spacecraft and subsystems	566
Scientific instruments	130
Ground segment systems and equipment	170
Suppliers of materials and components	122
Scientific and engineering support	50
Fundamental and applied research	78

Source: London Economics 2016

Benefits accrued by Space Manufacturing will also have associated effects to downstream segments within the space sector, in particular to Space Applications and Ancillary Services (Ancillary Services also lie in part within the upstream activities). An analysis of these potential associated effects can be found in Section 7.

The table below presents the activities within these downstream segments and their income in 2014/15. As the table shows, in 2014/15, Direct-To-Home (DTH) broadcasting and Supply of user devices and equipment accounted for the vast majority of UK downstream income, 68% and 18% respectively.

Table 4 Space Applications and Ancillary Services income by activity 2014/15

Segment	Activity	£m
Space Applications	Direct-To-Home (DTH) broadcasting	7,127
	Fixed satellite communication services (incl. VSAT)	376
	Mobile satellite communication services	331
	Location-based signal service providers	81
	Supply of user devices and equipment	1,886
	Processors of satellite data (e.g. EO)	94
	Applications relying on embedded satellite signals/data (e.g. GPS, meteorology)	197
Ancillary Services	Launch and satellite insurance (incl. brokerage) services	57
	Legal and financial services	65
	Software and IT services	81
	Market research and consultancy services	176
	Business incubation and development	9
	Policymaking, regulation and oversight	5

Source: London Economics 2016

2.2 Comparison to global space industry

Table 5 shows the UK's share of the global space industry as measured by two leading measures of the space economy: The OECD's The Space Economy at a Glance 2014, and The Space Foundation's The Space Report 2014.

Overall, in 2012/13, the UK captured between **6.3%** and **7.7%** of the global space economy market.

Table 5 Global comparison of UK space economy, 2012/13

Segment	UK space economy 2012/13 income (£m)	% OECD world estimate	% Space Report world estimate

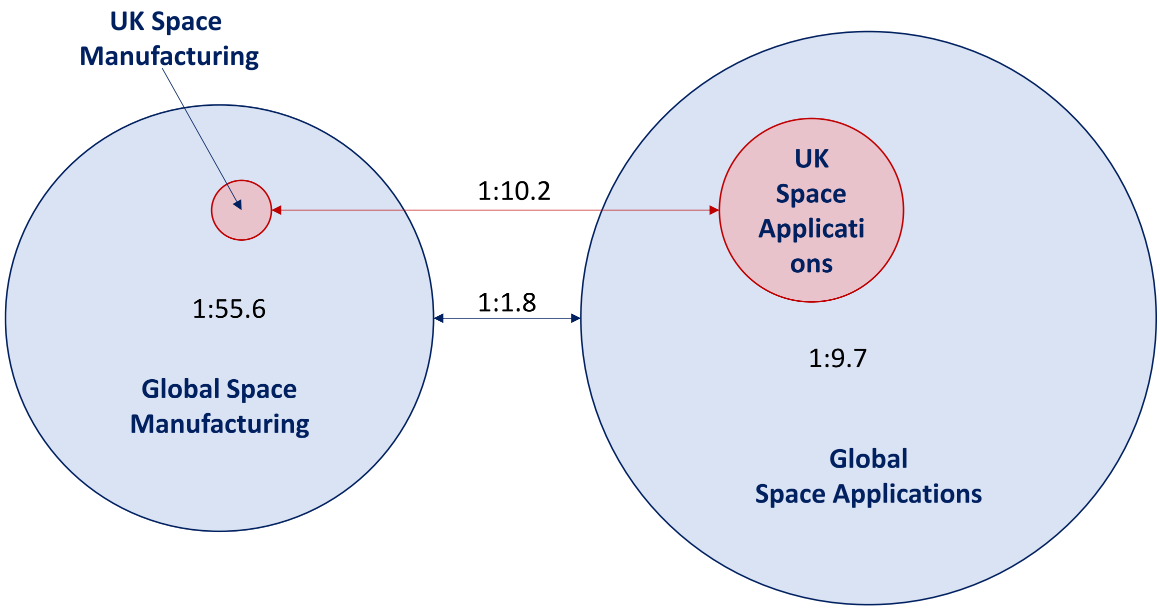
Space Manufacturing	907	1.8%	-
Space Operations	1,453	11.2%	-
Space Applications	9,253	10.3%	-
Ancillary Services	236	-	-
Total	**11,848**	**7.7%**	**6.3%**

Source: London Economics: The Case for Space 2015

Breaking the overall global market share down into shares of the segments reveals large variations. While the UK captured more than 10% of the global space economy market in both the Space Operations (11.2%) and Space Applications (10.3%) segment, UK Space Manufacturing captured a much smaller part of the global Space Manufacturing sector (1.8%).

Figure 8, puts the sizes of the UK Space Manufacturing and UK Space Applications sectors into perspective to each other, as well as their global counterparts.

Figure 8 Comparison UK Space Manufacturing and Applications, 2012/13



Source: London Economics, OECD's The Space Economy at a Glance 2014

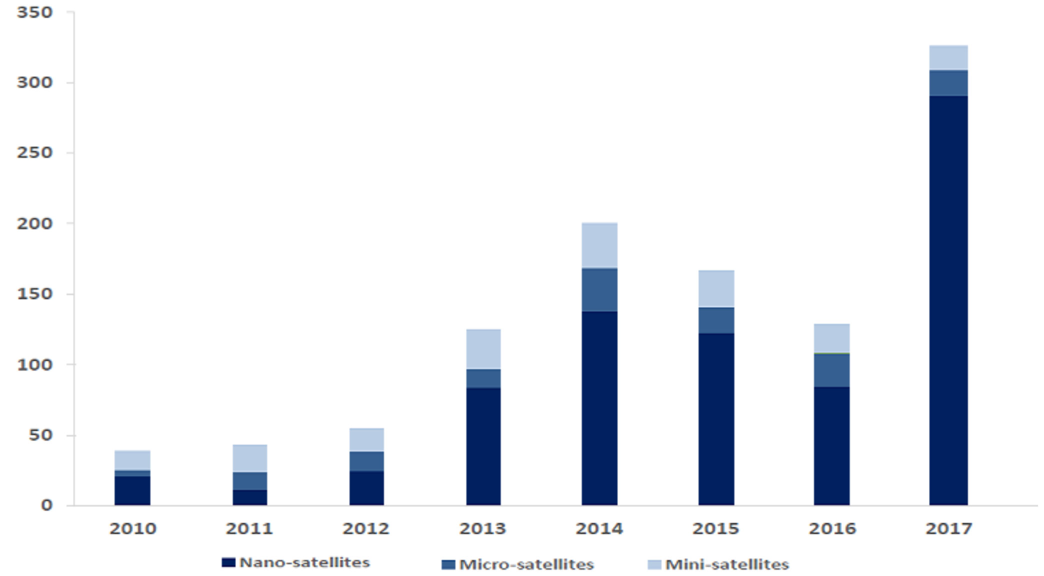
3 Trends in the space sector

This section provides an overview of important trends in the space sector, identified via desk research and consultations with industry experts; in summary:

- Decreasing size, weight and operational life of satellites
- Decreasing costs of satellites and commercial missions
- Increasing number of launches
- Rise in large-constellations
- Increasing demand for space data
- Rising investment in start-up space ventures

The last five years have seen a dramatic increase in the number of launches of small satellites (<500 kg). While approximately 50 small satellites were launched per year between 2009 and 2012, more than 300 small satellites were launched in 2017 alone, a six-fold increase. The majority of small satellites launched are Nano-satellites (<10 kg), which made up 90% of small satellites launched in 2017.[27]

Figure 9 Historical launches of small satellites, by type

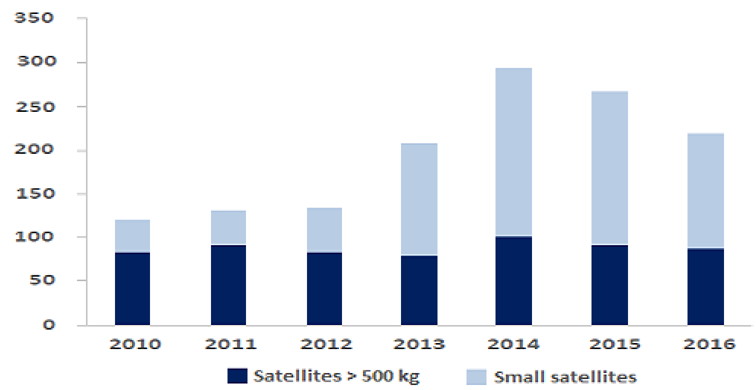


Notes: Satellite classification: Mini satellite: 100 kg – 500 kg; Micro satellite: 10 kg – 100 kg; Nano satellite: 1 kg – 10 kg. Launch failures and other setbacks impacted the number of small satellites launched in 2015/16.

Source: Satellite Applications Catapult (2018). Small satellite market intelligence – Q1 2018

In contrast, the launches of satellites over 500 kg have stayed more or less constant at around 50 to 100 launches per year, meaning that small satellites are capturing an increasing proportion of total launches. In 2016 small satellites accounted for approximately 60% of all launches.[28]

Figure 10 Historical launches of small and large satellites



Notes: Launch failures and other setbacks impacted the number of small satellites launched in 2015/16.

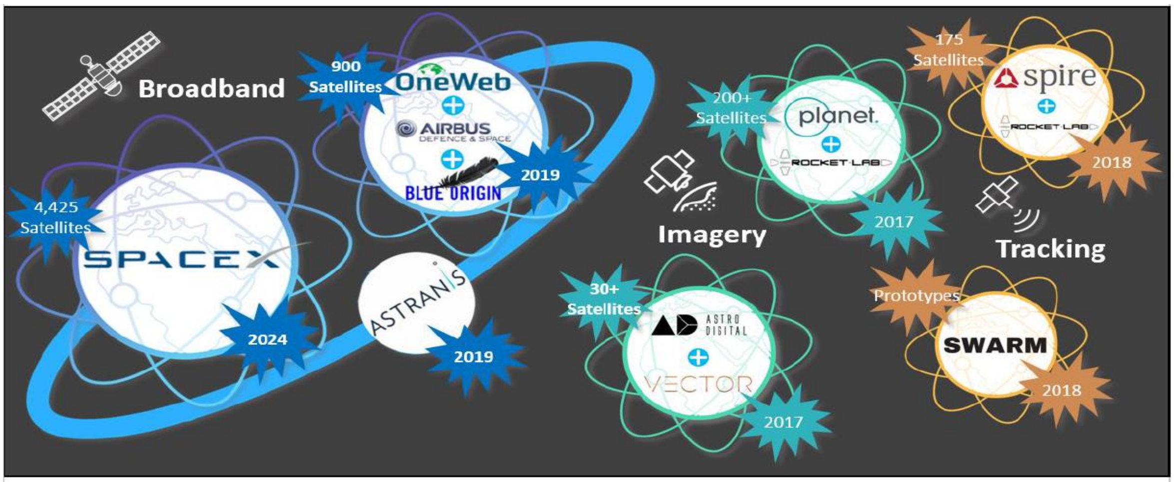
Source: Euroconsult (2017). Prospects for the Small Satellite Market

[27] Satellite Applications Catapult (2018). Small satellite market intelligence – Q1 2018
[28] Euroconsult (2017). Prospects for the Small Satellite Market

The cost of satellites has also fallen substantially in the last fifteen years, with launch costs of satellites having declined from around $200 million to around $60 million. Reusable rockets could see this cost fall further to as low as $5 million, while mass production has the potential to decrease the cost to $500,000 per satellite[29].

Looking into the future, the small satellite trend is set to continue with over 6,200 small satellites expected to be launched over the next decade and the total market value of small satellites projected to reach $30.1 billion over the 2017-2026 period.[30] More than two-thirds (70%) of these new satellites are expected to form part of large constellations of satellites[31] (Figure 11).

Figure 11 New Space entrants and forecast satellite launch



Source: Image taken from presentation by Jesse Koenig, Co-founder and Vice President of Technology at Tempo Automation at 'Ready to Pick up the pace? How to meet future demand by reducing your satellite production time'. Space Tech Expo USA 2018

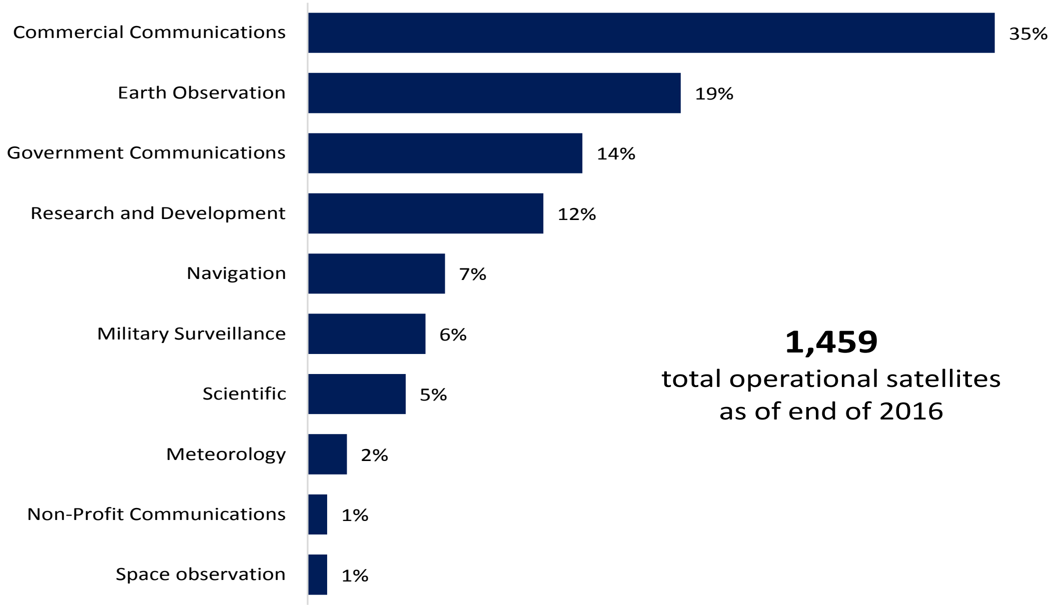
The increased appetite for small satellites and large-constellations in turn is driving the demand for lower cost launch vehicles and space craft. For small satellites themselves, reducing launch costs means that the concepts of cost and profit per kilogram will become increasingly important.

As a result, the traditional manufacturing paradigm of a three to five year development cycle, a single launch and in-orbit and a life-span of 15 to 20 years is viewed by many industry experts as changing. Today's small satellite approach is moving towards an eighteen month development period, multiple launches and two years in orbit.[32] On the applications side, these trends are expected to be reflected in an increased dependency on, and an increased demand for, space data, possibly opening up a range of new applications. With the rise of large-constellations, coverage of services is expected to increase, opening up access to space data in areas with no or limited coverage. This trend is sometimes referred to as the new Space Race[33], a movement towards 'always on' worldwide coverage of broadband, imagery and tracking and sensing information.

[29] Morgan Stanley (2017). *Space: Investing in the Final Frontier.* Available at: https://www.morganstanley.com/ideas/investing-in-space. [accessed 24/05/2018]
[30] Euroconsult (2017). *Prospects for the Small Satellite Market*
[31] Euroconsult (2017). *Prospects for the Small Satellite Market*
[32] It should be noted that some manufacturers are already offering such shorter lead times. For example, Airbus already offers 18 month lead times on geostationary telecoms satellites. Similarly, more recently developed satellites are also already designed for shorter lifespans. For example, China's recently launched high resolution earth observation satellites (Gaofen-1) are designed for a lifespan of six years (see Xinhua (2018). *China launches high resolution earth observation satellites*. Available at: http://www.xinhuanet.com/english/2018-03/31/c_137079574.htm [accessed 14/06/2018]
[33] Jesse Koenig, Co-founder and Vice President of Technology at Tempo Automation 'Ready to Pick up the pace? How to meet future demand by reducing your satellite production time'.

Satellite communications broadband and earth observation applications in particular could see significant growth. While the two areas already capture the majority of operational satellites - with the proportion of operational satellites standing, as of end of 2016, at 35% for commercial communications and 19% for earth observation (Figure 12) - thousands of satellites, including a number of constellations, are planned to be launched in these areas over the next decade.[34]

Figure 12 Operational satellites by segment (end of 2016)



Source: Satellite Industry Association (2017). State of the Satellite Industry Report

For the satellite antenna market these trends could mean increased demand for receiving technologies, with the overall global satellite antenna market forecast to grow at a compound annual growth rate of 7% between 2017 and 2022, reaching more than $2 billion by 2022[35].

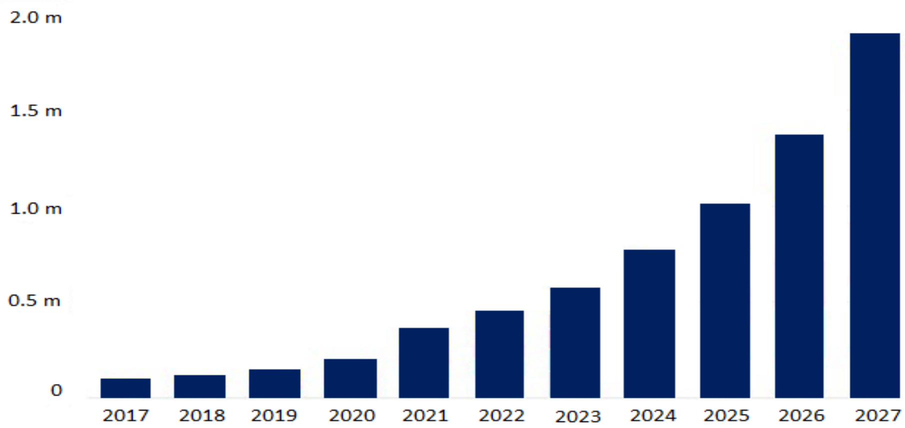
Annual shipments of flat panel satellite antennas specifically are forecast to rise to nearly 2 million units by 2027 (Figure 13). This rise in shipments is expected to translate into cumulative equipment revenues exceeding $8 billion by 2027, corresponding to a compound annual growth rate of 34.1%.[36]

[34] Euroconsult (2017). *Prospects for the Small Satellite Market*

[35] Market Research Engine (2017). Satellite Antenna Market By Antenna Type Analysis (Parabolic Reflector, Flat Panel, FRP, Horn, Iron Antenna with Mold Stamping); By Component Analysis (Reflector, Feed Horn, Feed Network, Low Noise Block Converter (LNB)); By Frequency Band Analysis (C Band, K/KU/KA Band, S & L Band, X Band, VHF & UHF Band); By Platform Analysis (Space, Land, Maritime, Airborne) and By Regional Analysis – Global Forecast by 2016 – 2022.

[36] Northern Sky Research (2018). Scaling up FPAS. Available at: http://www.nsr.com/news-resources/the-bottom-line/scaling-up-fpas/ [accessed 2018/05/04]

Figure 13 Global shipments of flat panel satellite antennas (units), 2017-2027



Source: Northern Sky Research (2018). Scaling up FPAS. Available at: http://www.nsr.com/news-resources/the-bottom-line/scaling-up-fpas/ [accessed 2018/05/04]

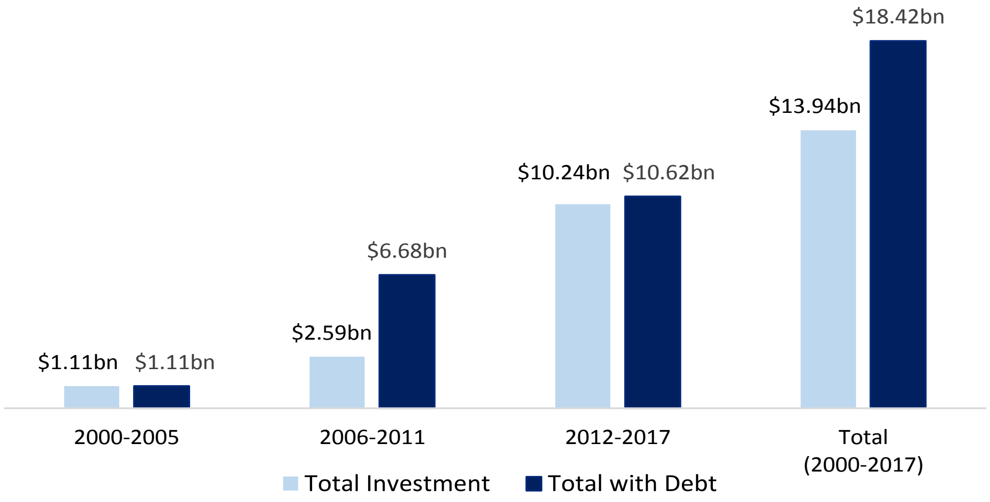
The composition of the space sector could also see a shake-up with many large-constellations planned to be launched by a range of new entrants (Figure 11) and space start-ups attracting significant investments.

Between 2000 and 2017 start-up space ventures attracted more than $18 billion in investment with total investment having increased significantly over the last two decades. While new space ventures attracted around $1.1 billion over the 2000 to 2005 period, investment increased by nearly ten times to $10.6 billion in the 2012 to 2017 period. (Figure 14)

The type of funding start-up space ventures attracted also changed significantly across periods (Figure 16):

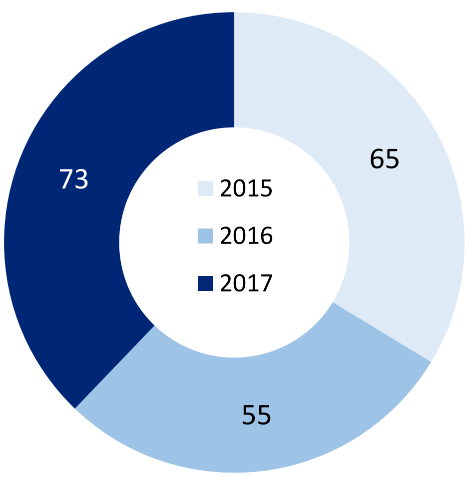
- In the 2000-2005 period the majority (58%) of funding came from seed, prize, or grant funding, while 21%, each, was obtained via private equity and venture capital funding.
- In the 2006-2011 period the majority (61%) of funding was obtained via debt financing. Private equity funding also still played a key role with 19% of funding obtained via this route.
- In the most recent period, 2012-2017, the share of venture capital funding increased dramatically to 53%. Acquisitions also saw a large increase, making up 28% of all funding in the most recent period, compared to only 9% between 2006 and 2011.

Figure 14 Total investment in start-up space ventures, 2000-2017



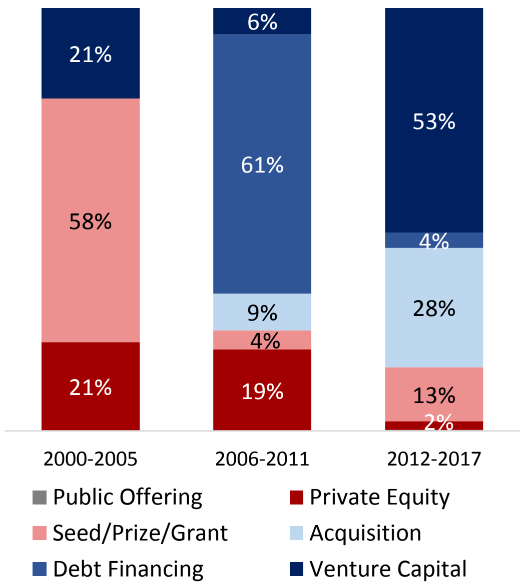
Source: Bryce (2018). Start-Up Space. Update on Investment in Commercial Space Ventures

Figure 15 Number of start-up space companies reporting new funding



Source: Bryce (2018). Start-Up Space. Update on Investment in Commercial Space Ventures

Figure 16 Proportion of investment in start-up space ventures by investment type

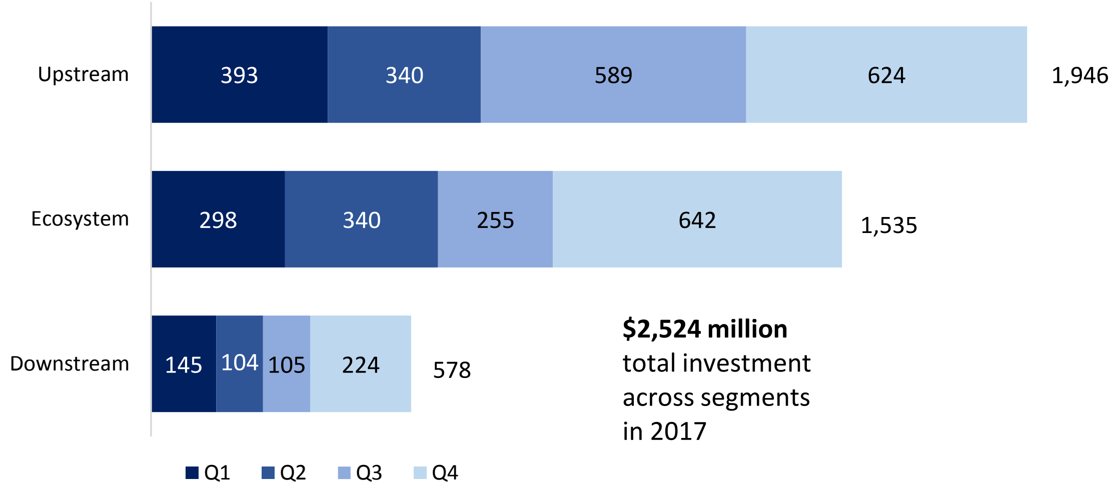


Source: Bryce (2018). Start-Up Space. Update on Investment in Commercial Space Ventures

In 2017 alone more than 4,000 space tech venture market transactions, with a total investment value of $2,524 million, were completed. The majority (1,946) of these transactions took part in the upstream segment. (Figure 17)

The number of start-up space companies reporting new funding also increased somewhat in 2017 to 73, compared to 55 and 65 in 2016 and 2015, respectively. (Figure 15)

Figure 17 Number of Space Tech Venture Market Transactions in 2017



Notes: Upstream includes 21 drone transactions totalling $164m. Downstream includes 6 drone companies totalling $79m. A $1bn Argo AI transaction was excluded from the Ecosystem numbers in the first quarter.

Source: Seraphim (2018). Seraphim Space Index - January 2017 to December 2017. Available at: http://seraphimcapital.co.uk/insight/news-insights/seraphim-space-index-january-2017-december-2017 [accessed 2018/05/02]

4 Industry 4.0

Industry 4.0 refers to the next big industrial revolution, making use of digital technologies in manufacturing supply chains to enhance performance and productivity.

The process of industrial revolution began with the first industrial revolution (1760-1840), bringing first advances in machine manufacturing, in particular driven by the advances of water and steam power.

The second and third industrial revolutions, respectively, brought assembly lines, enabling mass production, and advances in information technology leading to automated production.

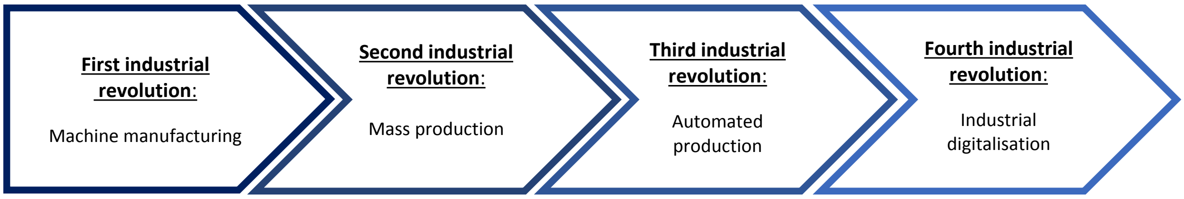
Now, the fourth industrial revolution integrates physical manufacturing technologies and processes with innovative digital technologies, such as:

- Intelligent Robots
- The Internet of Things
- Artificial Intelligence
- Data management and analytics
- 3D printing

For this reason, the fourth industrial revolution has also been described as an **industrial digitalisation**, fusing the boundaries between the physical and digital worlds.[37]

[37] Made Smarter Review: Industrial Digitalisation 2017

Figure 18 Industrial revolutions



Source: London Economics

The integration of digital and physical technologies, and the operation of digital technologies together (in concert) has the potential to generate new business forms, increase speed to market, integrate and strengthen supply chains, production of customised products and generate significant productivity gains.[38]

Industry 4.0 draws on the latest innovations from a number of fields, including advances in **robotics**. Robots were a key part of the third industrial revolution and are increasingly used in manufacturing factories across the globe. The robotics sector is currently dominated by industrial robots, which tend to perform a limited range of tasks that may be dangerous, repetitive or physically difficult when carried out by humans[39].

Another key component of Industry 4.0 is **automation**, allowing tasks normally carried out by humans to be carried out automatically by machines. Similarly to robotics, automation was already a key part of the third industrial revolution, when technological advancements first allowed machines to perform simple tasks repeatedly without human intervention.

Industry 4.0 adds a further layer, **combining robotics with innovative digital technologies** such as artificial intelligence and (big) data analytics. This combination of robotics, digital technology, and automation, allows the creation of autonomous robots, or autonomous systems, which are able to not only perform pre-defined tasks repeatedly, but to also take their environment into account and learn from, respond to, and adapt to certain events.

Collaborative robots (Cobots) are another example of how combining robotics with digital technologies can improve manufacturing operations and processes. As opposed to autonomous robots, which perform tasks independently, cobots are robots designed to work in collaboration with humans.

Moreover, the advent of the Internet of Things (IoT) allows the factory of the future to be ever more connected. This **increased connectivity** allows for a closer integration of machines, robots, factory equipment, and a company's IT systems, as well as closer supply chain and customer integration.

This is especially important, as manufacturers are increasingly required to be able to produce at both low and high volume, keeping costs down, in order to meet customer demand. Digital technologies enable them to do this through the capture and exploitation of **data** leading to flexible and reconfigurable production processes, optimised energy management and end-to-end supply chain efficiency.[40]

[38] Made Smarter Review: Industrial Digitalisation 2017
[39] Innovate UK (2016). Written evidence submitted by Innovate UK (ROB0060). Available at: http://data.parliament.uk/writtenevidence/committeeevidence.svc/evidencedocument/science-and-technology-committee/robotics-and-artificial-intelligence/written/32770.html [accessed 09/01/2018]
[40] Made Smarter Review: Industrial Digitalisation 2017.

Box 4 Industry 4.0: important concepts

Industry 4.0 refers to the next big industrial revolution, making use of digital technologies in manufacturing supply chains to enhance performance and productivity. It has also been described as an industrial digitalisation[41].

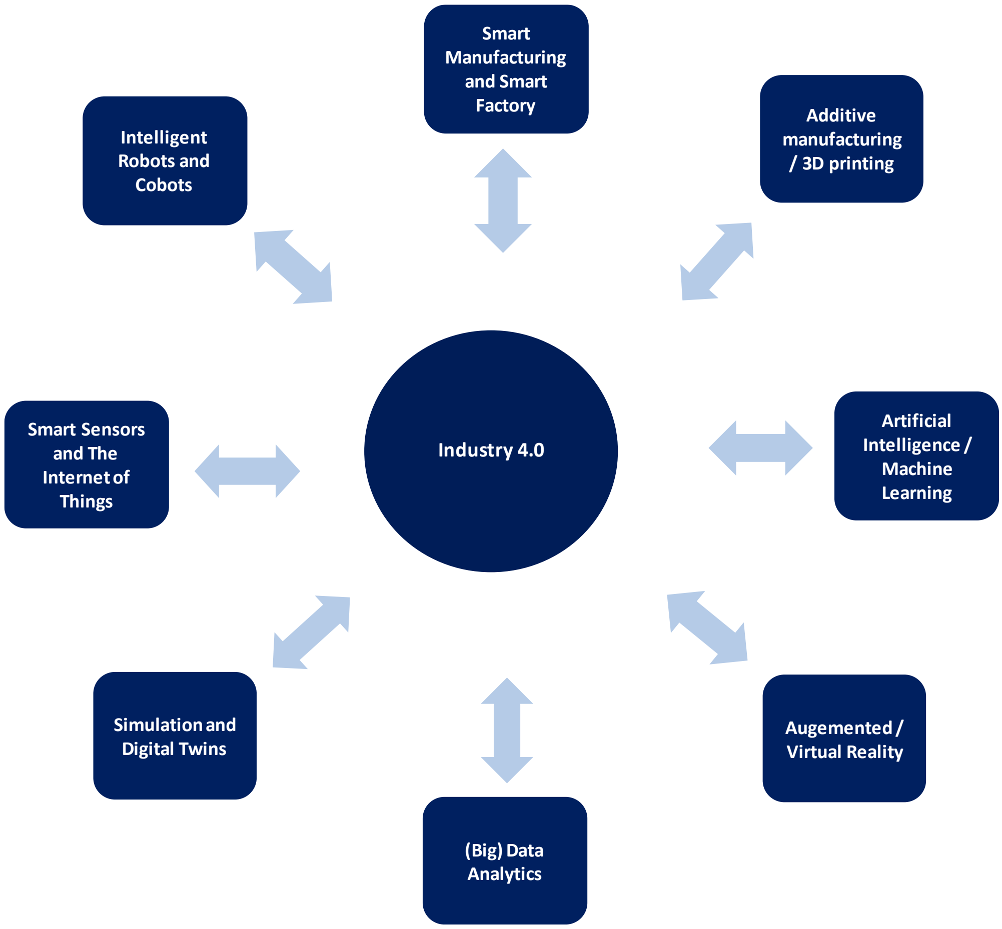
Industrial digitalisation is 'the application of digital tools and technologies to the value chains of businesses who make things (e.g. in the automotive and construction industries) or are otherwise operationally asset intensive (e.g. power grids and wind farms).'[42]

Automation refers to the process of introducing machines or computers to perform tasks previously carried out by humans.

4.1 Technologies of Industry 4.0

Many highly innovative technologies have been developed in recent history. Many of these have a vast disruptive potential, and are key drivers of the Industry 4.0 revolution. This section provides an introduction of some of these key technologies. A non-exhaustive overview is provided in Figure 19, followed by definitions and explanations of each technology.

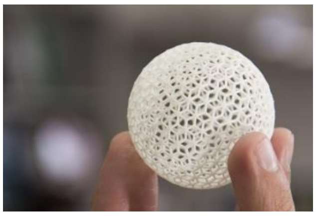
Figure 19 Industry 4.0 technologies



Source: London Economics

[41] Made Smarter Review: Industrial Digitalisation 2017
[42] Made Smarter Review: Industrial Digitalisation 2017

Additive Manufacturing and 3D Printing



Source: pixaby – graphic by metalurgiamontemar0 [43]

Additive Manufacturing refers to the process of creating objects by laying layer upon layer of material until the desired object is created. The blueprint for the desired object is created on a computer using 3D modelling software.

3D printing is often used as a synonym for Additive Manufacturing. Arguments can be made that the terms are slightly different. For example, additive manufacturing may be more appropriate to refer to industrial scale manufacturing, while the term 3D printing may be more appropriate for smaller scale hobby printing tasks. However, for the purpose of this stud, the terms will be treated as interchangeable.

Artificial Intelligence and Machine Learning

Artificial intelligence (AI) refers to the study and development of enabling machines to perform cognitive tasks normally undertaken by humans. Examples of such tasks are speech or voice recognition; pattern recognition, for example face recognition or recognising handwriting; or reasoning.

Source: Shutterstock – graphic by VLADGRIN[44]

Machine learning is an application of artificial intelligence seeking to enable machines to learn from data. A prominent example are self-driving cars, which improve their driving by learning from additional data collected while driving. This is opposed to traditional programming, where machines are programmed to perform certain tasks.

Augmented and Virtual Reality

Source: pixaby – graphic by StockSnap[45]

Virtual Reality (VR) refers to a computer generated environment with which humans can interact as if it were real. To access and interact with this environment special electronic equipment has to be used – for example virtual reality headsets.

Augmented Reality (AR) also refers to a computer generated environment. However, rather than being completely separate this environment alters a user's perception of reality. For example, an engineer could be presented with repair instructions and visual guidance overlaying the object to be fixed.

[43] Photo accessed from: https://pixabay.com/en/ball-3d-printing-design-597523/ [accessed 17/01/2018]
[44] Photo accessed from https://www.shutterstock.com/image-vector/concept-education-children-generation-knowledge-103580057 [accessed 17/01/2018]
[45] Photo accessed from https://pixabay.com/en/people-man-guy-mustache-2557494 [accessed 17/01/2018]

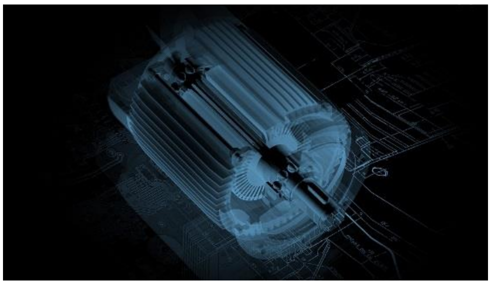
(Big) Data Analytics

Source: Shutterstock – graphic by Shutter_M[46]

Data analytics refers to the analysis of data, with the aim of obtaining insights from this data. For example, an analysis of historic sales data can bring insights about which customer group to target, when to hold sales, or likely future revenues.

Big data analytics is data analytics performed on large amounts of data. The availability of large amounts of data provides opportunities allowing richer insights to be drawn, but also special challenges, for example, desktop computers which are not powerful enough to process very large amounts of data. These opportunities and challenges have led to the development of special tools to derive insights from this data.

Simulation and Digital Twins



Source: pixaby – graphic by PIRO4D[47]

Digital Twins are digital replica of physical objects or processes, which function like the real object. Digital twins can be used throughout the product life-cycle, and are constantly updated to provide a near real-time representation of the physical object as it moves through design, manufacturing, all the way to operation. Digital twins provide different insights in each stage. For example, in the design stage a digital twin can be used to analyse and validate the object in a wide range of different scenarios, thereby optimizing the product, before the actual product has been manufactured. In the operational phase, a digital twin can be used to monitor wear and tear and provide insights into the operational behaviour of the product.

Simulations are closely linked with Digital Twins and are often used to analyse and validate how a product behaves in different conditions, or how it responds to extreme events. Simulations are also often used to evaluate processes. The rise of digital technologies in manufacturing, as part of Industry 4.0, and especially the Industrial Internet of Things, will take simulations one step further and allow the whole production line process to be simulated. This will allow testing and fine-tuning of the production plant and its manufacturing processes, before the plant starts operating. When the plant is in operation, the simulation can also be used to test changes to the production line before physically implementing them.

Smart sensors, the Internet of (Robotic) Things, and Cyber Physical Systems

Smart sensors key components of the Internet of Things. They measure, monitor, or collect data from the physical world. In addition, smart sensors have built in processing power, which allows them to perform an action with the collected data. For example, if connected to the internet, a smart sensor could automatically push the data to a phone app, or raise alerts if something is amiss.

[46] Photo accessed from: https://www.shutterstock.com/image-photo/business-hand-drawing-market-share-chart-94729690 [accessed 17/01/2018]
[47] Photo accessed from https://pixabay.com/en/motor-section-detail-copper-runner-2323189/ [accessed 19/01/2018]

The **Internet of Things (IoT)** refers, in very simple terms, to *things* being connected to the *internet*. This can be anything from a fridge or coffee machine, to street lights, manufacturing equipment, or even entire cities. Being connected to the internet allows these things to communicate with each other and possibly perform certain tasks. For example, your fridge may notify you when you are running out of milk, or even automatically reorder it; sensors along a pipeline could detect and report the position of a leak; manufacturing equipment could report its position in the factory and thus prevent losses.

Source: pixabay – graphic by jeferrb[48]

The Internet of Robotic Things (IoRT) is a concept similar to the IoT, but goes even further. Robots (or other smart devices) can monitor the physical world and not only relay this information via the internet, but also directly analyse the collected information, make autonomous decisions based on this analysis, and then take acts in the physical world.[49]

Industrial Internet of Things (IIoT) is a subset of the Internet of Things referring specifically to sensors, devices, and machines used in an industrial context. For example, industrial machines, robots, manufacturing equipment, etc. This allows companies to monitor their industrial processes in real time and increase productivity. Operational products can also be connected to the IIoT. This allows remote monitoring, maintenance, and failure detection of final products deployed at the client site. For companies this means they are much more in tune with their operational products, and enables them, for example, to detect and address failures before they cause outages[50].

Cyber Physical Systems refers to systems of computational components (e.g. sensors) which are intertwined and interact with the physical world. In other words, cyber physical systems are systems which bridge the digital and physical worlds. Examples of cyber physical systems include self-driving cars, smart cities, smart motorways, etc. Cyber Physical Systems are also sometimes called **Smart Systems.**

Robots, cobots, and cloud robotics

Source: pixabay – graphic by TPHeinz[51]

Automated systems / robots are computers or machines that perform certain pre-defined tasks automatically without human intervention. For example, an industrial packaging robot.

Autonomous systems / robots are similar to automated systems. However, autonomous systems are not only able to perform pre-defined tasks automatically, but in addition respond to, learn from, and adapt to their environment. In practice, the two terms are often used interchangeably.

[48] Photo accessed from https://pixabay.com/en/network-iot-internet-of-things-782707/ [accessed 18/01/2018]

[49] For further information see: ABI Research (2014). *The Internet of Robotic Things*. Available at: https://www.abiresearch.com/market-research/product/1019712-the-internet-of-robotic-things/ [accessed 17/01/2018]

[50] For further information see: PwC (2016). *The Industrial Internet of Things Why it demands not only new technology—but also a new operational blueprint for your business.* Available at: https://www.pwc.com/gx/en/technology/pdf/industrial-internet-of-things.pdf [accessed 18/01/2018]

[51] Photo accessed from https://pixabay.com/en/composing-industry-human-gear-1917694/ [accessed 18/01/2018]

Collaborative Robots (cobots) are robots that are designed to work alongside and interact with humans. This is in contrast to more traditional robots designed to perform tasks without human intervention.

Cloud Robotics combines robotics with cloud technologies such as cloud computing. In essence, robots are connected to the cloud, allowing them to utilise cloud functionality such as vast processing power or storage space. In this way, cloud robotics allows a robot to perform computationally less expensive tasks locally (e.g. collecting data from sensors) and offload computationally or storage intensive tasks to the cloud.

Smart Manufacturing and Smart Factory

Smart Manufacturing is an overall concept used to describe manufacturing processes utilising digitalisation technologies such as advanced robotics, big data analytics, or the Industrial Internet of Things with the aim of improving manufacturing processes and productivity. Smart manufacturing is also often associated with more flexibility in the production process, allowing manufacturers to respond more quickly to changing demands.

Source: pixabay – graphic by geralt[52]

Smart Factory is a term used to refer to the factory of the future, which will make extensive use of smart manufacturing technologies and processes. The smart factory is characterised by a high degree of automation and digitalisation, allowing product manufacturing with minimal human intervention. Another key characteristic of the smart factory is connectivity, fuelled by the Internet of Things. This yields a more efficient, flexible, and integrated production process, that can more easily adapt and respond to changing customer needs and supply chain characteristics. [53]

5 Current state of robotics, automation, and digitalisation in the UK

Advanced **robotics** is a key technological driver of Industry 4.0, with an estimated worldwide economic impact of between $1.7 to $4.5 trillion per annum by 2025[54], and an estimated market for non-military Robotics and Autonomous Systems (RAS) products and technologies of £70 billion by 2020-2025[55].

In the UK, RAS was identified as one of the Eight Great Technologies in the UK 2020 Industrial Strategy. Estimates of the impact of RAS on the UK economy suggest an estimated impact of 15% of

[52] Photo accessed from https://pixabay.com/en/industry-industry-4-0-2496192/ [accessed 18/01/2018]

[53] For a more detailed characterisation of the Smart Factory see Deloitte (2017). *The smart factory: Responsive, adaptive, connected manufacturing.* Available at: https://www2.deloitte.com/content/dam/insights/us/articles/4051_The-smart-factory/DUP_The-smart-factory.pdf [accessed 18/01/2018]

[54] McKinsey (2013). *Disruptive technologies: Advances that will transform life, business, and the global economy*. Available at: https://www.mckinsey.com/~/media/McKinsey/Business%20Functions/McKinsey%20Digital/Our%20Insights/Disruptive%20technologies/MGI_Disruptive_technologies_Full_report_May2013.ashx [accessed 15/01/2018]

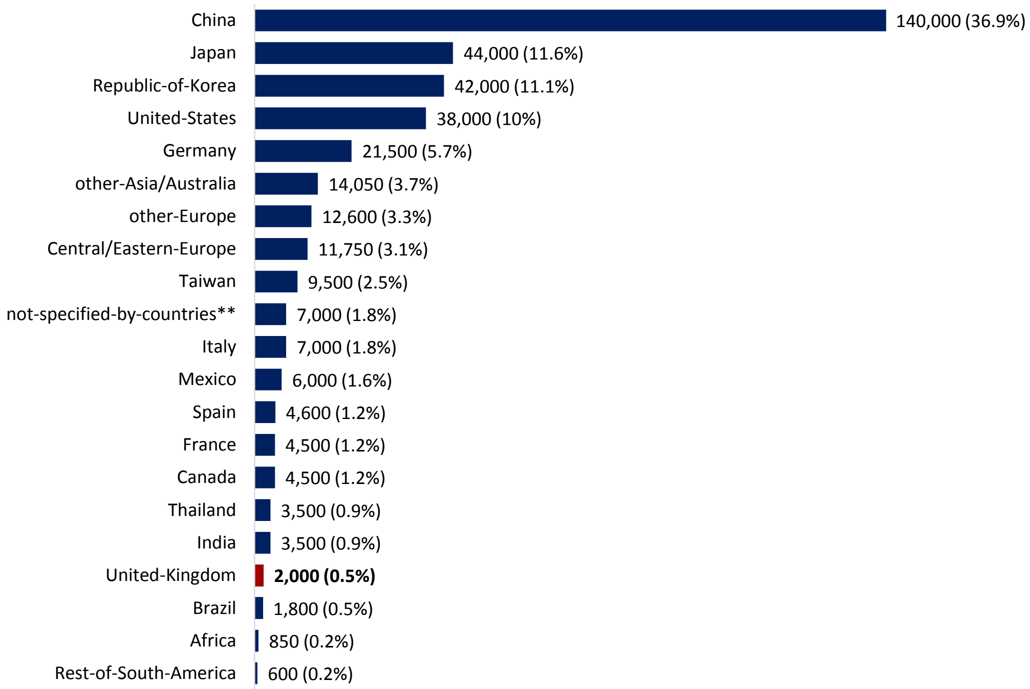
[55] Special Interest Group Robotics and Autonomous Systems (2014). *RAS 2020 Robotics and Autonomous Systems.*

GVA (more than £200 billion), and a potential to raise manufacturing sector productivity by up to 22%, generating a long-term employment increase of up to 7%[56].

The UK has world-leading robotics research, as well as highly innovative robotics companies[57]. This includes a number of collaborative research centres and institutes such as the Bristol Robotics Laboratory, Dyson Robotics Lab and the Hamlyn Centre at Imperial College, the Edinburgh Centre for Robotics, the EPSRC Centres for Innovative Manufacturing, and Sheffield Robotics; as well as thriving RAS groups at research institutions (e.g. Heriot-Watt University, Imperial College London, University College London, University of Bristol, etc.), and from industry (e.g. BAE Systems, Rolls-Royce, OC Robotics, the Shadow Robot Company, KUKA Robotics UK, etc.)[58].

However, the robotics sector lacks a supply chain in many areas, with Switzerland, Germany and Canada believed to be in a better position. Moreover, there are also fewer SMEs in the robotics sector in the UK compared to other European countries.[59]

Figure 20 Estimated annual shipments of multipurpose industrial robots in 2018



Notes: Numbers in parentheses represent percent of world total; (**) reported and estimated sales which could not be specified by countries. ***Source: International Federation of Robotics***

Industrial robot installations in the UK are also estimated to be relatively low when compared to the likes of Germany, the US, or China.

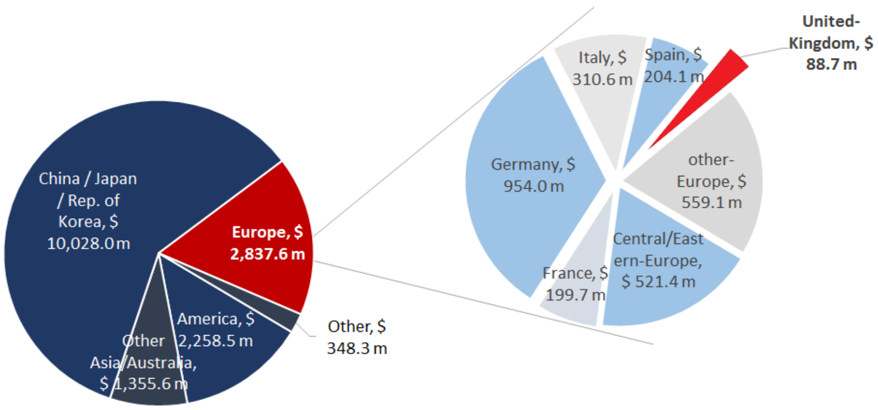
Around 2,000 industrial robots are estimated to be installed in the UK in 2018 (0.5% of an estimated world total of 379,250). This compares to estimates of around 4,500 (1.2% of world total) in France,

[56] Special Interest Group Robotics and Autonomous Systems (2014). *RAS 2020 Robotics and Autonomous Systems.*
[57] Made Smarter Review: Industrial Digitalisation 2017
[58] Council for Science and Technology *(2015). Science Landscape Seminar Series: Representative UK Robotics and Autonomous Systems (RAS) Infrastructure*. Available at: https://www.gov.uk/government/publications/science-landscape-seminar-robotics-and-autonomous-systems [accessed 15/01/2018]
[59] Council for Science and Technology *(2015). Science Landscape Seminar Series: Representative UK Robotics and Autonomous Systems (RAS)*. Available at: https://www.gov.uk/government/publications/science-landscape-seminar-robotics-and-autonomous-systems [accessed 15/01/2018]

7,000 (1.8%) in Italy, 21,500 (5.7%) in Germany, and 38,000 (10%) in the US, and 140,000 (36.9%) in China. (Figure 20)

Given estimated overall industrial robot revenues, in 2018, of approximately $16,828 million[60], this represents a UK market of approximately $88.7 million; about 1/10th of the market of Germany ($954 million). (Figure 21)

Figure 21 Estimated annual market for multipurpose industrial robots in 2018

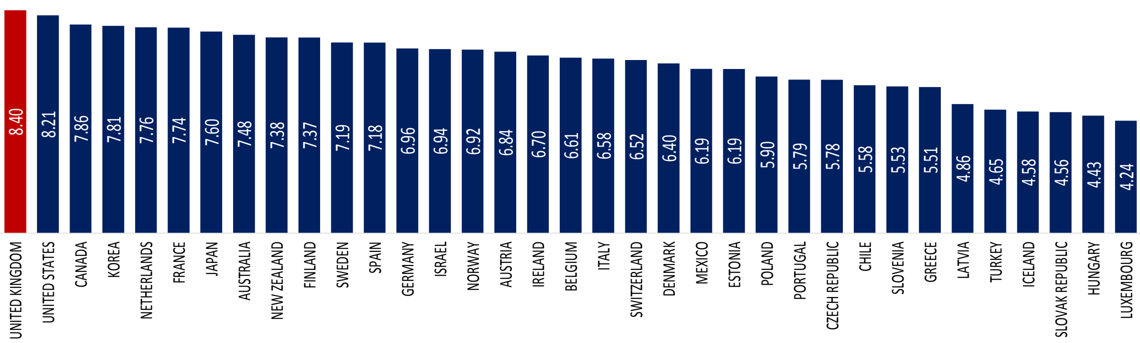


Notes: Annual market calculated as: World-wide industrial robot revenue times robot shipments in region/country as a ratio of robot shipments world-wide.

Source: London Economics; Estimated annual shipment data of multipurpose robots obtained from International Federation of Robotics; Estimated world-wide industrial robot revenue obtained from ABI Research

In terms of **digitalisation**, the UK is already seen a world leader in **artificial intelligence**, according to the most recent industrial strategy white paper[61]. The UK also ranks first in Oxford Insights' Government AI Readiness Index[62], closely followed by the United States, Canada, and Korea (Figure 22).

Figure 22 Government AI Readiness Index



Source: Oxford Insights

The index provides an estimate of how prepared a country's government is for implementing AI in public service delivery. It takes into account nine factors: technology skills available in the workforce,

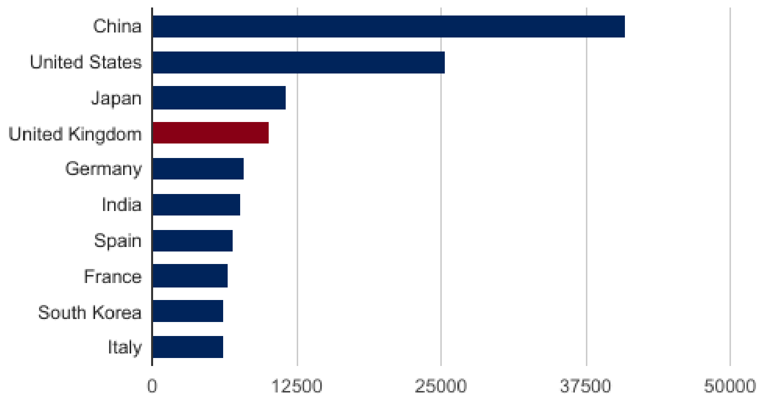
[60] ABI Research
[61] HM Government: Industrial Strategy White Paper
[62] Stirling, R., Mliller, H., and Martinho-Truswell, E. (2017). *GOVERNMENT AI READINESS INDEX*. Oxford Insights. Available at: https://www.oxfordinsights.com/government-ai-readiness-index/ [accessed 15/01/2018]

availability and quality of data, digitisation, AI start-ups, innovation and government effectiveness, and digital public services.

The UK also has many companies developing and using AI, some of which are seen among the world's most innovative. This includes major players such as IBM and Microsoft, as well as more than 200 start-ups and SMEs.[63] One prominent example is DeepMind, a London based AI start-up which, in 2014, was acquired by Google for $400 million.[64]

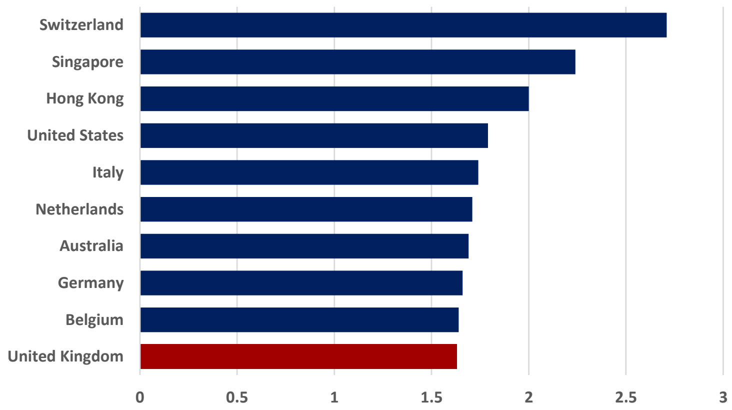
In terms of research, the UK was ranked fourth when judged by the number of publications in AI research between 2011 and 2015 (Figure 23), behind China, the United States and Japan, and tenth in terms of field-weighted citation impact (Figure 24).[65]

Figure 23 Number of AI publications between 2011 and 2015



Source: Times Higher Education; **Data source:** Elsevier/Scopus

Figure 24 AI: Field-weighted citation impact



Source: Times Higher Education; **Data source:** Elsevier/Scopus

[63] Hall, D. W., and Pesenti, J. (2017). *Growing the artificial intelligence industry in the UK: Full report.* Available at: https://www.gov.uk/government/publications/growing-the-artificial-intelligence-industry-in-the-uk [accessed 15/01/2018]
[64] Murgia, M. (2017). *Why Britain's homegrown AI talent leads the world.* Available at: https://www.ft.com/content/a6165cd6-2f89-11e7-9555-23ef563ecf9a [accessed 15/01/2018]
[65] Baker, S. (2017). *Which countries and universities are leading on AI research?.* Times Higher Education. Available at: https://www.timeshighereducation.com/data-bites/which-countries-and-universities-are-leading-ai-research [accessed 15/01/2018].

5.1 UK manufacturing overall

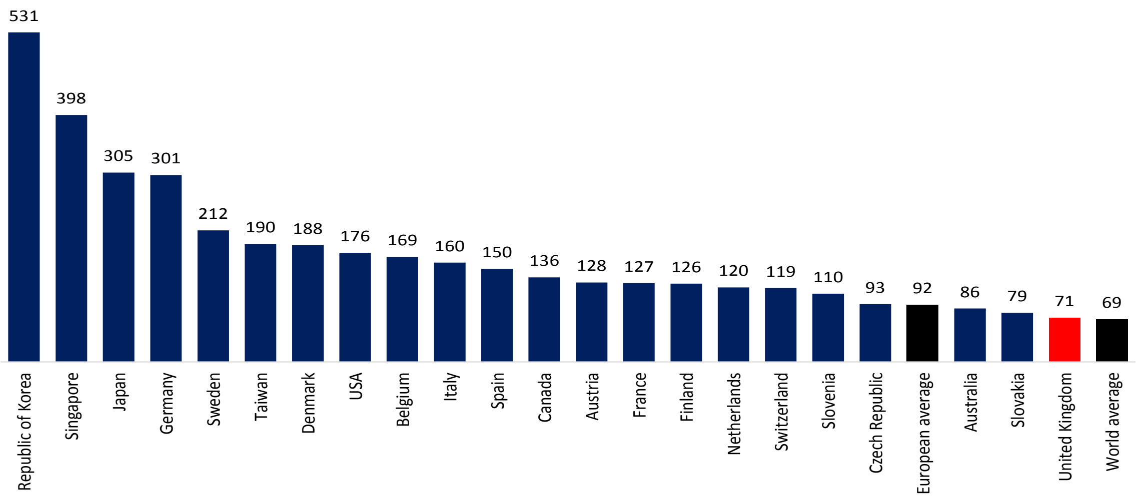
Use of robotics in UK manufacturing is lagging behind other advanced nations across a number of metrics, with the gap widening, as numbers cited in the 2017 Made Smarter Review show.[66]

The report cited numbers from the International Federation of Robotics (IFR) and the German Electrical and Electronic Manufacturers' Association (ZVEI) showing that:

- While Germany's manufacturing sector is only 2.7 times the size of the UK's, Germany invests 6.6 times more in automation.
- The UK has a comparatively low robot density in the general industry (excluding automotive), with only 33 installed per 10,000 employees, compared to 93 for the US and 170 for Germany.
- The number of robots per millions of hours worked, is a factor of 10 lower than Germany or Japan.

Examining the robot density in the overall manufacturing sector (including automotive), paints a similar picture. In 2015 the UK had a robot density of 71 multipurpose industrial robots per 10,000 employees in the manufacturing industry, barely above the world average (69), and far off the European average (92).

Figure 25 Robot density in the manufacturing sector across the world (2015)



Notes: The graphic shows the number of all types of multipurpose industrial robots per 10,000 employees in the manufacturing industry in 2015.

Source: International Federation of Robotics: World Robotics Report 2016

However, a recent survey of UK and German manufacturers, undertaken by Barclays[67], paints a more positive picture of the state of automation and robotics in UK manufacturing.

Over half (53%) of managers surveyed by Barclays said their business has invested in automation / robotic equipment, which is still in use, while a further 5% said they had previously invested in

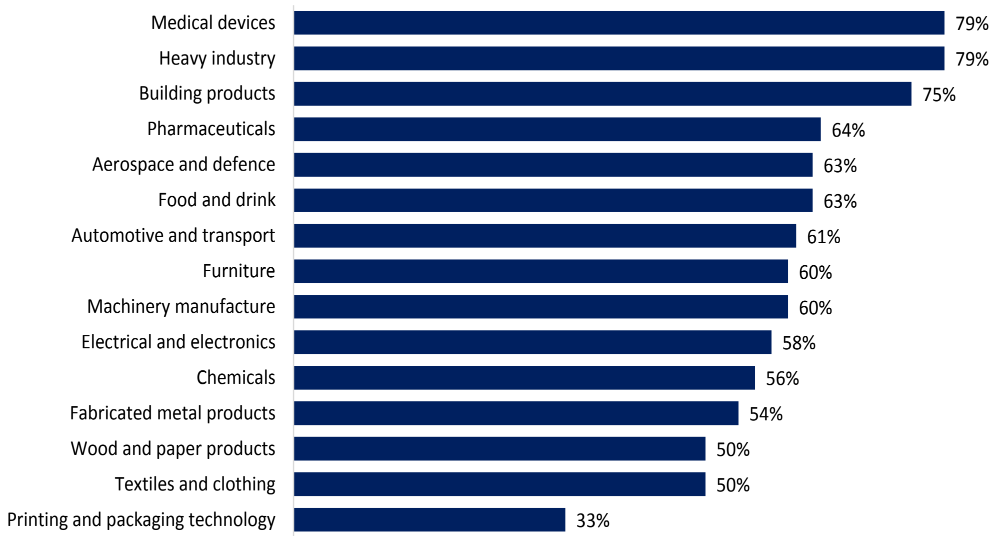
[66] Made Smarter Review: Industrial Digitalisation 2017

[67] Rigby, M. (n.d.). *Future-proofing UK manufacturing: Current investment trends and future opportunities in robotic automation.* Barclays. Available at: https://www.barclayscorporate.com/content/dam/corppublic/corporate/Documents/research/automation-report.pdf [accessed 10/01/2018]

automation / robotic equipment but no longer use it. In addition, 13% said they have considered investing in automation, while 68% of respondents see potential for future investment (Table 5).

In terms of **manufacturing subsectors**, the Barclays survey[68] suggested, that the highest level of investments were in medical devices, and heavy industry sectors (79%), as well as in building products (79%). Moreover, with the exception of printing and packaging technology, at least half of the respondents in each sector said that they had invested in automation (Figure 26).

Figure 26 Investment in automation across UK manufacturing subsectors



Notes: Graph shows the proportion of respondents, which have invested in automation; total sample size = 639 UK managers. Some of the subsectors are based on a relatively small sample size, therefore the figures should be treated with caution.

Source: Barclays: Future-proofing UK manufacturing

While the Barclays survey was based on a relatively small sample size, meaning that the sectoral estimates should be treated with caution, the numbers nevertheless suggest that automation is now seen as an important topic in many sectors outside the traditional suspects, such as the automotive manufacturing sector.

The UK numbers also compare favourably to the figures for Germany, where 61% of respondents said their business has invested in automation / robotic equipment and is still using it. Similar to the UK, 5% of German respondents said they had previously invested, but no longer use automation / robotics equipment. (Table 6)

Similarly, nearly two-thirds (65%) of UK manufacturing businesses said that they had invested in automation over the past 12 months in response to The Manufacturer's 2017 annual survey of UK manufacturers[69]. Moreover, 62% said they were planning a move to Industry 4.0, while 23% said they are already undertaking such a move.

One year earlier, more than four-fifths (83%) said they had implemented some form of automation in their production processes in the past five years, in response to The Manufacturer's 2016 annual

[68] Rigby, M. (n.d.). *Future-proofing UK manufacturing: Current investment trends and future opportunities in robotic automation.* Barclays. Available at: https://www.barclayscorporate.com/content/dam/corppublic/corporate/Documents/research/automation-report.pdf [accessed 10/01/2018]
[69] The Manufacturer (2016): Annual Manufacturing Report 2017

survey of UK manufacturers[70] . Slightly more than two-fifths said they were implementing a major project (large relative to the scale of their business) in 2015, and only 9% said they had never implemented a major automation project.

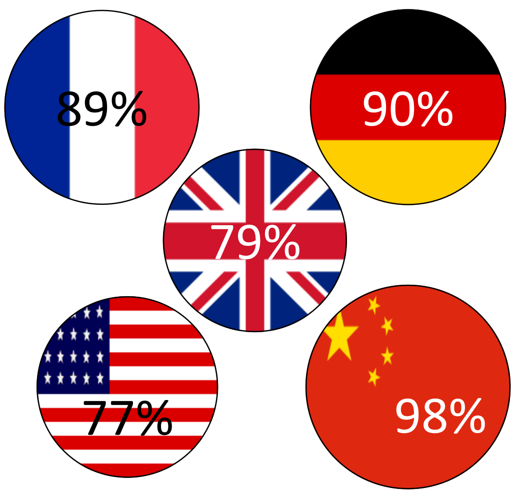
Table 6 Investment in the use of automation/robotics equipment: UK vs. Germany

Invested in the use of automation/robotic equipment?	UK	Germany
Yes, used before and still uses	53%	61%
Yes, used before but no longer use	5%	5%
No, but has considered investing	13%	11%
No, and has not considered investing	25%	21%

Notes: Total sample size = 639 UK managers, 100 German managers. ***Source: Barclays: Future-proofing UK manufacturing***

Indeed, in response to a Boston Consulting Group survey[71], 79% of the 322 managers of industrial companies surveyed in the UK felt suggested they had made at least some progress towards Industry 4.0. Moreover, of those surveyed, 70% indicated that they had at least partially reached their goals in the year before, 71% indicated that they were prepared for Industry 4.0 technologies, while 70% indicated they were prepared for skills changes.

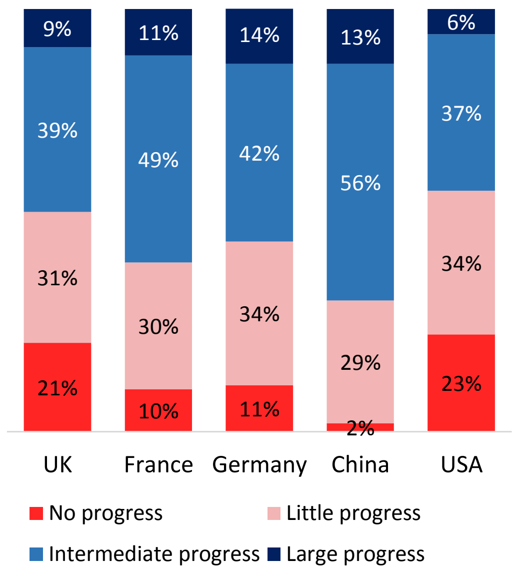
Figure 27 Proportion of managers indicating they had made at least some progress towards Industry 4.0



Notes: Sum of respondents indicating they made "large progress", "intermediate progress", or "little progress" towards Industry 4.0. Nr. of respondents: Germany = 312, France = 322, UK = 322, China = 258.

***Source: Boston Consulting Group (2017).* Is UK Industry ready for the Fourth Industrial Revolution?**

Figure 28 How would you estimate the progress of your company towards Industry 4.0 in the last year?



Notes: Nr. of respondents: Germany = 312, France = 322, UK = 322, China = 258.

***Source: Boston Consulting Group (2017).* Is UK Industry ready for the Fourth Industrial Revolution?**

While high, the UK numbers are nevertheless lagging behind France and Germany, where 89% and 90% of surveyed managers, respectively, indicated that they had made some progress towards Industry 4.0. In the case of China, nearly all (98%) of respondents indicated that they had made some

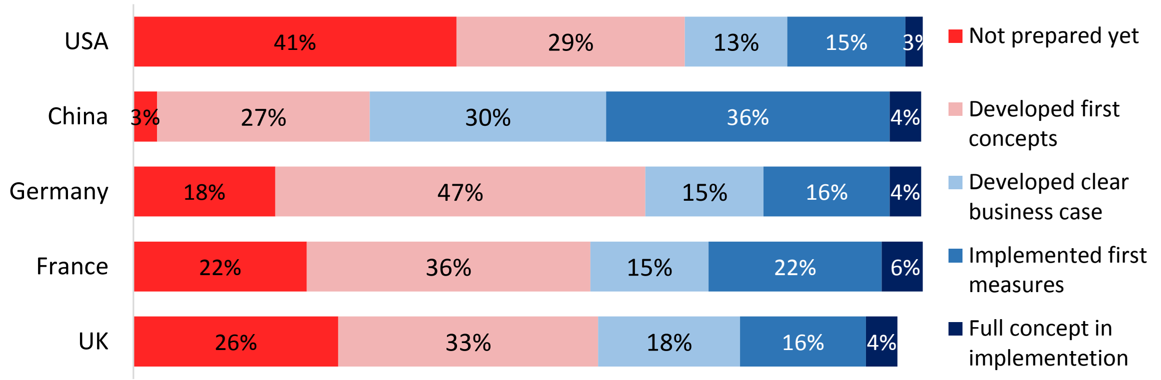
[70] The Manufacturer (2015): Annual Manufacturing Report 2016

[71] Boston Consulting Group (2017). *Is UK Industry ready for the Fourth Industrial Revolution?*

progress. Only in the case of the US, slightly fewer managers indicated that they had made progress towards Industry 4.0 (Figure 27).

Moreover, of those who indicated that they had made at least some progress towards Industry 4.0, only 9% had made large progress, while 39%, 31%, and 21% had made intermediate, little, and no progress, respectively (Figure 28).The UK was also lagging behind Germany and France in terms of goals reached, preparation for skills, and preparation for technologies. For example, of UK managers surveyed, 26% said they were not prepared for the introduction of new technologies for Industry 4.0 yet. This compares to 22% of French, and 18% of German managers (Figure 29).

Figure 29 How well is your company prepared for the introduction of new technologies for Industry 4.0?



Notes: Nr. of respondents: Germany = 312, France = 322, UK = 322, China = 258, USA = 315.

Source: Boston Consulting Group (2017). **Is UK Industry ready for the Fourth Industrial Revolution?**

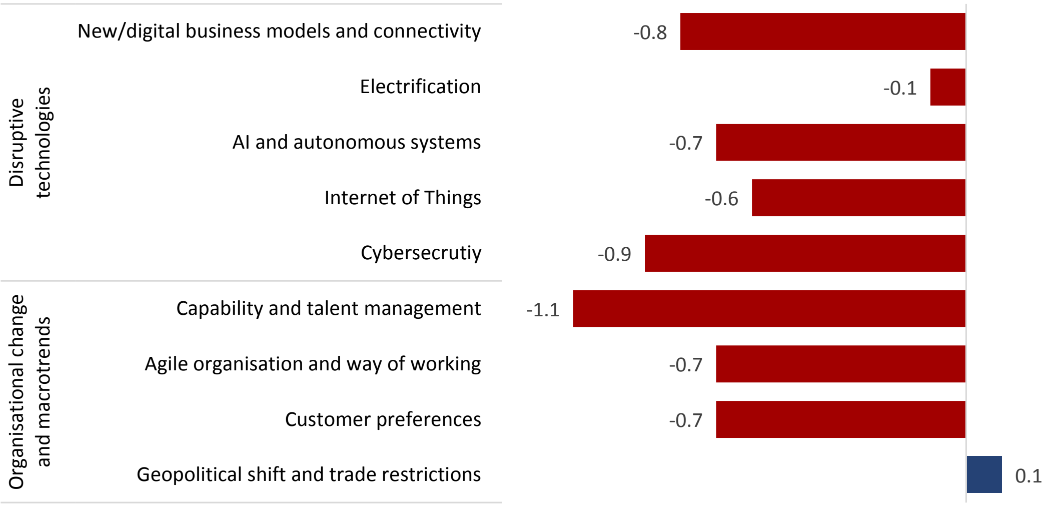
This lack of preparedness is also reflected in a recent McKinsey study[72] seeking to understand the implications of disruptive forces - such as connectivity-driven business models, AI and autonomous systems, Internet of Things (IoT), electrification, and cybersecurity - in the automotive, diversified industrials, and aerospace and defence industries.

McKinsey's analysis revealed substantial gaps between readiness and impact for most disruptive forces (Figure 30), with new-entrants perceiving themselves to be much better prepared than incumbents.

Moreover, 85% of leaders consulted agreed that these major disruptions pose a significant shift compared to the gradual evolution of earlier disruptions in terms of speed of change (74%) and magnitude/impact (46%), meaning it is harder for companies to keep up with the pace and magnitude of changes.

[72] *McKinsey (2018). Disruptive force in the industrial sectors*

Figure 30 Readiness vs. Impact



Notes: Answer options:

- Impact on business from 1 (not affecting business) to 5 (affecting at least half of the business)
- Readiness: 1 = no measures so far, 2 = assessment available, 3 = strategy in place, 4 = strategy in place, pilot initiatives started, 5 = holistic program/transformation started

Source: McKinsey (2018). Disruptive force in the industrial sectors

5.2 Automotive manufacturing

The automotive sector is a major customer of industrial **robots** around the world, with 35% of total supply in 2016 going to the automotive industry[73].

Robots are used in a wide range of areas in the automotive manufacturing process, including[74]:

- Assembly
- Coating
- Die casting
- Large part transfer
- Material handling
- Painting
- Welding

In the UK robots also play a key role in the automation strategies of multinationals such as Jaguar Land Rover and Nissan in their UK factories[75].

[73] International Federation of Robotics: World Robotics Report 2017
[74] Nowak, J. (2015) *Industrial Robotics in the Automotive Industry. Bastian Solutions*. Available at: https://www.bastiansolutions.com/blog/index.php/2015/09/17/industrial-robotics-automotive-industry/ [accessed 11/01/2018]
[75] Made Smarter Review: Industrial Digitalisation 2017

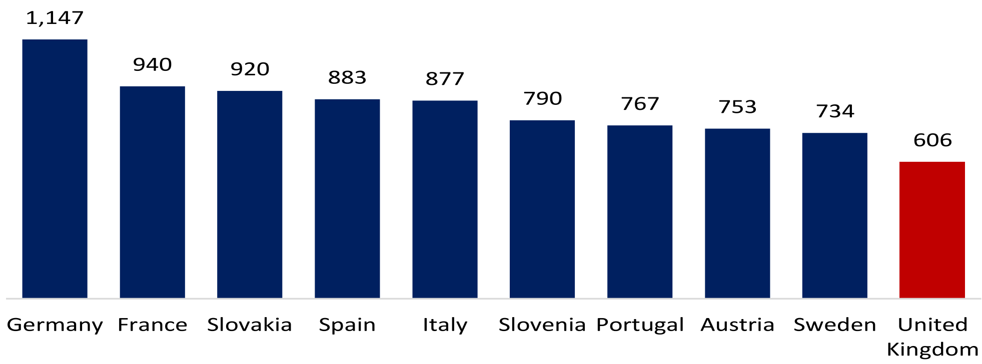
Indeed, the body shop, Nissan's welding facility, at Nissan's Sunderland plant is already 93 percent automated, while the new welding facility for the Nissan Infinity makes use of 141 robots to achieve complete automation[76].

Similarly, Jaguar Land Rover's body shop and final assembly line at its Solihull facility contains 615 high-tech robots allowing one Jaguar XE to be produced every 78 seconds[77].

Aston Martin, traditionally focused on manual labour in the production of its cars, is also moving towards the use of more robots in their manufacturing processes, including investments into 3D printers to produce unique parts[78].

Overall, the UK's automotive manufacturing sector ranked 10th in the European Union in 2015 with 606 installed industrial robots per 10,000 employees. The highest uptake in the automotive sector was in Germany (1,147), France (940), and Slovakia (920) (Figure 31).

Figure 31 Robot density in the automotive manufacturing sector



Notes: Graph shows the number of installed industrial robots per 10,000 employees in the automotive industry in 2015.

Source: International Federation of Robotics

In terms of **digitalisation**, evidence from KPMG[79] suggests that uptake in the UK automotive industry may be lagging behind, especially when compared to leading countries such as Germany.

While, the automotive sector already has a number of digitalisation pilots at both vehicle manufacturers and suppliers, according to the 2016 KPMG report, the authors could not find any fully digital factory implementations. Digitally connecting supply chains and customers was found to be at an even earlier stage.

Similarly, the authors noted that advanced robotics is starting to play a key role in supporting human operators. However, their survey of members of The Society of Motor Manufacturers & Traders (SMMT) suggests that most SMMT members have not yet implemented advanced digitalisation technologies in their manufacturing operations.

[76] The Financial Times (2018). *Nissan builds on loyalty at Sunderland plant*. Available at: https://www.ft.com/content/7487772a-d703-11e5-829b-8564e7528e54 [accessed 11/01/2018]

[77] Jaguar Land Rover (2016). A manufacturing success story. Available at: http://media.jaguarlandrover.com/2016/manufacturing-success-story. [accessed 11/01/2018]

[78] Campbell, P. (2016). *Aston Martin to crank up use of robots in profitability drive.* Financial Times. Available at: https://www.ft.com/content/885b0e46-8a1e-11e6-8cb7-e7ada1d123b1 [accessed 11/01/2018]

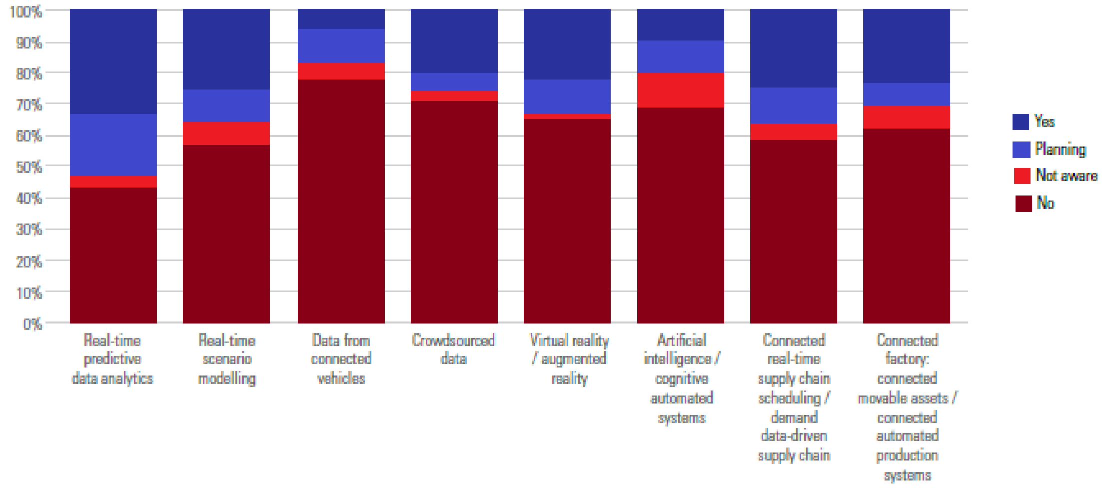
[79] KPMG (2016): The Digitalisation of the UK Automotive Industry

According to this survey, the technology with the highest uptake is real-time predictive analytics, with more than 30% of respondents saying they use this technology in their operational processes. More than 20% of respondents use virtual / augmented reality, while less than 10% use artificial intelligence / cognitive automated systems. Data from connected vehicles was the technology used least.

KPMG also compared their results with other surveys in Germany and the US, which suggested that the UK currently has a lower rate of digitalisation in the automotive sector compared to these countries.

Their interviews further revealed that, in general, suppliers have a far lower adoption of digitalisation technologies than vehicle manufacturers.

Figure 32 Digitalisation technologies used in the UK automotive industry



Source: KPMG (2016): The Digitalisation of the UK Automotive Industry

5.3 Aerospace manufacturing

In the Aerospace Manufacturing industry **robots** are frequently used for drilling and fastening jobs. Thousands of holes may need to be drilled into the main body of an aircraft, making drilling a labour intensive task. Robots can automatically detect where holes need to be drilled by using vision systems, and are able to perform the job faster and with more precision and consistency than humans. Robots are also used for inspection processes, material handling, as well as painting and coating applications.[80, 81]

In the UK, GKN Aerospace, a supplier of airframe structures and other aeroplane parts, uses robots for automatic carbon fibre placement for the rear wing spar, automated guidance of vehicles

[80] Anandan, T. M. (2016). Aerospace Manufacturing on Board with Robots. Available at: https://www.robotics.org/content-detail.cfm/Industrial-Robotics-Industry-Insights/Aerospace-Manufacturing-on-Board-with-Robots/content_id/5960 [accessed 12/01/2018]

[81] RobotWorx (n.d.). *Robots in the Aerospace Industry*. Available at: https://www.robots.com/articles/viewing/robots-in-the-aerospace-industry [accessed 12/01/2018]

carrying wing structures, and drilling tasks in their Bristol plant. The company also uses robots for welding tasks and installing fasteners on other assemblies.[82]

At its Filton plant Airbus already used a machine to automatically perform drilling, countersinking and fettling operations back in 2007.[83]

More recently, Airbus completed a new additive manufacturing facility / 3D printing facility at Filton[84], and first installed a 3D printed titanium bracket on a series production commercial aircraft (A350 XWB) in 2017.[85]

The Aerospace Manufacturing sector is also already supporting the development and adoption of **digitalisation** technologies such as additive manufacturing, co-bots, artificial intelligence, data analytics, and virtual / augmented reality.[86]

Early adopters are establishing the requirements to deliver digital twins, a digital replica of a physical object, for example part of an aeroplane, or process, which can be used predict properties and behaviour, or run diagnostics. However, greater co-ordination of operating practices and standards as well as a more flexible data architecture are required to deliver the consistency and data accuracy needed.[87]

Many companies are also already using Radio-frequency identification (RFID) tags, which provide operational prognostics as well as information on assemblies and in-process performance monitoring, helping to avoid bottlenecks.[88] RFID tags are also used for tools or parts tracking, for example by Airbus in their Filton assembly line.[89]

Big data analytics are also used across the aerospace value chain, for example, to measure product performance or to assess the impact of weather on the supply chain.[90] In the future, big data will enable further improvements in all stages of the aeroplane lifecycle.[91]

Globally, more than three quarters (76%) of aerospace, defence and security companies reported that they are investing in digital operation solutions and expect to have achieved a high level of digitalisation within the next five years, in response to PwC's 2016 Global Industry 4.0 Survey.

[82] Tieman, R. (2016). *Robots' debut in aerospace production lines create new human jobs.* Financial Times. Available at: https://www.ft.com/content/3a1f55a0-3c50-11e6-8716-a4a71e8140b0. [accessed 12/01/2018]

[83] Machinery (2007). *Automating aerospace.* Available at: http://www.machinery.co.uk/article-images/11605%5CAutomating_aerospace.pdf [accessed 12/01/2018]

[84] Airbus (2017). *#15 - QUICK NEWS - MARCH 2017 - AIRBUS COMPLETES NEW ADDITIVE MANUFACTURING FACILITY AT AIRBUS' FILTON FACILITY.* Available at: http://com.airbus-fenice.customers.artful.net/presscentre/quick-news/15-march-2017/ [accessed 12/01/2018]

[85] Davies, S. (2017). *Airbus installs first 3D printed titanium bracket on commercial A350 XWB aircraft*. Available at: https://www.tctmagazine.com/3d-printing-news/airbus-3d-printed-titanium-bracket-a350-xwb-aircraft/ [accessed 12/01/2018]

[86] Made Smarter Review: Industrial Digitalisation 2017

[87] Aerospace Technology Institute (2017). *Insight 01 Digital Transformation.* Available at: http://www.ati.org.uk/wp-content/uploads/2017/09/ATI-INSIGHT-01-Digital-Transformation.pdf [accessed 12/01/2018]

[88] Aerospace Technology Institute (2017). *Insight 01 Digital Transformation.* Available at: http://www.ati.org.uk/wp-content/uploads/2017/09/ATI-INSIGHT-01-Digital-Transformation.pdf [accessed 12/01/2018]

[89] Swedberg, C. (2014). *Airbus to RFID-Tag and Track All Parts Made In-House*. RFID Journal. Available at: http://www.rfidjournal.com/articles/view?11752/2 [accessed 12/01/2018]

[90] Aerospace Technology Institute (2017). *Insight 01 Digital Transformation.* Available at: http://www.ati.org.uk/wp-content/uploads/2017/09/ATI-INSIGHT-01-Digital-Transformation.pdf [accessed 12/01/2018]

[91] Bicos, A. S. (2015). Interview with Sethi, C. ASME. *Aerospace Bets on Big Data*. Available at: https://www.asme.org/engineering-topics/articles/design/aerospace-bets-on-big-data [accessed 12/0. 1/2018]

Moreover, 32% of respondents reported that they had already achieved a high level of digitalisation today.[92]

5.4 Food and drinks manufacturing

The UK food and drinks manufacturing sector lags behind other UK manufacturing sectors in terms of automation, with the number of robots installed standing at only around 10% of those installed in the automotive industry[93], and a 10 year average adoption rate of just 63 robots per year[94] (data from 2016).

However, investment in automation is increasing, with 66% of companies surveyed for the 2017 Food and Drink Report[95] planning to invest in manufacturing automation, and 52% of respondents surveyed for the 2015 Barclays Food for thought report[96] saying that they are increasing investment in process automation for food and drink production.

Robots in the food industry are typically used for tasks such as picking, packaging, cutting, or palletising. For example, Charnwood Foods, based in Leicester, uses a robot to palletise cases of pizza bases for restaurants. The robot allows palletising of up to 320 cases per hour, around the clock.[97]

More recently, in 2016, the University of Lincoln's National Centre for Food Manufacturing and Olympus Automation (OAL) launched APRIL, an Automatic Processing Robotic Ingredient Loading system, which can mix, load and cook ingredients on an industrial scale with minimal human intervention. Typical applications for APRIL could be the manufacture of soups, sauces, and ready meals. [98]

According to Mark Reeve, Chairman of the Eastern Agri-Tech Growth Initiative, APRIL will "kick-start the industry's move towards fully automated production lines, allowing food to be produced quicker, with less waste and greater precision".[99]

6 Benefits to the UK economy from Industry 4.0 technologies

A number of studies have been undertaken to estimate the benefits that Industry 4.0 could bring to the UK economy and the world. This includes studies quantifying the overall benefit of Industry 4.0,

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[92] *PwC (2016). Industry 4.0: Building the digital enterprise – Aerospace, defence and security key findings.* Available at: https://www.pwc.com/gx/en/aerospace-defence-and-security/publications/assets/industry-4.0-aerospace-key-findings.pdf [accessed 12/01/2018]

[93] Aurora Ceres Partnership (2016). *Robotics in food and beverage manufacturing.* Available at: http://auroraceres.co.uk/robotics-in-food-and-beverage-manufacturing/ [accessed 12/01/2018]

[94] OAL (2016). *Time to act: Robotics in food and beverage manufacturing.* Available at: https://www.oalgroup.com/news/time-act-robotics-food-beverage-manufacturing [accessed 12/01/2018]

[95] BDO (2017). *2017 Food and Drink Report.* Available at: http://www.bdo.co.uk/getmedia/1c77e27b-69eb-40ff-987f-9f1a597ddb7e/BDO-Food-and-Drink-Report-2017-May.aspx [accessed 12/01/2018]

[96] Barclays (2015). *Food for thought: The changing landscape of the food and drink industry.* Available at: https://www.barclayscorporate.com/content/dam/corppublic/corporate/Documents/research/Food-and-drink-report.pdf [accessed 12/01/2018]

[97] BARA (n.d.). *Pizza Cartons palletised by Robot.* Available at: http://www.bara.org.uk/info/casestudies/motomannew.html [accessed 30/01/2018]

[98] Allen, E. (2016). *APRIL the 'robotic chef' that will transform food manufacturing industry to be unveiled at NCFM.* The University of Lincoln. Available at: http://www.lincoln.ac.uk/news/2016/04/1216.asp [accessed 23/01/2018]

[99] Reeve, M. as cited in Food (2016). *Robochef to be launched in the UK.* Available at: http://www.foodprocessing.com.au/content/prepared-food/news/robochef-to-be-launched-in-the-uk-9749438 [accessed 23/01/2018]

as well as studies aiming to estimate the benefits of specific technologies. A non-comprehensive overview of studies undertaken can be found in Table 7.

Analysis cited in the 2017 Made Smarter Review[100] found that the benefits of a faster adoption of Industry 4.0 technologies could be as high as **£455 billion** over the next decade[101], result in a net gain of **175,000** jobs[102], reduce CO2 emissions by **4.5%[103],** and improve industrial productivity by more than **25%[104]** by 2025.

Moreover, analysis undertaken by the Boston Consulting Group (BCG)[105] found that, by leading the next industrial revolution, the UK could increase manufacturing sector growth rates by **1.5 to 3** percent and realise industrial efficiency gains of around **25%**. Taken together these gains could deliver growth of around **0.5%** of GDP annually, according to the BCG estimates.

In terms of specific technologies, estimates of potential impacts on the world economy suggest that:

- The **Internet of Things** could generate potential direct impacts of around **$2.7 trillion to $6.2 trillion** per annum in 2025[106], while the **Industrial Internet of Things** could add between **$10.6 trillion and $14.2 trillion** to the world economy by 2030[107].
- The **Industrial Internet**, could generate average income gains, in the US, of between **25%-40%** of US GDP per capita by 2030 and deliver global health-care cost savings of roughly **25%** (approximately **$100 billion** per year)[108].
- The potential direct impacts of **advanced robotics** on the world economy could be in the region of around **$1.7 trillion to $4.5 trillion** per annum by 2025[109].
- **Additive manufacturing** (3D printing) could generate around **$0.2 trillion to $0.6 trillion** in direct effects per annum by 2025[110].
- **Artificial intelligence** could contribute up to **£15.7 trillion** to the world economy in 2030, $6.6 trillion of which would be derived from increased productivity, while $9.1 trillion would be derived from consumption side-effects[111].

In the UK, a moderate increase in investment of around £1.24 billion in **automation and robotic equipment** was estimated to yield around **£60.5 billion** in value added to the UK manufacturing sector over the next decade in direct effects only, and a further **£2.5 (£3.9) billion** a year by 2020 (2025) in indirect effects[112]. Moreover, non-military Robotics and Autonomous Systems were

[100] Made Smarter Review: Industrial Digitalisation 2017
[101] ACCENTURE REPORT: *2017 Industrial Digitalisation Review Benefits Analysis* as reported in the *Made Smarter Review: Industrial Digitalisation 2017*
[102] Made Smarter Review (2017) working group report on jobs and the economy as reported in the *Made Smarter Review: Industrial Digitalisation 2017*
[103] Made Smarter Review (2017) sustainability working group report as reported in the *Made Smarter Review: Industrial Digitalisation 2017*
[104] Made Smarter Review: Industrial Digitalisation 2017
[105] Boston Consulting Group (2017). *Is UK Industry ready for the Fourth Industrial Revolution*
[106] McKinsey (2013). *Disruptive technologies: Advances that will transform life, business, and the global economy*
[107] Accenture (2015). *The Growth Game-Changer: How the Industrial Internet of Things can drive progress and prosperity*
[108] Evans and Anninziata (2012). *Industrial Internet: Pushing the Boundaries of Minds and Machines*
[109] McKinsey (2013). *Disruptive technologies: Advances that will transform life, business, and the global economy*
[110] McKinsey (2013). *Disruptive technologies: Advances that will transform life, business, and the global economy*
[111] PWC (2017). *Sizing the prize – What's the real value of AI for your business and how can you capitalise?*
[112] Rigby, M. (n.d.). *Future-proofing UK manufacturing: Current investment trends and future opportunities in robotic automation.* Barclays.

estimated to impact more than **15%** of GVA **(£218 billion**) by 2020-2025, and increase long-term employment by up to **7%**, if current RAS technology was optimised[113].

In terms of productivity improvements, the Boston Consulting Group[114] estimates that Industry 4.0 could deliver productivity increases of around **20-30%** in the components manufacturing and other manufacturing sectors, while food and beverage, machinery, and automotive manufacturing could see a productivity increase of around **10-20%**, as measured by conversion rates.

Productivity improvements of specific technologies are estimated to be:

- **Additive manufacturing** could deliver cost reductions of around **48%** compared to traditional manufacturing methods when used in the production satellites[115].
- **Robotics and Autonomous Systems** have the potential to raise manufacturing sector productivity by up to **22%**[116], and are already delivering operating expense savings of picking and packing processes of around **20%** in Amazon's fulfilment centres[117].
- **Data-driven decision making** could improve output and productivity of adopters by **5% - 6%** compared to expectations given their investments information and communication technology.[118] Moreover, presenting data more concisely and consistently across company platforms could yield a **14%** increase in labour productivity for a 10% increase in the usability of data.[119]
- **Autonomous mine haulage trucks** could increase output by **15-20%**, reduce fuel consumption by **10-15%**, and reduce maintenance costs by **8%**[120], while **autonomous drill rigs** could deliver productivity improvements of **30-60%**[121].
- Industrial adopters of the **Internet of Things** reported cost reductions of **16%**, on average, and revenue increases of **19%**, on average[122].

[113] Special Interest Group Robotics and Autonomous Systems (2014). *RAS 2020 Robotics and Autonomous Systems.*
[114] Boston Consulting Group (n.d.). *The Benefits of Industry 4.0*. Available at: https://www.bcg.com/expertise/centers-accelerators/innovation-operations/default.aspx [accessed 30/01/2018]
[115] Lockheed Martin (n.d.). *3D Printing 101*. Available at: https://www.lockheedmartin.com/us/news/features/2014/1-15-3dmanufacturing/3d-printing-101.html [accessed 29/01/2018]
[116] Special Interest Group Robotics and Autonomous Systems (2014). *RAS 2020 Robotics and Autonomous Systems.*
[117] Dave Clark, Senior Vice President of Worldwide Operations and Customer Service at Amazon. Cited by: Citigroup-Oxford (2017). *TECHNOLOGY AT WORK v3.0: Automating e-Commerce from Click to Pick to Door*
[118] Brynjolfsson, Hitt and Kim (2011). *Strength in Numbers: How Does Data-Driven Decisionmaking Affect Firm Performance?*
[119] Barua, Mani and Mukherjee (2013). *Measuring the Business Impacts of Effective Data*
[120] Meech, J. (2012). *Simulation of Autonomous Mine Haulage Trucks*
[121] Citigroup-Oxford (2015). *TECHNOLOGY AT WORK: The Future of Innovation and Employment*
[122] Vodafone (2017). *IoT Barometer 2017/18*

Table 7 Estimates of the economic impact of robotics, automation, and digitalisation

Source	Regional coverage	Sectoral coverage	Technological coverage	Estimated impact
Accenture (2017). *Industrial Digitalisation Review Benefits Analysis* (Made Smarter Review (2017))	UK	Manufacturing	Industry 4.0	Value at stake estimated to be approximately £455 billion over the next decade
		Construction		Value at stake estimated to be approximately £89 billion over the next decade
		Food and drink		Value at stake estimated to be approximately £56 billion over the next decade
		Pharmaceuticals		Value at stake estimated to be approximately £22 billion over the next decade
		Aerospace		Value at stake estimated to be approximately £18 billion over the next decade
Made Smarter Review (2017). *Working group report on jobs and the economy*	UK	Total economy	Industry 4.0	Net gain of 175,000 jobs.
Made Smarter Review (2017). *Sustainability working group report*	UK	Total economy	Industry 4.0	Reduction in CO2 emissions by 4.5 percent.
Made Smarter Review: Industrial Digitalisation 2017	UK	Total economy	Industry 4.0	Improve industrial productivity by more than 25% by 2025.
BCG (2017). *Is UK Industry ready for the Fourth Industrial Revolution*	UK	Manufacturing	Industry 4.0	Industrial efficiency gains of 25% and increased manufacturing sector growth rates of 1.5-3 percent, delivering growth of around 0.5% of GDP annually.
BCG (n.d.), *The Benefits of Industry 4.0.*	UK	Automotive	Industry 4.0	10-20% productivity increase, measured by conversion costs
		Food and beverage		10-20% productivity increase, measured by conversion costs
		Components		20-30% productivity increase, measured by conversion costs
		Machinery		10-20% productivity increase, measured by conversion costs
		Other manufacturing		20-30% productivity increase, measured by conversion costs
Accenture (2015). *The Growth Game-Changer: How the Industrial Internet of Things can drive progress and prosperity*	World	Total economy	Industrial Internet of Things	Add $10.6 trillion to the world economy by 2030, given current investment levels. The estimate could rise to up to $14.2 trillion with greater investment and the enactment of key measures to absorb IIoT technologies.
KPMG (2016). *The Digitalisation of the UK Automotive Industry*	UK	Automotive	Industry 4.0	Fully embracing digitalisation could yield gains of £6.9 billion every year by 2035 for the automotive sector, and a benefit to the total economy of around £74 billion cumulatively by 2035.
Barclays (n.d.). *Future-proofing UK manufacturing*	UK	Manufacturing	Automation / robotic equipment	Estimated the value added to the UK by the manufacturing sector of a moderate increase in investment in automation of £1.24 billion to be £60.5 billion over the next decade (direct effects), and a further £2.5 billion a year by 2020 and £3.9 billion a year by 2025 (indirect effects).

Source	Regional coverage	Sectoral coverage	Technological coverage	Estimated impact
McKinsey (2013). *Disruptive technologies: Advances that will transform life, business, and the global economy*	World	Total economy	Internet of Things	Potential direct economic impact of $2.7 to $6.2 trillion per annum in 2025.
			Advanced Robotics	Potential direct economic impact of $1.7 to $4.5 trillion per annum in 2025.
			3D Printing	Potential direct economic impact of $0.2 to $0.6 trillion per annum in 2025.
McKinsey (2018). *Disruptive force in the industrial sectors*	Global	Total economy	Artificial Intelligence	Market size for AI estimated to grow at an annual rate of 50% - 60% from $2 billion in 2016 to $130 billion in 2025.
			Connected devices	Connected devices estimated to growth at an annual rate of 15% - 20% from 18 billion units in 2016 to 75 billion units in 2025.
			Cybersecurity	Market size for cybersecurity estimated to grow at an annual rate of 5% - 10% from $96 billion in 2016 to $210 billion in 2025.
Special Interest Group Robotics and Autonomous Systems (2014). *RAS 2020 Robotics and Autonomous Systems.*	UK	Non-military	Robotics and Autonomous Systems	Estimated market for non-military Robotics and Autonomous Systems (RAS) products and technologies of £70 billion by 2020-2025, impacting 15% of GVA (£218 billion) on the UK economy, and a potential to raise manufacturing sector productivity by up to 22%, generating a long-term employment increase of up to 7%, if current RAS technology was optimised.
Lockheed Martin (n.d.). *3D Printing 101*.	Firm level	Satellite production	3D Printing	Utilising 3D titanium printing in satellite production can reduce cycle time by 43% and yield a cost reduction of 48% compared to traditional satellite production.
PWC (2017). *Sizing the prize – What's the real value of AI for your business and how can you capitalise?*	World	Total economy	Artificial intelligence	Contribution of up to £15.7 trillion in 2030 ($6.6 trillion from increased productivity and $9.1 trillion from consumption side-effects).
Brynjolfsson, Hitt and Kim (2011). *Strength in Numbers: How Does Data-Driven Decisionmaking Affect Firm Performance?*	United States	Firm level	Data-driven decision making	Firms that adopt data-driven decision making have 5% - 6% higher output and productivity than expected, given their investments in other information and communication technology.
Barua, Mani and Mukherjee (2013). *Measuring the Business Impacts of Effective Data*	Fortune 1000 firms	Firm level	Data-driven decision making	A 10% increase in the usability of data - presenting data more concisely and consistently across company platforms (e.g. laptops) - is associated with a 14% increase in labour productivity on average.
Citigroup-Oxford (2015). *TECHNOLOGY AT WORK: The Future of Innovation and Employment*	Firm level	Mining	Autonomous drill rigs	Shifting to autonomous drill rigs can increase productivity by 30% - 60%.

Source	Regional coverage	Sectoral coverage	Technological coverage	Estimated impact
Meech, J. (2012). *Simulation of Autonomous Mine Haulage Trucks*	Firm level	Mining	Autonomous mine haulage trucks	Shifting to autonomous mine haulage trucks is associated with a 15-20% increase in output, a 10-15% decrease in fuel consumption, and an 8% reduction in maintenance costs.
Dave Clark, Senior Vice President of Worldwide Operations and Customer Service at Amazon. Cited by: Citigroup-Oxford (2017). *TECHNOLOGY AT WORK v3.0: Automating e-Commerce from Click to Pick to Door*	Firm level	e-Commerce	Autonomous warehouse robots	Automated picking and packing processes, utilising Kiva robots, reduce operating expenses of Amazon's fulfilment centres by ~20%.
Evans and Anninziata (2012). *Industrial Internet: Pushing the Boundaries of Minds and Machines*	US	Total economy	Industrial Internet	If the industrial internet could achieve a productivity growth differential similar to the internet revolution (3.1%), it could generate average income gains of $20,000 by 2030, approximately 40% of current US GDP per capita. A more conservative productivity growth of 2.6% would still deliver average income gains equivalent to 25% of US GDP per capita.
	Global	Health care		Deployment of the industrial internet can drive health-care costs down by roughly 25% - equivalent to approximately $100 billion in savings per year.
		Commercial aviation		Cost reductions of 1% from better flight planning and operational changes, brought about by the industrial internet, could save the global commercial airline business nearly $2 billion in fuel costs per year, or approximately $30 billion over 15 years. A 1% reduction in capital expenditures, brought about by the industrial internet, could result in cost savings of $1.3 billion per year, or approximately $29 billion over 15 years. A 1% improvement in maintenance efficiency due to the industrial internet could reduce commercial jet engine maintenance costs by $250 million.
		Rail transportation		A 1% reduction in rail operations systems inefficiencies, brought about by the industrial internet, would save about $1.8 billion per or, or approximately $27 billion over 15 years.
		Power production		Improvements in country-level average gas generation efficiency of 1%, due to the industrial internet, would reduce fuel spending by more than $3 billion in 2015 and $4.4 billion in 2020, or approximately $66 billion over a 15 year period.
		Oil & Gas Development and Delivery		An additional 1% reduction in capital expenditure, due to the industrial internet, would translate into savings of $6 billion per year or $90 billion over 15 years.
Vodafone (2017). *IoT Barometer 2017/18*	World	Firm level	Internet of Things	Among industrial adopters, the Internet of Things increased revenue by 19% on average and cut costs by 16% on average.

Source: London Economics

7 Benefits to the UK space sector

7.1 Methodology

To understand the economic impacts Industry 4.0 technologies could bring to the UK Space Manufacturing sector an economic impact assessment was undertaken. This section provides an overview of the methodology employed. Estimated benefits to the UK industry are presented in Section 7.2. A more detailed methodological discussion can be found in Annex 1.

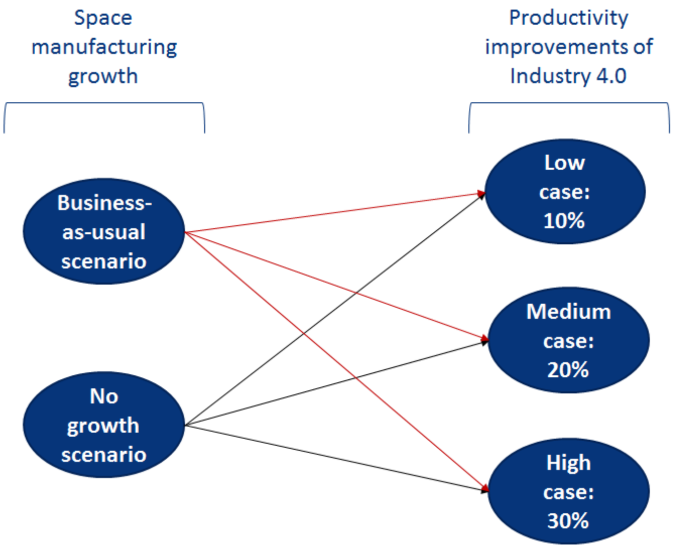
Economic impacts, up to 2035, were estimated relative to two baseline scenarios:

- **Business-as-usual scenario**[123]: Linear projection of past upstream trend – based on Size and Health of the UK Space Industry 2016 data[124]
- **No growth scenario**[125]: No further growth to Space Manufacturing over the next decade, i.e. no further innovations, no large-constellations, etc.

For each baseline scenario, three cases, based on estimated productivity improvements in other sectors (see beginning of Section 6), were estimated:

- **Low case**: Industry 4.0 could deliver productivity improvements of **10%**
- **Medium case**: Industry 4.0 could deliver productivity improvements of **20%**
- **High case:** Industry 4.0 could deliver productivity improvements of **30%**

Figure 33 Impact assessment: Overview of scenarios



Source: London Economics

[123] While actual Space Manufacturing growth is likely to differ from past trend in practice, this scenario provides a useful counterfactual, which allows estimation of benefits relative to what may have happened in the absence of adoption. The business-as-usual scenario is also recommended as the preferred scenario for evaluations by the UK government (HM Treasury (2018). *The Green Book: Central Government Guidance on Appraisal and Evaluation).*

[124] Size and Health of the UK Space Industry 2016, a report for the UK Space Agency by London Economics https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/575769/Size_and_Health_summary_report_2016.pdf

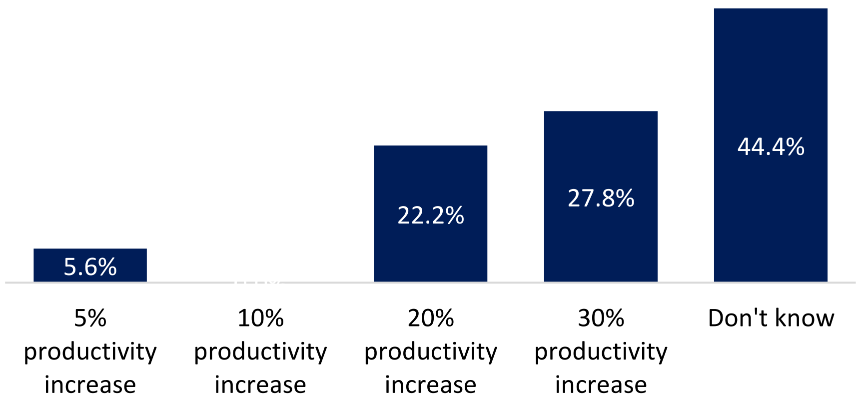
[125] Failure of adoption of Industry 4.0 may put the UK Space Manufacturing sector at a disadvantage relative to countries that do adopt. This may result in a contraction of the UK Space Manufacturing sector. However, whether such a contraction will occur, and, if it does, how sizable this contraction may be is very difficult to predict.

Two of these, the 20% and 30% case, were selected as the most likely cases, for the following reasons:

- Current adoption of Industry 4.0 technologies in UK Space Manufacturing is low. Therefore, productivity improvements of adoption are likely to be higher than in sectors where robotics and other technologies are already widely used, such as automotive.
- As Industry 4.0 is not, currently, widely used in Space Manufacturing, it could help increase productivity in both the design as well as the manufacturing stage. In this respect, Space Manufacturing is more similar to the components and other manufacturing industries, for which the productivity benefits are estimated to lie in the region of 20% - 30%[126], than to sectors that are further ahead in terms of adoption.
- Industry experts judged these cases as more likely (Figure 34).

Estimates for these two cases are presented in Section 7.2. Estimates for the **low case**, assuming Industry 4.0 could deliver productivity improvements of **10%**, are presented in Annex A1.3.

Figure 34 What productivity benefits do you think Industry 4.0 can bring to your organisation or sector?



Note: Nr. of responses = 18 Space Manufacturing firms.

Source: London Economics

To estimate economic benefits, assumptions regarding the adoption process of Industry 4.0 technologies have to be made. Assumptions made were based on previous experience of the UK space sector, consultations with industry experts and comparison of assumptions and the resulting adoption process with the literature (Section A1.3).

Section A1.3 further provides a discussion on the robustness of these assumptions as well as the sensitivity of estimated benefits to assumptions made.

The following assumptions regarding current and future use[127] of Industry 4.0 technologies in the Space Manufacturing sector were made:

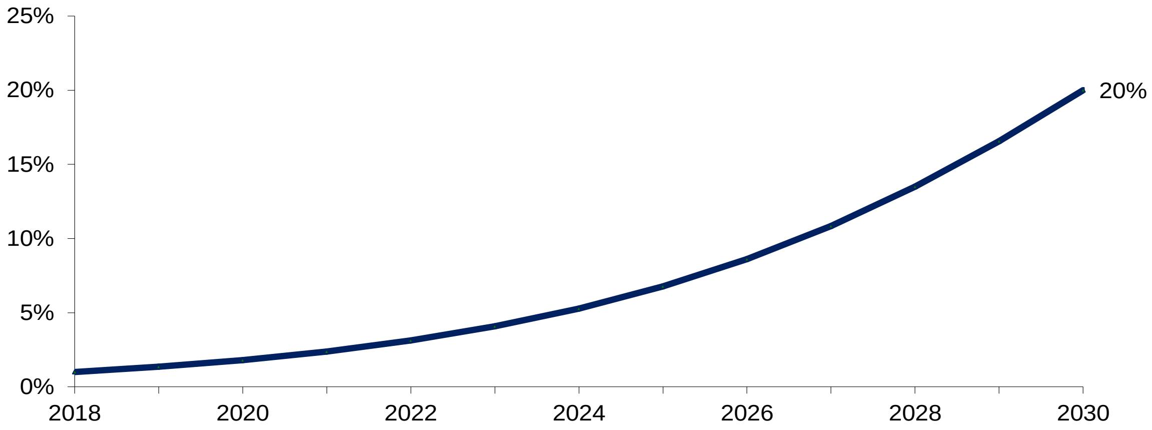
[126] Boston Consulting Group (n.d.). *The Benefits of Industry 4.0*. Available at: https://www.bcg.com/expertise/centers-accelerators/innovation-operations/default.aspx [accessed 30/01/2018]

[127] In terms of space manufacturing revenue. I.e.: By 2030, Industry 4.0 technologies could support 20% of Space Manufacturing revenue and could ultimately support up to 50% of Space Manufacturing revenue.

- Current adoption: 1%
- Adoption by 2030: 20%
- Adoption potential[128]: 50%

Given these assumptions, an adoption process, depicted in Figure 35, was derived.

Figure 35 Estimated adoption of Industry 4.0 technologies in the UK Space Manufacturing sector



Source: London Economics

Given these three elements, potential benefits to the UK Space Manufacturing sector were derived as follows:

Potential benefit in t =

Baseline Income in t *
Potential productivity improvements delivered by Industry 4.0 *
Potential adoption rate of Industry 4.0 technologies in t

Associated effects to the downstream segment are based on an econometric analysis of the relationship between the growth in the UK upstream and downstream segments using revenue data obtained from the 2016 Size and Health of the UK Space Industry 2016[129] (see Annex 1).

To estimate associated downstream effects, estimated UK Space Manufacturing benefits were converted to corresponding changes in UK upstream revenue growth. The estimated relationship between the upstream and downstream segments was then used to estimate associated changes in downstream revenue growth.

Associated downstream effects were estimated relative to three baseline scenarios, mirroring the Space Manufacturing baselines:

[128] Note that the model implies that the full potential of Industry 4.0 technologies in the UK Space Manufacturing sector is not reached until the mid-2040s. This is consistent with other estimates as well as well as with historical data from other technologies, for example the Boston Consulting Group estimates that a full shift towards Industry 4.0 in manufacturing could take 20 years. For further discussions see Annex 1.
[129] Size and Health of the UK Space Industry 2016, a report for the UK Space Agency by London Economics https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/575769/Size_and_Health_summary_report_2016.pdf

- **Business-as-usual scenario**: Linear projection of past upstream and downstream trends – based on Size and Health of the UK Space Industry 2016 data
- **No growth scenario**: No further growth to upstream and downstream over the next decade, i.e. no further innovations, no large-constellations, etc.

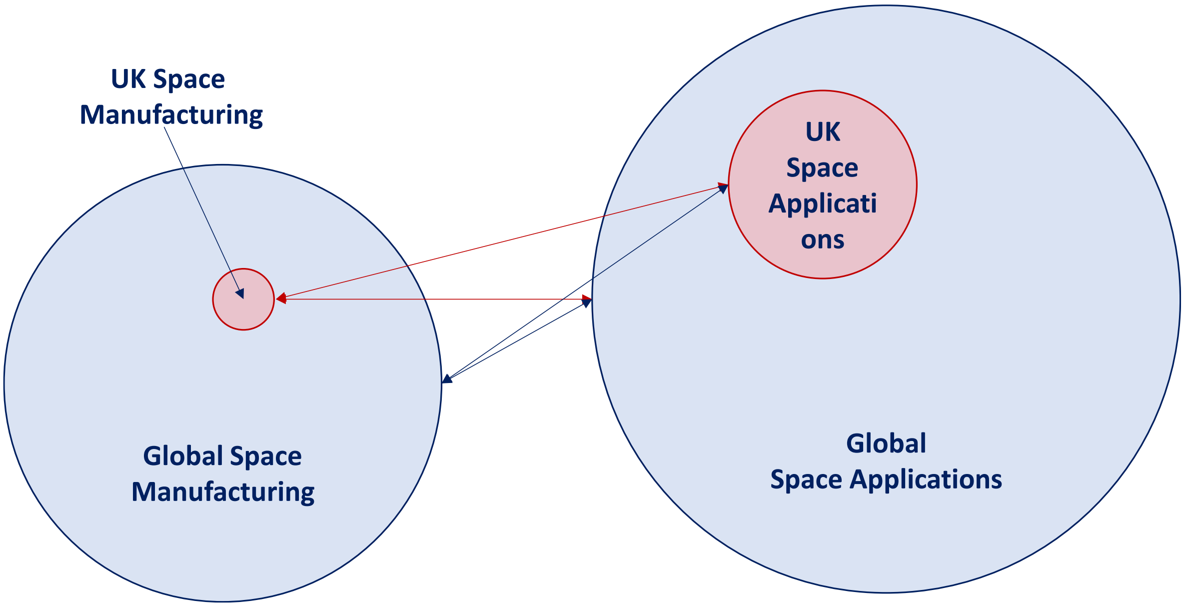
Note, that associated downstream benefits are benefits accruing to the UK downstream segment, associated with **adoption of Industry 4.0 in terrestrial Space Manufacturing in the UK**.

However, companies outside the UK can utilise, for example, satellites produced in the UK. Therefore, there will likely be further associated downstream effects outside the UK – these are not quantified.

Similarly, companies in the UK can also utilise, for example, satellites produced outside of the UK. Therefore, wider adoption of Industry 4.0 in Space Manufacturing outside of the UK will likely be associated with further downstream effects in the UK – these are not quantified.

This relationship is represented in Figure 36, below.

Figure 36 Relationships between UK and global Space Manufacturing and Applications



Source: London Economics; data on global sector sizes obtained from OECD's The Space Economy at a Glance 2014

It should also be noted, that benefits of adoption of Industry 4.0 in downstream, or benefits of potential market opportunities (including large-constellations) are not quantified.

7.2 Estimated benefits

This section presents the estimated benefits, of wider adoption of Industry 4.0 technologies, to the UK space industry. Section 7.2.1 provides a comparison of estimated benefits with other sectors. Sections 7.2.2, and 7.2.3 discuss the business-as-usual, and no-growth scenarios, respectively. Figure 37 and Table 7 provide an overview of the estimated annual and cumulative benefits, in real terms, by 2035, in terms of potential increases in space industry revenue, across the scenarios considered.

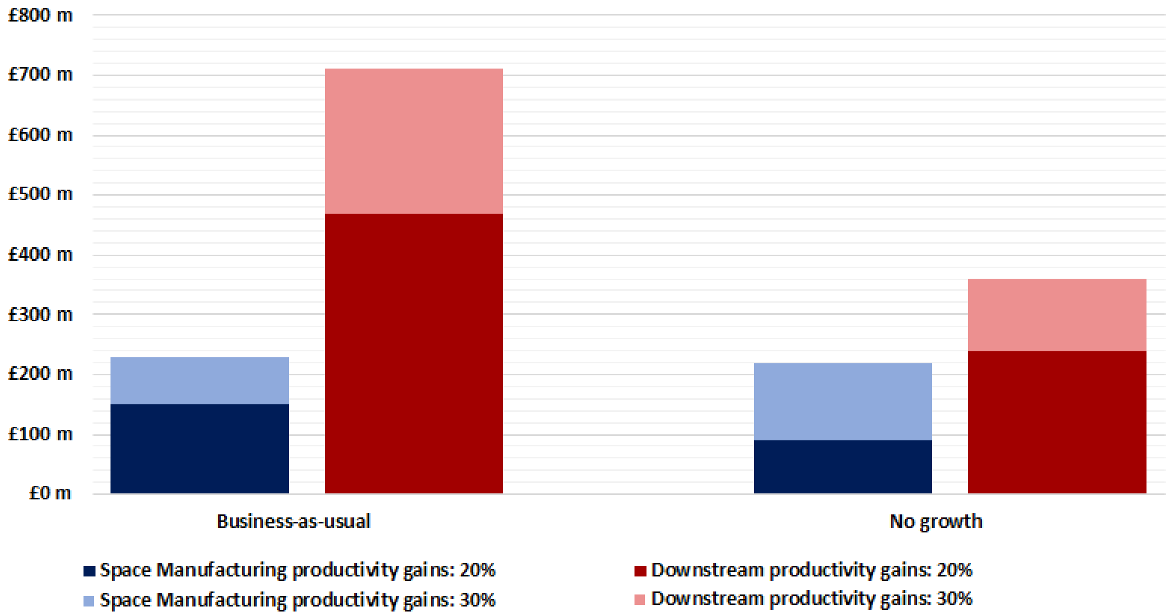
In the scenario that the **UK space industry continues to grow as indicated by past trends** (business-as-usual scenario), annual revenue increases, by 2035, associated with wider adoption of Industry 4.0 technologies, as shown in Figure 37, are estimated to be between:

- **£150 million** (20% productivity improvements) and **£230 million** (30% productivity improvements) to the Space Manufacturing sector, and
- **£470 million** (20% productivity improvements) and **£710 million** (30% productivity improvements) in associated downstream effects.

This is equivalent to, approximately, between:

- **5%** (20% productivity improvements) and **8%** (30% productivity improvements) of 2035 baseline Space Manufacturing revenue (£3.0 billion), and
- **2%** (20% productivity improvements) and **3%** (30% productivity improvements) of 2035 baseline downstream revenue (£23.4 billion).

Figure 37 Overview of potential annual increase in revenue by 2035



Notes: Graph shows the potential cumulative increase in revenue, by 2030, associated with a more widespread adoption of Industry 4.0 technologies. ***Source: London Economics***

Cumulative revenue increases, by 2035, associated with wider adoption of Industry 4.0 technologies, as shown in Table 8, are estimated to be between:

- **£0.9 billion** (20% productivity improvements) and **£1.4 billion** (30% productivity improvements) to the Space Manufacturing sector, and
- **£2.5 billion** (20% productivity improvements) and **£3.8 billion** (30% productivity improvements) in associated downstream effects.

Estimated benefits to the UK Space Manufacturing sector are in line with estimates of the benefits of wider adoption of Industry 4.0 technologies, from previous studies, for other sectors. Estimated associated downstream effects are also in line with expectations, given historical differences in size between the upstream and downstream segments. (See Section 7.2.1)

Table 8 Overview of potential cumulative increase in revenue by 2035

Baseline scenario	Productivity improvements of Industry 4.0	UK Space Manufacturing	Associated effects: UK downstream segment		Total
			Primary	Secondary	
Business-as-usual	Medium case: 20%	£0.9 bn	£1.1 bn	£1.4 bn	**£3.4 bn**
	High case: 30%	£1.4 bn	£1.6 bn	£2.1 bn	**£5.1 bn**
No growth	Medium case: 20%	£0.6 bn	£0.6 bn	£0.8 bn	**£2.0 bn**
	High case: 30%	£0.9 bn	£1.0 bn	£1.2 bn	**£3.1 bn**

Notes: Table shows the potential cumulative increase in revenue, by 2030, associated with a more widespread adoption of Industry 4.0 technologies. ***Source: London Economics***

The following **caveats** should be noted:

- Increased adoption beyond the levels assumed in this report could deliver additional benefits to the UK space industry. The impact of changes in assumed adoption are discussed in Annex A1.6.4. Moreover, a rise in large-constellations, or other disruptions, could also deliver additional benefits to the space industry. However, due to the uncertainty surrounding these constellations, benefits were not quantified.
- A rise in adoption in UK Space Manufacturing is likely to have additional effects on the downstream segment outside the UK (not quantified). For example, satellites manufactured in the UK can be utilised by Space Applications developed outside the UK.
- Wider adoption of Industry 4.0 technologies in Space Manufacturing outside of the UK is also likely to have additional effects on the UK downstream segment (not quantified). For example, satellites manufactured outside the UK can be utilised by Space Applications developed in the UK.

7.2.1 Comparison of estimated benefits with other studies

Table 9 provides a comparison between cumulative benefits of wider adoption of Industry 4.0 for the UK Space Manufacturing sector, with estimates for other sectors.

As can be seen, estimated benefits for other sectors tend to be larger than those estimated in this study. However, this is mainly due to the relatively larger size of those sectors compared to the UK Space Manufacturing sector. When sector size is taken into account, estimated benefits are in line with those for other sectors.

Table 9 Industry 4.0 benefits, comparison with UK manufacturing

Sector	Benefits accrued over	Benefit type	Cumulative benefits		Cumulative Space Manufacturing revenue increase, by 2035	
			as reported	adjusted by sector size	Business-as-usual	No growth
Manufacturing	10 years, by 2027	Revenue increases and cost reductions	£455.0 bn	£0.9 bn	£0.5 bn - £1.4 bn	£0.3 bn - £0.9 bn
Construction			£89.0 bn	£0.4 bn		
Food and drink			£56.0 bn	£0.6 bn		
Pharmaceuticals			£22.0 bn	£1.5 bn		
Aerospace			£18.0 bn	£0.7 bn		
Automotive	20 years, by 2035	GVA	£74.0 bn	£1.2 bn		

Note: Benefits were adjusted based on sector size using 2014/15 turnover of each sector relative to Space Manufacturing turnover. Cumulative Space Manufacturing benefits are provided as a range with the low estimate for the case of 10% productivity improvements and the high estimate for the case of 30% productivity improvements.

Source: London Economics; benefits of other sectors obtained from 2017 Made Smarter Review, except for automotive, which was obtained from KPMG (2016). The Digitalisation of the UK Automotive Industry; sectoral turnover obtained from BEIS: business population estimates for the UK and regions 2015 for manufacturing, construction, food and drink, and pharmaceuticals, from ADS: Industry Facts & Figures 2016 for aerospace, from The Society of Motor Manufacturers and Traders: Motor Industry Facts 2016, and from Size and Health of the UK Space Industry 2016 for Space Manufacturing

To sense check the estimated associated downstream benefits, we compared the size of the downstream sector to the size of the upstream sector (Figure 10). This was done by comparing historical revenues in the two sectors between 2010/11 and 2014/15 based on data from the Size and Health of the UK Space Industry 2016 (section 7.2.1). The ratio of revenue between the upstream and downstream sector was 1 to 7.4.

The associated downstream UK benefits estimated in this study are 1 to 2.8. This is reasonable given the following features of the sector:

- Companies outside the UK can utilise, e.g., satellites produced in the UK. Hence, there will likely be further associated downstream effects outside the UK.
- UK companies can also utilise, e.g., satellites produced outside the UK. Hence, part of the difference in size between the UK upstream and downstream segments can be explained by this.
- There are other factors besides Industry 4.0 adoption in Space Manufacturing that affect downstream growth. Estimates in this study seek to isolate the relationship between the UK upstream and downstream sectors.

Table 10 Associated downstream effects, comparison with historical differences in UK upstream and downstream sector size

Year	Downstream income (£m)	Upstream income (£m)	Size of downstream segment relative to upstream segment	Size of associated downstream effects relative to Space Manufacturing benefits*	
				Business-as-usual	No growth
2010/11	9,133	1,112	8.2	2.8	2.5
2011/12	10,475	1,505	7.0		
2012/13	10,970	1,368	8.0		
2013/14	11,682	1,787	6.5		
2014/15	11,998	1,704	7.0		
Average:	-	-	7.4		

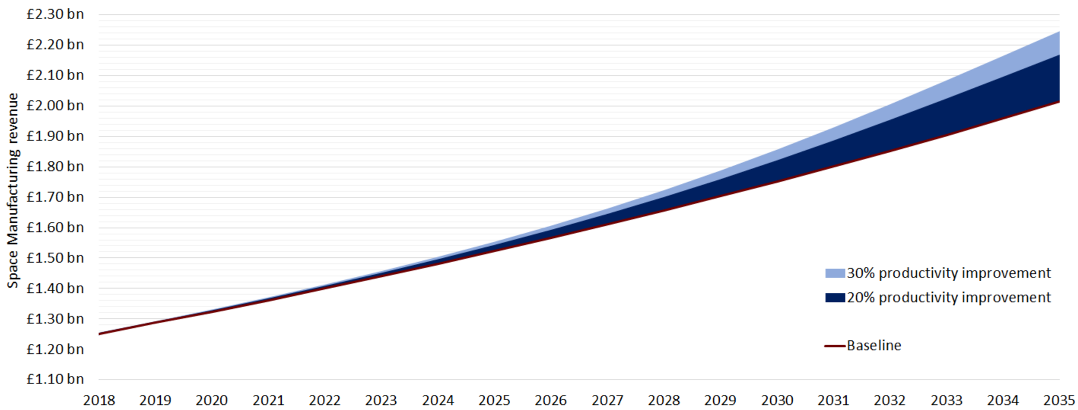
Note: As companies outside the UK can utilise, e.g., satellites produced in the UK, not all associated downstream benefits are expected to accrue to the UK sector. Conversely, the UK can also utilise, e.g., satellites produced outside the UK. Therefore, associated downstream effects are expected to be lower than the historical difference in size between the UK upstream and downstream segments. (*) Refers to the relationship of cumulative downstream benefits over the whole study period, relative to cumulative Space Manufacturing benefits over the whole study period. Relationship is not static, but changes in line with adoption. See Annex A1.4 for further details.

Source: London Economics; downstream and upstream income obtained from Size and Health of the UK Space Industry 2016

7.2.2 Business-as-usual scenario

If the UK space industry continues to grow as indicated by past trends, wider adoption of Industry 4.0 technologies, as shown in Figure 35, is associated with potential annual increases in UK Space Manufacturing revenue, by 2035, of approximately **£150 million**, for a 20% increase in productivity. Estimated annual revenue increases, by 2035, could rise to **£230 million**, for an increase in productivity of 30%.

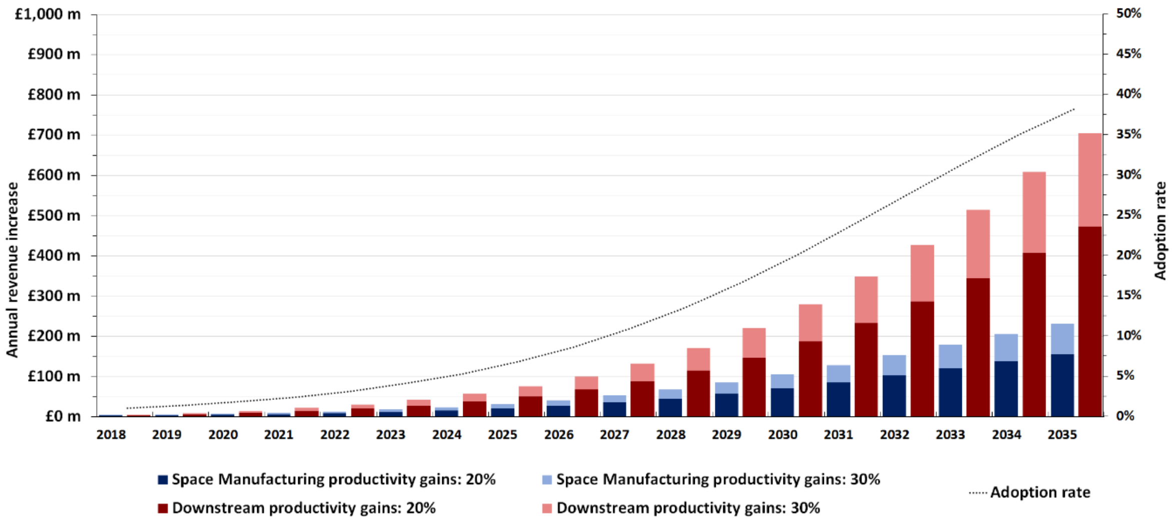
Figure 38 Estimated revenue compared to baseline, UK Space Manufacturing



Source: London Economics

Revenue increases in the upstream segment are also associated with further revenue increases in the downstream segment. If the UK space industry continues to grow as indicated by past trends, annual associated downstream effects (primary and secondary) are estimated to be **£470 million** in higher downstream revenues by 2035, for a 20% in productivity. If Industry 4.0 technologies can deliver productivity improvements of 30%, annual associated downstream effects are estimated to rise to **£710 million**, by 2035.

Figure 39 Estimated annual revenue increases, UK Space Manufacturing and UK downstream



Source: London Economics

Overall, in the case that the UK space industry continues to grow as indicated by past trends, wider adoption of Industry 4.0 technologies is associated with potential cumulative revenue increases to the UK Space sector (upstream + downstream) of **£3.4 billion**, for a 20% increase in, rising to **£5.1 billion** for a 30% increase in productivity.

Approximately 74% of benefits are estimated to accrue through associated effects to the UK downstream segment, while 26% are estimated to accrue directly to the UK Space Manufacturing sector. (Figure 40 and Figure 41)

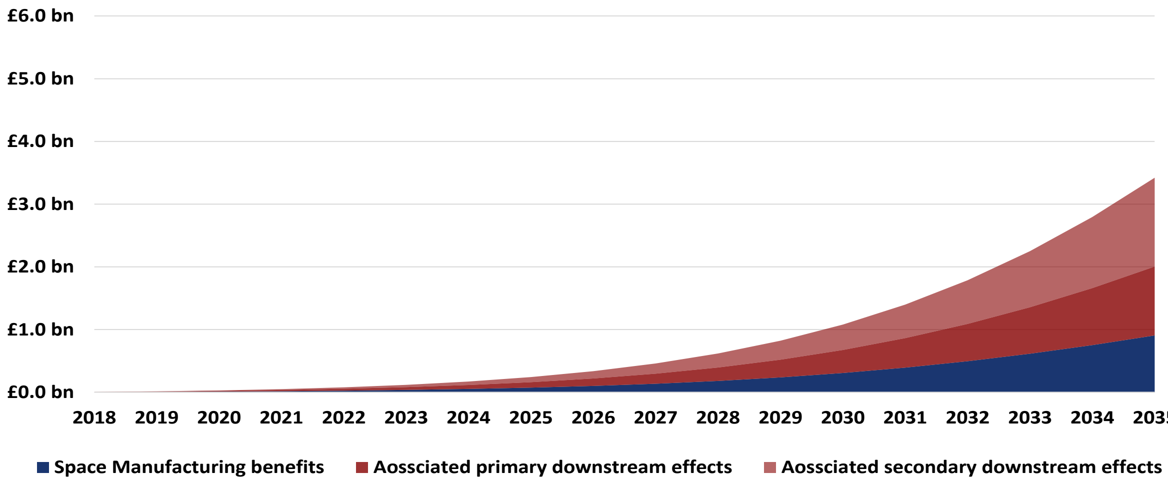
Due to the current low levels of adoption and the associated slow initial uptake of Industry 4.0 technologies, it is estimated that a large share of estimated benefits will only accrue in later periods (Table 11).

Table 11 Estimated cumulative revenue increases, UK Space Manufacturing and UK downstream, by period

Sector	Space Manufacturing		Downstream	
Productivity improvements	**20%**	**30%**	**20%**	**30%**
Whole period	£0.9 billion	£1.4 billion	£2.5 billion	£3.8 billion
2025-2035	£0.9 billion	£1.3 billion	£2.4 billion	£3.6 billion
2030-2035	£0.7 billion	£1.0 billion	£1.9 billion	£2.9 billion

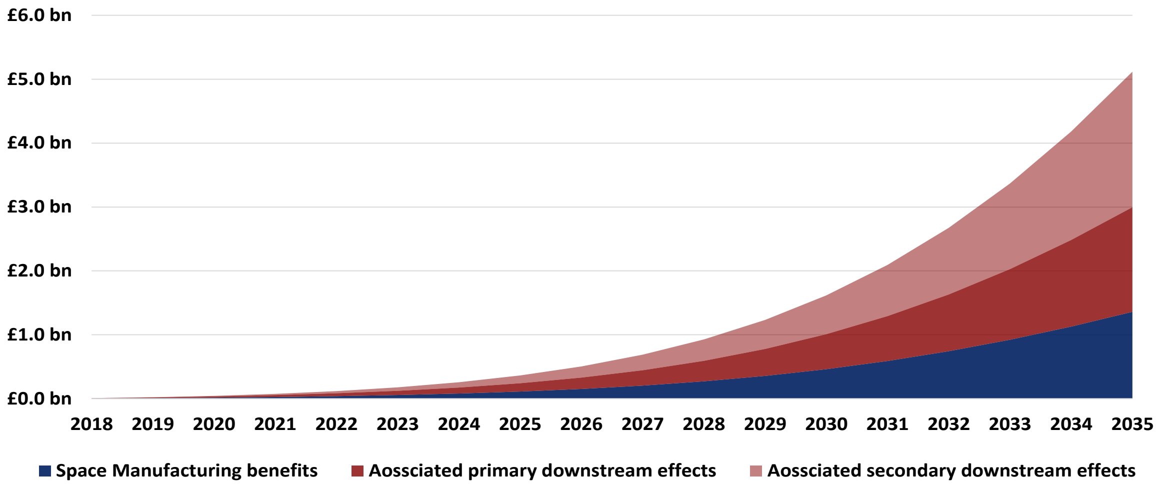
Source: London Economics

Figure 40 Estimated cumulative revenue increases, UK Space Manufacturing and UK downstream - 20% productivity increase



Source: London Economics

Figure 41 Estimated cumulative revenue increases, UK Space Manufacturing and UK downstream - 30% productivity increase



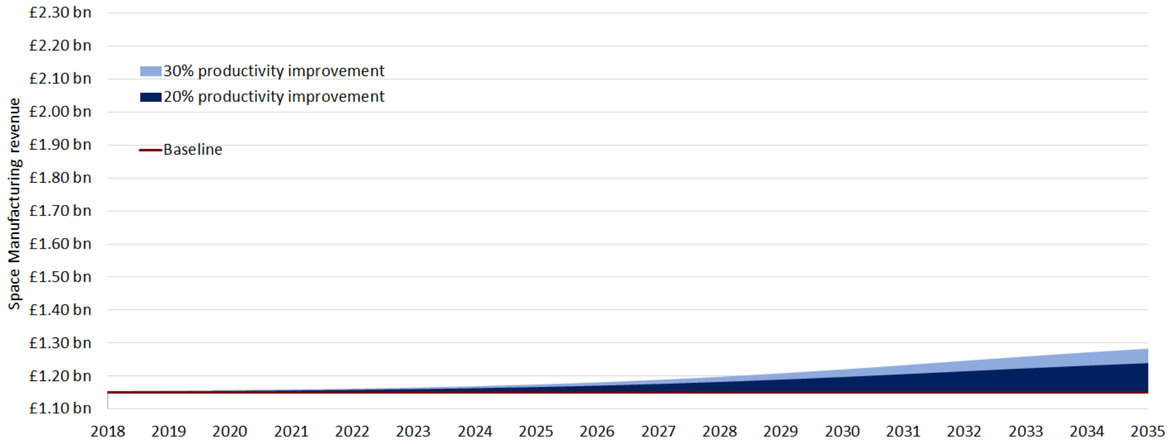
Source: London Economics

7.2.3 No growth scenario

Even in the case that the UK space industry does not see any further growth over the next decade, wider adoption of Industry 4.0 technologies could still deliver annual revenue increases, by 2035, to the UK Space sector (upstream + downstream) of between **£330 million**, for a 20% increase in productivity, due to adoption, and **£500 million**, for a 30% increase in productivity.

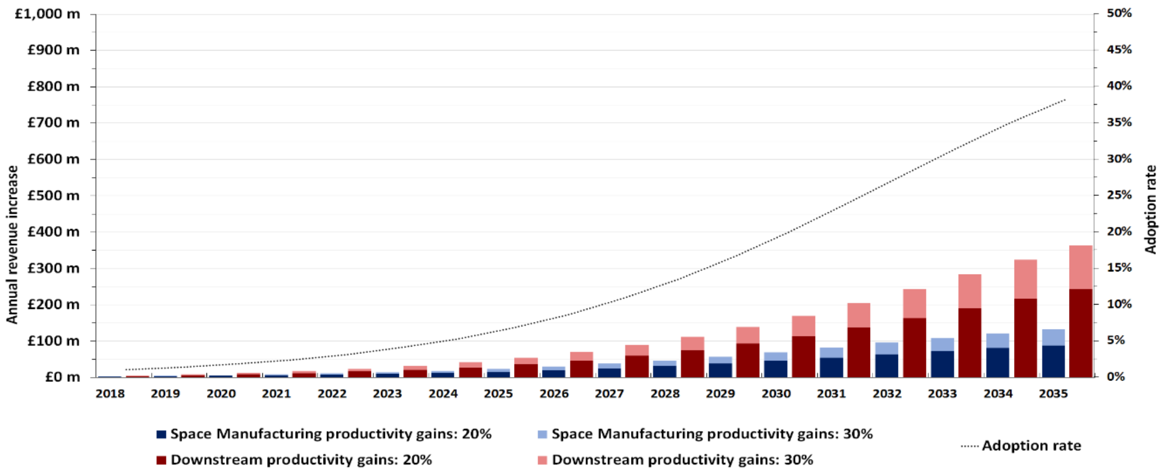
Slightly less than **one-third** (27%) – between **£90 million** (20% productivity gains) and **£130 million** (30% productivity gains) – of these increases are estimated to accrue in the UK Space Manufacturing sector. The remaining 73% – between **£240 million** (20% productivity gains) and **£360 million** (30% productivity gains) – derive from associated effects (primary + secondary) to the downstream segment.

Figure 42 Estimated revenue compared to baseline, UK Space Manufacturing



Source: London Economics

Figure 43 Estimated annual revenue increases, UK Space Manufacturing and UK downstream



Source: London Economics

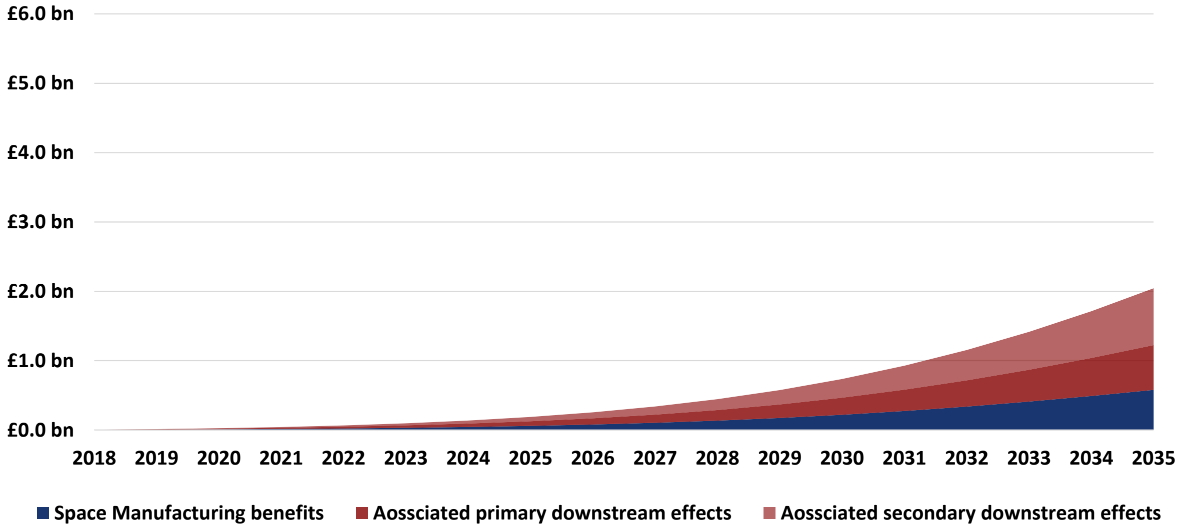
Cumulative UK Space Manufacturing revenue is estimated to be between **£0.6 billion** (20% productivity gains) and **£0.9 billion** (30% productivity gains) higher, by 2035, compared to the no-growth baseline without adoption. Annual associated effects, by 2035, to the downstream segment are estimated to be between **£1.5 billion** (20% productivity gains) and **£2.2 billion** (30% productivity gains).

Table 12 Estimated cumulative revenue increases, UK Space Manufacturing and UK downstream, by period

Sector	Space Manufacturing		Downstream	
Productivity improvements	20%	30%	20%	30%
Whole period	£0.6 billion	£0.9 billion	£1.5 billion	£2.2 billion
2025-2035	£0.5 billion	£0.8 billion	£1.4 billion	£2.1 billion
2030-2035	£0.4 billion	£0.6 billion	£1.1 billion	£1.6 billion

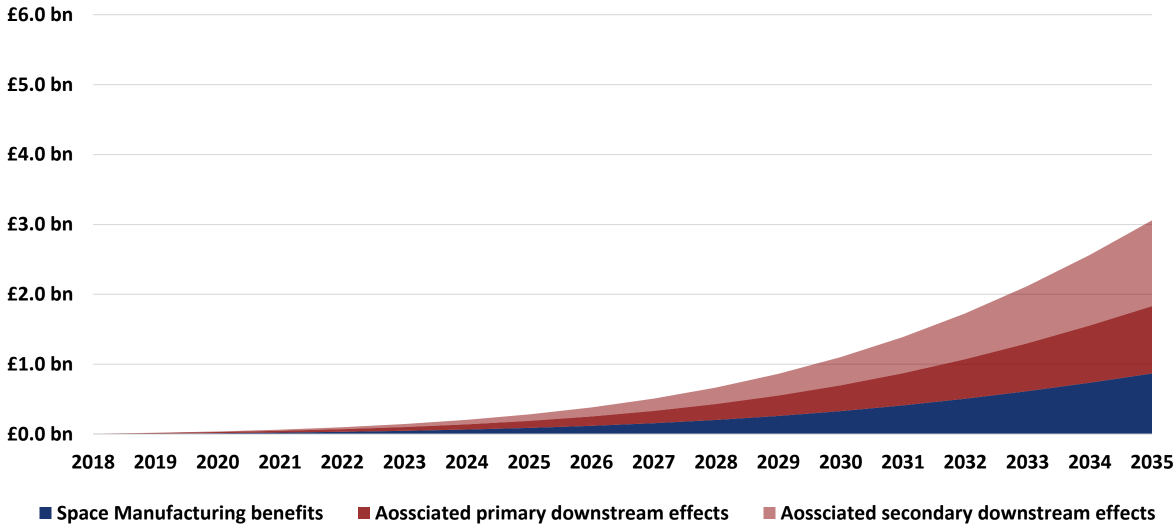
Source: London Economics

Figure 44 Estimated cumulative revenue increases, UK Space Manufacturing and UK downstream - medium case (20% productivity increase)



Source: London Economics

Figure 45 Estimated cumulative revenue increases, UK Space Manufacturing and UK downstream - high case (30% productivity increase)



Source: London Economics

7.3 Estimated benefits of accelerated adoption

This section explores the impact that accelerated uptake of Industry 4.0 in the UK Space Manufacturing sector could have, relative to the estimated adoption used in the previous section (Figure 35).

Adoption is a key driver of Industry 4.0 benefits, with faster uptake of Industry 4.0 technologies meaning that benefits of adoption materialise earlier. Crucially, adoption is also a key policy variable which can be influenced by the UK Government.

This section explores two scenarios:

- An increase in the target adoption rate, by 2030, from 20% to **25%**
- An increase in the target adoption rate, by 2030, from 20% to **30%**

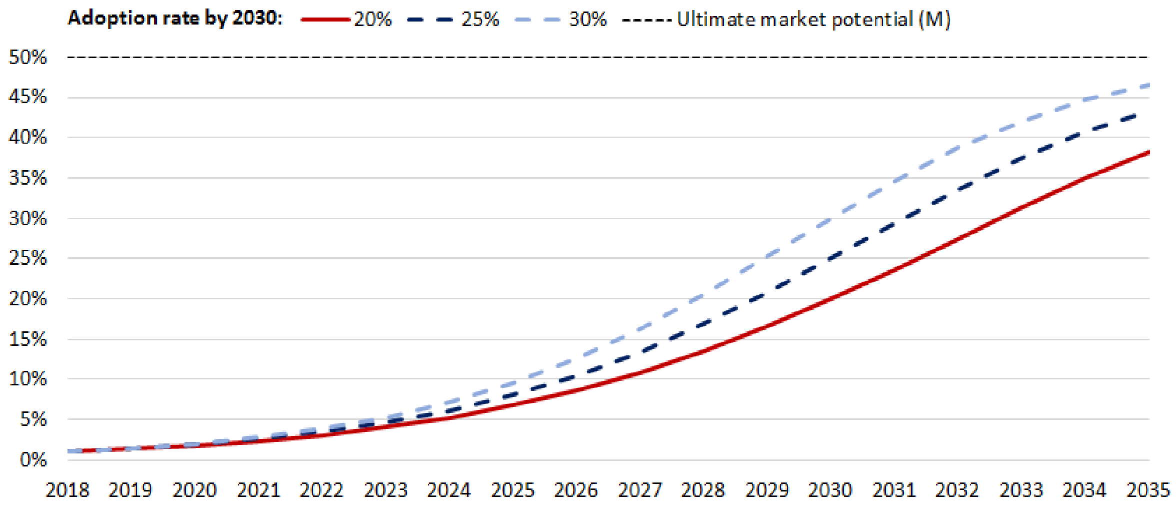
Each scenario is analysed relative to the **business-as-usual scenario** (Section 7.2.2). The impact of lower adoption, by 2030, is explored in Annex A1.6.4.

Figure 46 shows the estimated adoption rate, in each year, between 2018 and 2035, for the different target adoption rates, by 2030. Figure 47 and Figure 48 show the estimated annual benefits, for each scenario, for the UK Space Manufacturing sector and the UK downstream segment, respectively. Figure 49 shows the estimated cumulative benefits, for each target adoption rate.

An **adoption rate of 25%, by 2030**, implies an increase in annual benefits, by 2035, to the UK Space Manufacturing sector of around **14%**, from, approximately, **£150 million** (£230 million) to **£175 million** (£260 million) in the case of a 20% (30%) productivity improvement.

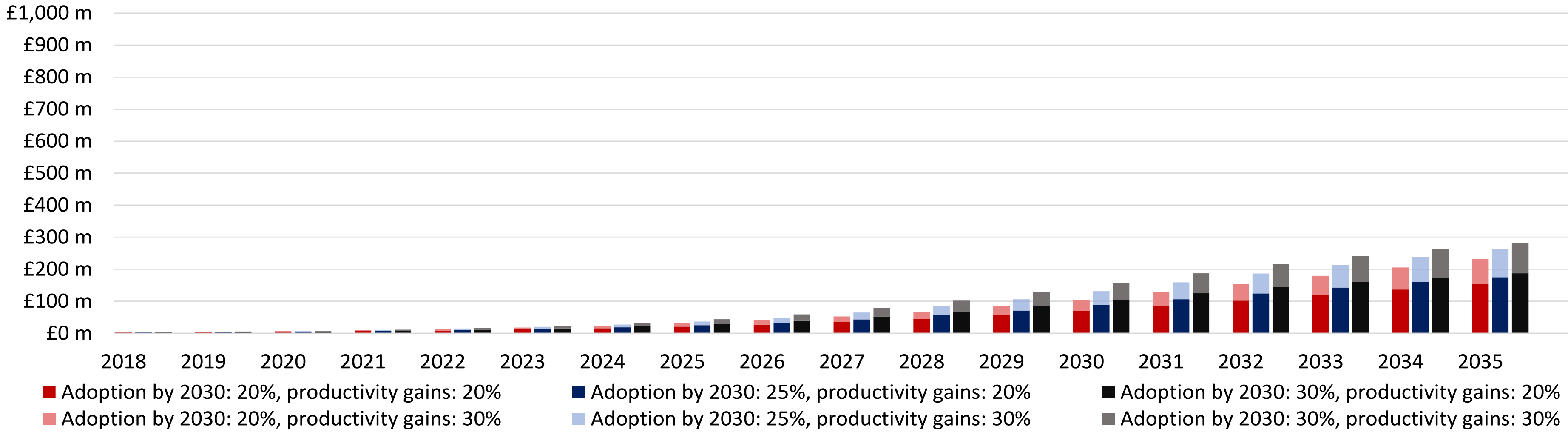
Cumulative benefits to the UK Space Manufacturing sector are estimated to increase by around **20%**, from, approximately, **£0.9 billion** (£1.4 billion) to **£1.1 billion** (£1.6 billion) in the case of a 20% (30%) productivity improvement.

Figure 46 Estimated adoption of Industry 4.0 technologies in the UK Space Manufacturing sector, by target adoption rate in 2030



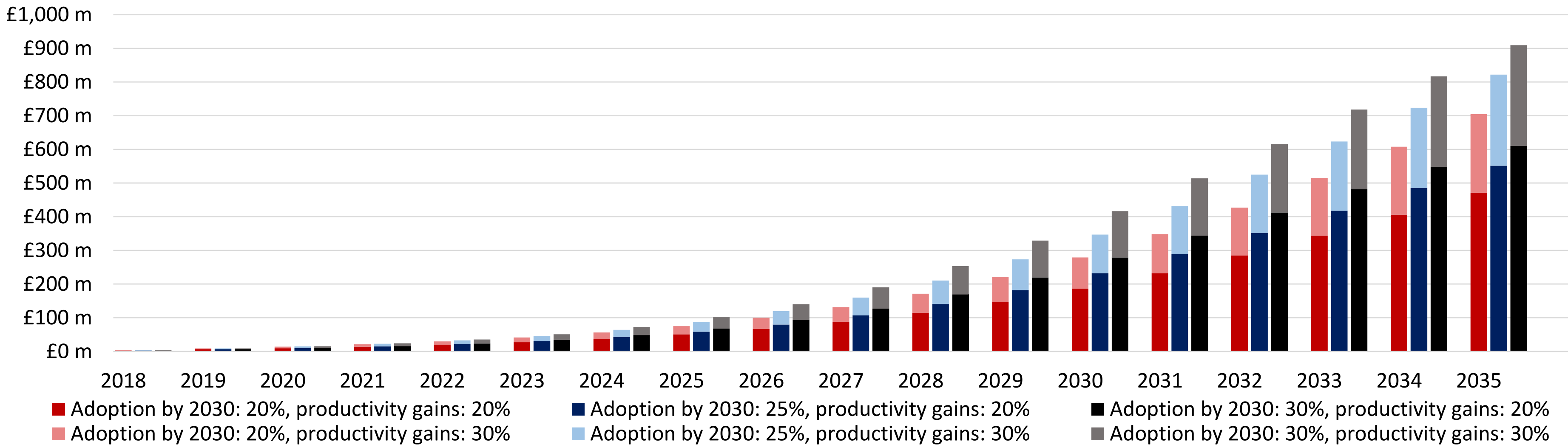
Source: London Economics

Figure 47 Estimated annual revenue increases, UK Space Manufacturing, by target adoption rate in 2030



Source: London Economics

Figure 48 Estimated annual revenue increases, UK downstream segment, by target adoption rate in 2030

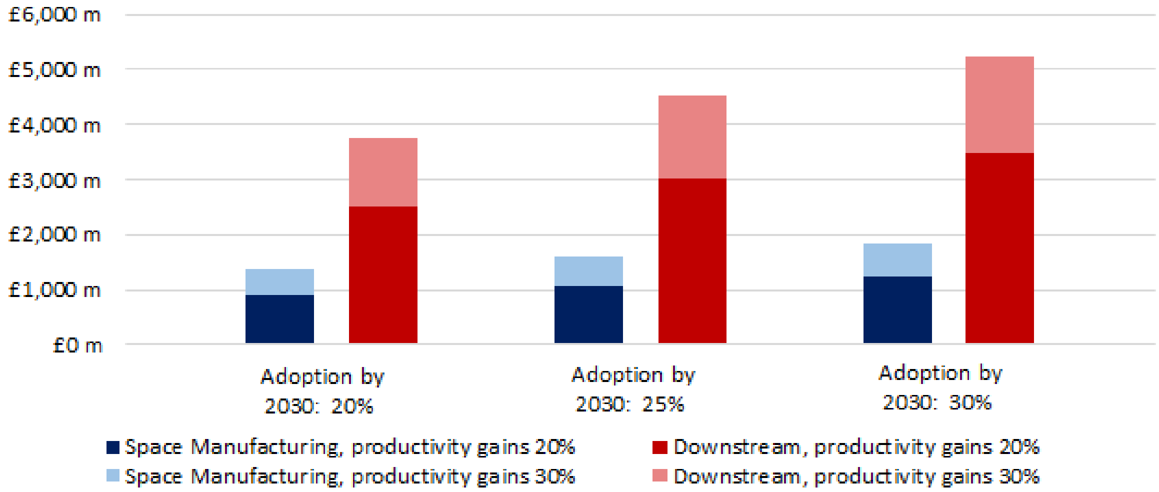


Source: London Economics

An **adoption rate of 30%, by 2030**, implies an increase in annual benefits, by 2035, to the UK Space Manufacturing sector of around **22%**, from, approximately, **£150 million** (£230 million) to **£190 million** (£280 million) in the case of a 20% (30%) productivity improvement.

Cumulative benefits to the UK Space Manufacturing sector, are estimated to increase by around **31%**, from, approximately, **£0.9 billion** (£1.4 billion) to **£1.2 billion** (£1.9 billion) in the case of a 20% (30%) productivity improvement.

Figure 49 Estimated cumulative revenue increases, UK Space Manufacturing and UK downstream segment, by target adoption rate in 2030



Source: London Economics

An increase in adoption of Industry 4.0 technologies in the UK Space Manufacturing sector is also associated with increased **downstream** benefits, detailed below.

An increase in the target adoption rate from 20% to **25%,** by 2030, is associated with an increase in downstream benefits of, approximately, **£80 million** (£120 million) annually, by 2035, in the case of 20% (30%) productivity improvements. Cumulative benefits are estimated to increase by, approximately, **£0.5 billion** (£0.8 billion), in the case of 20% (30%) productivity improvements.

An increase in the target adoption rate from 20% to **30%**, by 2030, is associated with an increase in downstream benefits of, approximately, **£140 million** (£205 million) annually, by 2035, in the case of 20% (30%) productivity improvements. Cumulative benefits are estimated to increase by, approximately, **£1.0 billion** (£1.5 billion), in the case of 20% (30%) productivity improvements.

7.4 Applying the model to the whole UK Space Sector

The main focus of this study was on the impact of Industry 4.0 on Space Manufacturing. The modelling assumptions have been built based upon literature and consultations focused on Space Manufacturing. However, in order to provide an illustration of the relative size of the estimates if the model is applied to the Space Industry as a whole, the model was run for both the upstream and downstream segments (see Annex A1.5). When this is done the benefits are in the region of £2 billion annually by 2035, and £11.7 billion over the whole study period. Much care needs to be taken in the interpretation of these estimates. Further research would be required to calibrate the model to the downstream sector.

8 Challenges and barriers to the uptake of digitalisation technologies in the UK manufacturing sector (non-space)

UK manufacturing is lagging behind other developed countries in the adoption of industry 4.0 technologies. Moreover, low levels of adoption of digitalisation and automation technologies are particularly prevalent amongst SMEs, as the Made Smarter Review[130] points out.

The review identifies a number of barriers to the adoption of Industry 4.0 technologies by UK manufacturing; in particular:

- A **disjointed landscape** of business support with no clear path to access assistance and guidance
- **Perceived risks** particularly around cyber security and a lack of common standards, which would allow different technologies to connect
- **Tax system** is not targeted to incentives adoption
- **Skills shortage**

The review also identifies key challenges and threats to adoption. This includes **competitive threats** due to the fact that other countries are further ahead than the UK, putting competitive pressure on UK manufacturers to keep pace.

Moreover, digitalisation reduces barriers to entry, allowing new entrants to scale up more cheaply and get their products on the market faster, without the need for large investments in capital assets. This may lead to existing manufacturers being overtaken, and possibly crowded out, by their competitors.

Digitalisation may also lead to a **displacement of manufacturing roles** away from manual work, towards more highly skilled knowledge based roles. This poses a threat if the UK cannot adequately equip manufacturing workers with the new digital skills they will require.

The review also highlights the potential **cybersecurity threats,** which come hand-in-hand with higher levels of digitalisation. According to the review, manufacturing is particularly at risk due to legacy equipment with minimal or no security, gaps between IT and operations technology, patchwork architectures, lack of documented training, processes and procedures that detail responsibilities and access, and failure to conduct risk assessments.

Increased digitalisation also brings **data and privacy** challenges. One particular challenge highlighted by the review is keeping information accurate and up-to-date as multiple versions may be shared directly with clients or suppliers or saved in different locations. This is especially important if the information is used for decision-making. This also raises a concern about unwanted disclosure of information to unauthorised parties.

Moreover, due to the increased reliance on electronic data, there is a risk that disruption of servers or other key IT infrastructure may lead to not being able to access the necessary information. This

[130] Made Smarter Review: Industrial Digitalisation 2017

may lead to delays and disruptions in the manufacturing process, or even have impacts across the supply chain.

Lastly, the review points to increased risk of loss **or theft of intellectual property (IP)**, which is increasingly available in digital form. This also increases the risk of such a loss going undiscovered. In addition, digitalisation technologies may make reverse engineering and counterfeiting easier.

Managers of British manufacturing companies surveyed by Barclays[131] further said that **a lack of finances** is preventing them from investing in automation. This includes a lack of internal funds (23% of respondents), as well as external grants and other sources of finance (15%). Further, 26% of respondents said they were simply prioritising other capital expenditure projects over automation.

Respondents to the Barclays survey were also worried about the time/investment they would need to identify appropriate robotics equipment or automation solutions (14%), or felt that robotics equipment or automation solutions are not flexible enough for their business's products (18%). Some respondents also had concerns about the returns on their investment (16%), or concerns over the impacts on their workforces (11%), for example lowered morals of workers due to a fear of losing their jobs, which stopped them from investing more in automation/robotic equipment.

A study of manufacturing firms in the South Yorkshire region[132], commissioned by the Digital Catapult, further identified that, among companies hesitant to invest in digitalisation technologies, there is a **lack of understanding of Industry 4.0,** and the benefits that adoption of digitalisation technologies can have on their business, as well as confusion and scepticism about the claims and sales pitches of large digital manufacturing companies.

Interviewed manufacturers also felt that they already have **enough data**, which they are not utilising properly. Rather than investing in technology allowing them to gather even more data, they suggested that they needed help making better use of the data they already have. A lack of skills was also seen as a barrier to implement digital transformation strategies.

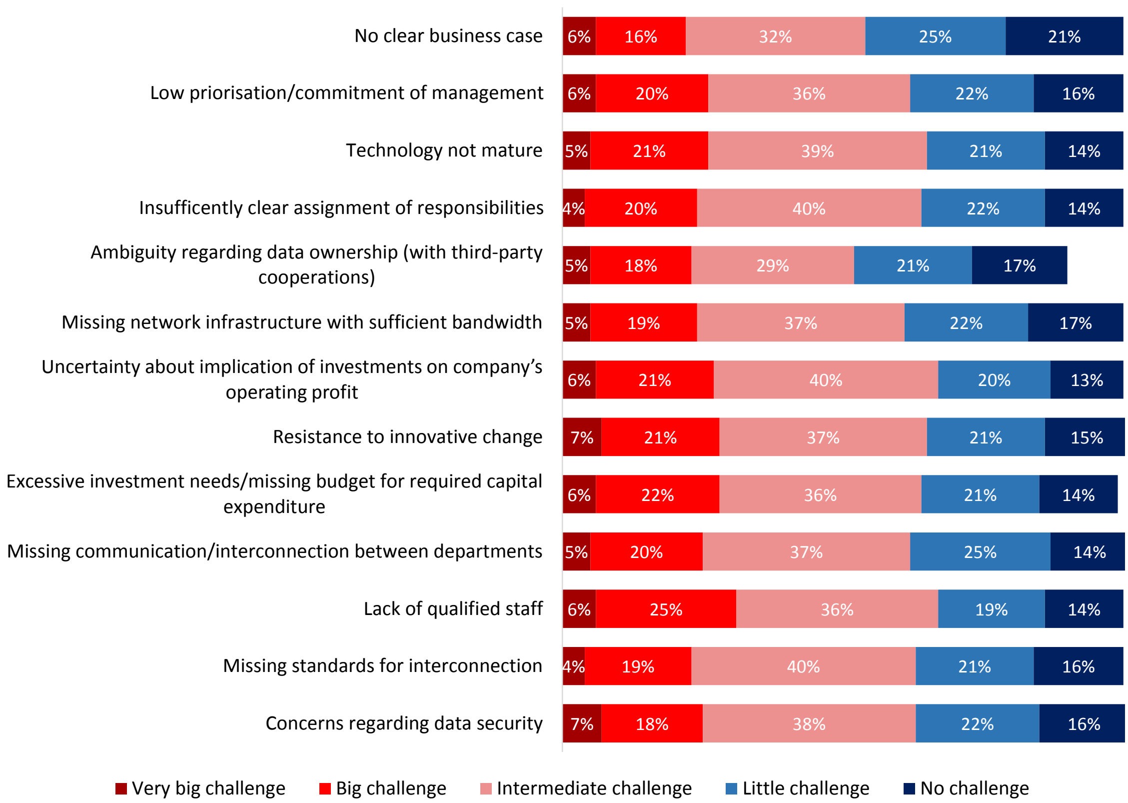
Other challenges identified by the cohort include a **lack of time** to think about new technologies; use of **legacy systems**; **previously unsuccessful attempts** to integrate digital technology in their processes; as well as the **cost and potential risk** associated with investment in transformative technologies.

The Boston Consulting Company in a survey of manufacturers in the UK, China and the US identified **resistance to innovative change**, **uncertainty about the impact of adoption on profitability** and **lack of investment capacity** were key challenges facing industry in the adoption of Industry 4.0 technologies (Figure 50).

[131] Rigby, M. (n.d.). *Future-proofing UK manufacturing: Current investment trends and future opportunities in robotic automation.* Barclays. Available at: https://www.barclayscorporate.com/content/dam/corppublic/corporate/Documents/research/automation-report.pdf [accessed 10/01/2018]

[132] Devitt, J. (2017). *The Future of Manufacturing in the Digital Age.* Available at: https://www.digitalcatapultcentre.org.uk/wp-content/uploads/2017/10/20171023_DC_ManufacturingDigitalAge_Report_DigitalVersion.pdf [accessed 25/01/2018]

Figure 50 Which are the biggest challenges for progress towards Industry 4.0 for your company?



Notes: Nr. of respondents: UK = 322, China = 258, USA = 315.

Source: Boston Consulting Group (2017). **Is UK Industry ready for the Fourth Industrial Revolution?**

9 Future Industry 4.0 opportunities for the Space Manufacturing sector

Digitalisation technologies provide significant opportunities for the Space Manufacturing sector to meet future challenges such as the development of mega-constellations which require faster production timescales, lower costs and high volumes, but do not necessarily need the high lifetime and full failure proofing of traditional satellites.

While large-constellations provide the opportunity for high volumes in space manufacturing, the traditional bespoke nature of Space Manufacturing raises the challenge of economically efficient manufacture of highly customised products. This is also known as 'Batch Size 1'. The challenge facing production engineering is the need to enable companies to produce customised products industrially and, at the same time, economically.

Building for a reduced operational life gives rise to potential opportunity for the use of Industry 4.0 technologies. The challenge identified by industry experts is in reducing the manufacturing and launch costs enough to make this **move from a low volume, high lifetime product to** a product with a **shorter lifetime** produced at much lower production costs, but at **higher frequencies** attractive, and reduce the time from initial design to space launch.

Box 5 Boeing Defence, Space and Security rate production for satellites

In its move away from unit build based on bespoke customised production Boeing has focused on process driven design. The starting point is a change in the overall production strategy.

Unit build was based on individual contracts with suppliers, products were proto-qualified and corrected to meet the client's requirements, production performance was focused on single unit delivery models and unique parts to fit bespoke design. Movement towards rate production of satellites required a shift away from heritage practices. Partnerships between customers and suppliers established for the longer-term and not based on single unit delivery contracts. Products are designed for assembly with interchangeable parts used wherever possible, minimization in the number of parts and simplification of components. The production system is qualified as if it were part of the design with repeatable and reproducible processes used to build the product, and production processes are statistically proofed before they are put in place to reduce the need for inspection. Virtual factories are also used to identify possible bottlenecks that may occur. Technologies such as Event Simulation and Visualisation tools are used optimize the factory and reduce work-in-progress time.

The utilization of design for assembly, design for manufacturing and design for high Takt rate can "*generate production gains of between 85% and 95%*".

Source: Danny Pace, Director of Advanced Manufacturing Space and Missile Systems & Autonomous Systems, Space Tech Expo USA 2018.

Industry experts considered that higher rate production of satellites will **lower barriers to entry** allowing for more flexibility and innovation in the design and manufacturing process and creating opportunities for innovative SMEs to bring their technology to the Space Manufacturing sector through greater engagement between major players and start-ups. In addition to start-ups, **attracting non-Space Manufacturing firms** to sector was also seen as a potential opportunity, allowing utilisation of existing manufacturing processes and supply chains of manufacturing firms in non-space sectors.

As other manufacturing industries have shown, automation of simple or repetitive tasks could **reduce development times** and therefore lead to faster product development, reducing time-to-market and increasing productivity. Reduced development times in turn lead to cost reductions and a more efficient manufacturing process overall. Automating simple or repetitive tasks of the manufacturing process could also free up staff to perform more skilled tasks, further **reducing development costs**. Moreover, industry experts also pointed to potential increases in the **accuracy** with which repeated tasks are performed.

Box 6 Automated manufacturing process RUAG Space

RUAG space developed an automation process for the manufacture of lightweight sandwich panels to meet the business challenge of producing three satellite structures a day as part of the One Web programme. The bottle neck and cost barrier to meeting the required increase in through-put was identified as the installation of inserts in the sandwich panels. To overcome this challenge, the inserts were re-designed such that they could be installed using an automated process (Automated Potting Machine).

Automation lead to a reduction in through-put time, in addition repetition and improved stability in the production process fed through to improvements in performance in terms of load carrying and improved position accuracy of the product. Furthermore, automation was also introduced into the engineering stage. A database of inserts was defined with different tolerance levels and calculations for sandwich design were automated. This allows RUAG to perform iteration loops with the customer in order to optimise the design of the spacecraft.

Automation along the production chain has lead to significant time and cost savings, and allows the customer to freeze the design of the sandwich pattern at a late stage having further knock-on benefits to customer.

Source: Franck Mouriaux, Chief Engineer, product Group Spacecraft, RUAG Space, Space Tech Expo USA 2018. Henry, C. (2016). **Modernizing Manufacturing: How to Build the Satellite of the Future.** ***Available at: http://interactive.satellitetoday.com/via/april-2016/modernizing-manufacturing-how-to-build-the-satellite-of-the-future/ [accessed 23/01/2018]***

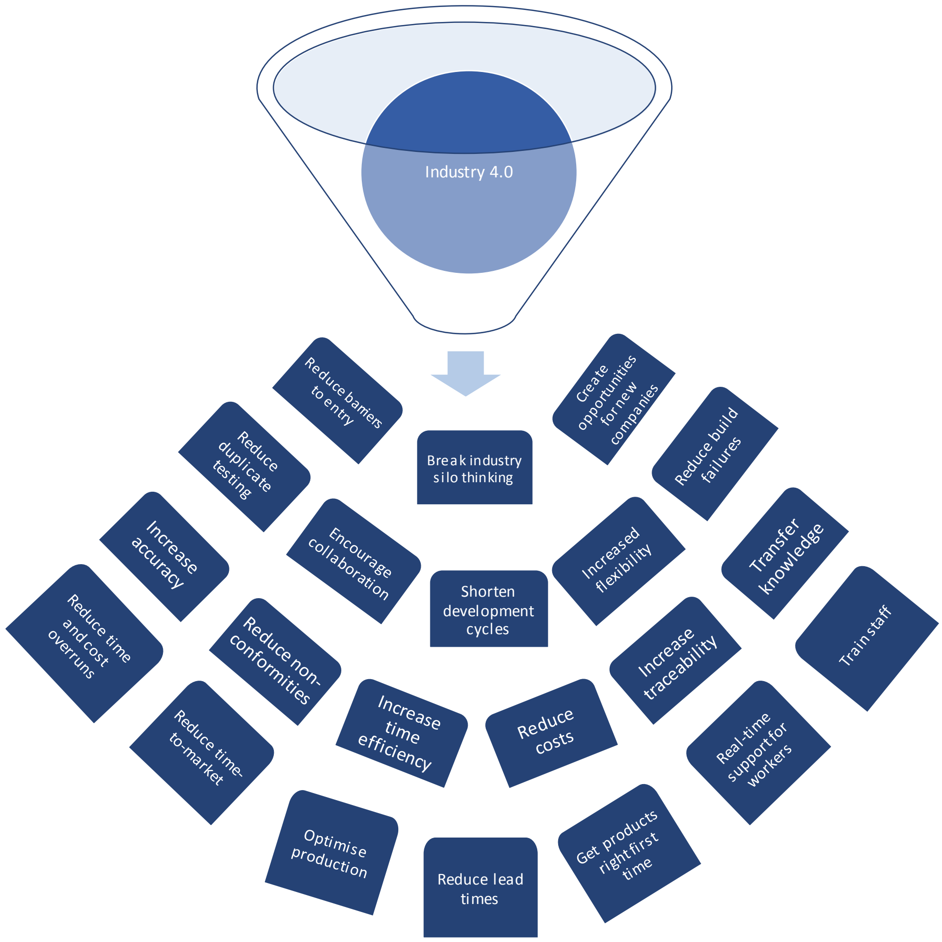
Advanced digitalisation technologies could also be used to optimise the product development and manufacturing process, reduce qualification costs and times, and deliver benefits across the supply chain, as well as help attract tech-savvy workers to the sector.

Lower costs and increased competitiveness in the Space Manufacturing sector could in turn lead to **growth in the downstream sector**, by attracting new applications and opening up new markets**, as well as for receiving technologies** such as flat-pack antennas.

Industry experts also saw an important for Industry 4.0 technologies for in-orbit manufacturing and servicing, though detailed treatment of these subjects is beyond the scope of this study.

Illustrations of the potential benefits specific digitalisation technologies could bring to the Space Manufacturing sector are detailed below. A visual summary is provided in Figure 51.

Figure 51 Potential benefits of Industry 4.0 for the Space Manufacturing sector



Source: London Economics; based on desk research and consultation of industry experts

Artificial intelligence

Advanced analytics technologies such as artificial intelligence and machine learning could be used to gain detailed insights into the design and manufacturing process, helping to identify areas where optimisations can be made. This could lead to a more efficient manufacturing process, and help **reduce time and cost overruns**.

In this regard industry experts felt that a lot of data is already available, but is not utilised very well. Therefore, **making better use of the available information**, rather than generating additional data, was seen as the preeminent opportunity for advanced analytics technologies.

Additive manufacturing

Additive manufacturing (3D printing) could also be utilised to quickly and accurately manufacture bespoke components, **reducing the time from initial product design to finished product**. Indeed, there is already an increased interest in additive manufacturing technologies. Additive manufacturing technologies are already used to fabricate models and prototypes in the space sector, and more recently, these technologies are also increasingly used to manufacture components for active missions, as the OECD[133] notes.

Using additive manufacturing techniques for prototyping has the potential to significantly **reduce prototyping time** compared to other methods, with time savings ranging between 43% and 75% in the aerospace sector, thereby **reducing time-to-market**.[134]

For example, additive manufacturing techniques are already used by Boeing, who use 3D printed parts for its 702 satellites[135], and Made in Space who provide 3D printing services to NASA and commercial customers directly in space through their additive manufacturing facility on the International Space Station (ISS).[136] Airbus UK has also already developed flight-qualified 3D printed components for Eurostar E3000 telecommunications satellites[137].

RUAG Space also utilises additive manufacturing techniques to produce 3D printed parts for the space and non-space sectors. Additive manufacturing allows RUAG to produce lighter components, with shorter lead times, and with reduced costs for more complex components.

A recent example is the redesign of an S-Band Antenna bracket utilising 3D printing techniques, a collaboration between RUAG, the European Space Agency (ESA), and the client.[138]

[133] OECD (2016). *Space and Innovation.* OECD Publishing. Paris. http://dx.doi.org/10.1787/9789264264014-en

[134] Stratasys (2012). *A New Mindset in Product Design.* Available at: http://usglobalimages.stratasys.com/Main/Secure/White%20Papers/WP_FDM_NewMindset.pdf?v=635905246245235050 [accessed 04/09/2018]

[135] Henry, C. (2016). *Modernizing Manufacturing: How to Build the Satellite of the Future*. Available at: http://interactive.satellitetoday.com/via/april-2016/modernizing-manufacturing-how-to-build-the-satellite-of-the-future/ [accessed 23/01/2018]

[136] Made in Space (n.d.) *Additive Manufacturing Facility.* Available at: http://madeinspace.us/projects/amf/ [accessed 23/01/2018]

[137] Airbus (2015). *Airbus Defence and Space optimising components using 3D printing for new Eurostar E3000 satellite platforms*. Available at: http://www.airbus.com/newsroom/press-releases/en/2015/03/airbus-defence-and-space-optimising-components-using-3d-printing-for-new-eurostar-e3000-satellite-platforms.html [accessed 14/06/2018]

[138] RUAG Space (n.d.). *3D Printed Parts.* Available at: https://www.ruag.com/en/products-services/space/spacecraft/satellite-structures/3d-printed-parts [accessed 23/01/2018]

Digital twins

Industry experts also pointed to digital twins, digital replica of the physical product or production process, as a way to **optimise production and reduce lead times**.

On the one hand digital twins of the product could be used to analyse and qualify the product in a range of different scenarios prior and during manufacturing, allowing immediate feedback into the production process, thereby optimising production and reducing the need for multiple prototypes.

On the other hand, digital twins of the factory could also be used to validate the whole manufacturing process and identify areas for improvements. In this way digital twins could help integrate product testing throughout the product development and manufacturing process, **helping manufacturers get products right the first time round** and reducing time spent on validating the final product.

Augmented reality

Augmented reality (AR) could also be utilised to **visualise data** more easily and intuitively and **support workers in real time**. For example, in the Aerospace Manufacturing sector, Airbus uses AR glasses, developed in collaboration with Accenture, to help engineers fit aircraft seats on the A330 aircraft, increasing productivity by 500% and reducing the error rate to zero.[139] In its space business, Airbus also already uses virtual reality to help its engineers work on artificial 3D objects for design purposes[140]. Virtual or augmented reality technologies could also be used to **train staff**, or to **transfer knowledge** from experienced staff to less experienced employees.

RFID tags

Tracking technology such as radio-frequency identification (RFID) tags, in combination with the Industrial Internet of Things, could help **monitor and improve the usage of equipment and facilities** and **increase traceability**.

Automated qualification

Testing and qualifying each satellite or spacecraft individually is both time consuming and costly. Digitalisation technologies could help to **reduce cost** and **increase time efficiency**.

One particular way in which digitalisation technologies could help is automated qualification. Advanced analytics technologies such as machine learning could be used throughout the manufacturing process to detect and **reduce non-conformities** and concessions.

In addition, automated qualification systems could be designed to learn from past mistakes, thereby **increasing accuracy** and **reducing build failures**. While this would likely not eliminate the need for manual testing completely, digitalisation technologies could support the quality assurance process and help reduce the time spent on extensive testing of satellites and their components.

[139] Accenture (n.d.). *Airbus soars with wearables.* Available at: https://www.accenture.com/gb-en/success-airbus-wearable-technology [accessed 21/03/2018]

[140] Airbus (2016). *Virtual reality – Eyes wide open.* Available at: https://www.airbus.com/newsroom/news/en/2016/12/I-Spy-With-My-Little-Eye.html [accessed 14/06/2018]

Virtual testing

In the medium to long term moving from or complementing physical testing with virtual testing environments could lead to **efficiency gains** and **cost reductions**. For example, simulations could be used to assess critical component's durability in extreme space environments without leaving the factory floor.

Virtual testing environments could also provide **increased flexibility** to test a wide range of different scenarios, which can be modified to adapt to specific demands. Importantly, virtual testing could be integrated throughout the manufacturing process, allowing fine-tuning of product designs early on in the manufacturing process, and thereby **reducing** the overall **time to market**.

Standardisation and COTS

A shift towards higher volumes in the sector could encourage a move towards standardisation. Standardised components were seen as key by experts consulted to achieving greater standardisation. In particular, industry experts saw wider introduction of commercial off-the-shelf (COTS) parts, that have been tested against a wide range of challenging space scenarios and optimised for the specific challenges the space environment, as an opportunity for the sector. This could allow increased use of COTS over custom components, thereby **reducing overall cost** and **shortening development cycles**. Higher standardisation in turn presents opportunities for the use of digitalisation technologies such as higher automation of the production process or the integration of co-bots.

However, it should be noted that the space sector presents particular challenges for COTS compared to other sectors such as automotive. In particular, the low volume high-value nature of traditional satellite manufacturing means that satellite manufacturers need to mitigate any potential risk, as component failure is simply not an option. The space environment itself also presents special challenges for the use of COTS (e.g. space radiation, and the difficulty of repairing or replacing components in-orbit), which users of COTS in other sectors do not face. Given these challenges, it is of vital importance that COTS are properly qualified for the specific application in order to avoid introducing unnecessary risk.

The rise of lower cost, shorter lifetime satellites and large-constellations could thus provide a unique opportunity for the wider use of COTS within the space sector, as the economic costs of failure are reduced significantly: if one large satellite fails, this means loss of 100% capacity as well as years of work and millions of pounds. In contrast, if one small satellite within a constellation of, for example, 900 satellites fails, the resulting loss in capacity could be less than 1% and the economic costs of loss are comparatively small.

With higher standardisation industry experts also saw opportunities for more **flexible platforms**, which are smaller and cheaper, have shorter lead times, and include more digital configuration with standard interfaces. Highly flexible platforms could allow the application of standardised products to different applications by reconfiguring products to specific customer needs.

Industry experts also saw an opportunity for a **higher integration of components** at the system level. These integrated components could combine the functionality of many different individual components and be delivered fully tested, thus reducing the need for a large number of individual components and shortening validation times.

Integrated supply chain

Another area where digitalisation technologies could address existing challenges is by connecting companies across the supply chain, thus creating a more integrated supply chain and **improving collaboration, flexibility and visibility along the supply chain.**

Automated feedback

For example, automated feedback mechanisms could be used to keep other companies along the supply chain updated about manufacturing progress and quality assurance tests performed. Such mechanisms could also be used to inform supply chain members when a non-conformity was detected, thereby **reducing duplicate testing**.

Real-time monitoring

Tracking technologies such as Radio-frequency identification (RFID) tags could also be used to allow real-time monitoring of parts or components in real time. In this way a more integrated supply chain could help **increase traceability** of both components and requirements along the supply chain.

In the long term a more integrated supply chain, combined with increased traceability of components, was seen as an opportunity towards the adoption of **just-in-time (JIT) manufacturing**, yielding further efficiency gains and cost reductions.

Market diversity

Digitalisation technologies were also identified to create potential **opportunities for new companies**, thereby increasing competitiveness in the Space Manufacturing sector, and leading to a larger and more diverse market sector.

In particular, workshop participants saw the open source industry as a potential source of **breaking industry silo thinking**, **encouraging collaboration** and **reducing barriers to entry**, for example by lowering intellectual property barriers by encouraging a sharing culture, thereby granting greater access to start-ups and innovative SMEs.

Increased collaboration

Increased collaboration was also seen as a potential opportunity for early adopters of Industry 4.0 technologies to **share information** on the challenges faced in the uptake of these technologies with smaller suppliers such as SMEs to facilitate adoption along the supply chain and thus increase the benefits to the sector overall.

Box 7 and Box 8 provide examples of how these technologies can be integrated in the space manufacturing factory of the future.

Box 7 Space factory of the future & collaborative robots

Thales Alenia Space is building an automated manufacturing facility for the production of photovoltaic assemblies (PVA), which are used to generate electricity on satellite solar panels. The new facility will be located in Belgium, and will become Thales Alenia Space's showcase for Industry 4.0 manufacturing.

The factory will make use of automation technologies such as robotized assembly of panels, digital data management and traceability, online tests and inspections, augmented and virtual reality, 3D printing, artificial intelligence and big data analytics, and connected devices Internet of Things.

As part of its "Tomorrow's Factory" and the shift towards high volume production of satellites, Thales Alenia Space identified a number of future manufacturing opportunities for collaborative robots. Collaborative robots differ from standard industrial robots in that they are adaptable, mobile and designed to work with people. The flexibility of collaborative robots makes robotics technology economically feasible for low-volume manufacturing.

Kitting: Assembling components to undertake a specific production task. Collaborative robots can select components and pass them to the human operator, this collaboration leads to efficiency improvements in production flow.

Elimination of errors and quality assurance: Collaborative robots using their cameras can check for errors or damage in components. Further, through data integration collaborative robots can feed directly back to 'back-office' systems which improves compliance and inventory control.

Provision of a 'third arm': Collaborative robots can assist in the assembly of fragile products or products that need to be held at angles difficult (or uncomfortable) for humans.

Raytheon – specialising in defence, civil government, and cybersecurity solutions - also utilises robots as part of an automated production line to build small satellites in a specialised factory in the Arizona desert. The satellites, which are small enough to be carried by hand, are designed to give soldiers real-time battlefield pictures.

Turning to the manufacture of ground receiving antennae's, collaborative robots can improve accuracy of production. For example, a satellite dish has a small 'feed horn' which must be positioned facing the disk within 1/1000th of an inch in three dimensions of tolerance.

Compared to traditional production methods, the collaborative robot has the potential to save tens-of-thousands of pounds in design effort tooling costs and reduce production time from one week to a matter of hours.

Source: (i) Jean-Philippe Jahier, director of Innovation and Industrialisation of New Technologies with Thales Alenia Space reported in Thales Innovation #4, July 2015 https://www.thalesgroup.com/sites/default/files/asset/document/thales4_innovations_english_final_1.pdf. (ii) Thales Alenia Space (2017; (ii) Raytheon (2016). **Tiny Satellite Work Ramps Up: Diminutive devices will give troops real-time battlefield pictures.** ***Available at: https://www.raytheon.com/news/feature/small_satellites.html [accessed 23/01/2018]. (iii) Thales Alenia Space (2017). Thales Alenia Space to build a new automated facility dedicated to photovoltaic assemblies for satellite solar panels. Available at: https://www.thalesgroup.com/en/worldwide/space/press-release/thales-alenia-space-build-new-automated-facility-dedicated [accessed 23/01/2018]; (iv) Thales Alenia Space (2018). Space Factory of the Future. Avilable at: https://www.youtube.com/watch?v=zsTWGuSSyAM [accessed 24/05/2018]. (v) Interviews conducted by London Economics***

Box 8 The paperless factory: Revolutionising the economics of space

OneWeb is on a mission to provide affordable internet access for everyone. Currently, over 50% of the world has no access to reliable high-speed connectivity, with developing countries and remote areas particularly affected[141]. OneWeb's longer term goal is to fully bridge this gap, and make internet access available to everyone, by 2027.

To help achieve this goal, OneWeb has teamed up with Airbus and created a joint venture – OneWeb Satellites – to manufacture low-cost, high-performance satellites at high volumes. OneWeb Satellites will initially produce 900 satellites (each weighing less than 150 kilograms), forming part of a large constellation of satellites orbiting around the globe.

The first 10 satellites, designed and manufactured in their manufacturing facility in Toulouse, are planned to be launched into low Earth orbit by end of 2018. The remaining satellites will be built in a new factory in Florida, which will be twice the size of the Toulouse facility, featuring two production lines instead of one. The OneWeb Satellites' factory in Toulouse continue to produce satellites for future Customers of Airbus/OneWeb Satellites.

To manufacture satellites at this volume, OneWeb Satellites had to dramatically transform the way satellites are built.

In contrast to traditional satellite manufacturing, OneWeb Satellites' manufacturing process is completely paperless. All planning takes place electronically, with electronic plans interlinked with smart tooling. Instructions are sent directly to tools, with torque values being supplied to machines automatically by a central software and values being recorded in an automated way. Cameras are used to compare assembled components to models of correct assemblies, allowing automated visual inspection of components to ensure consistent, repeatable quality. 3D scanners are used to automatically check the geometry and alignment of critical areas.

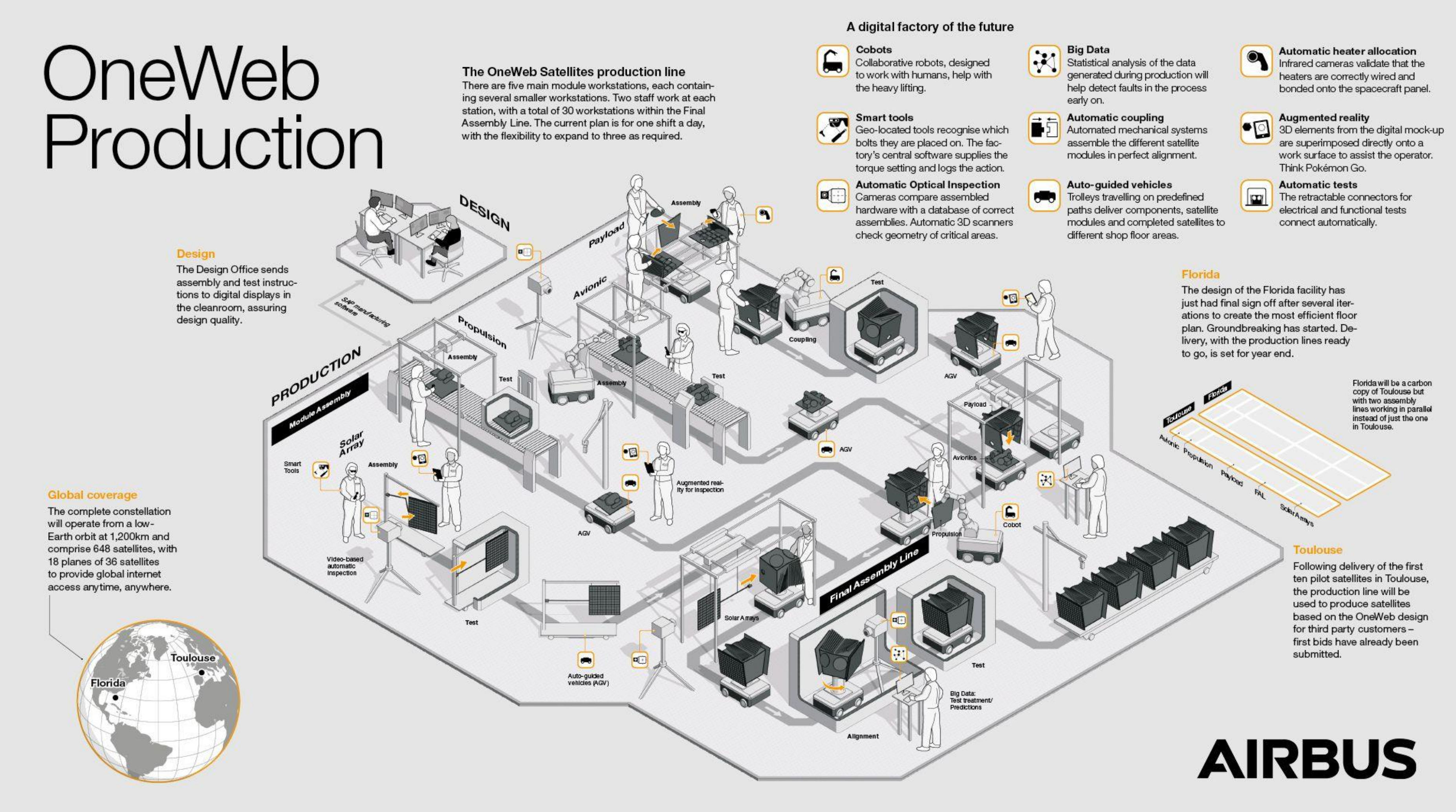
"[OneWeb Satellites] is enabled not by technology, but by the approach and the way proven technologies are combined."

Tony Gingiss, CEO, OneWeb Satellites

This paperless manufacturing process also allows OneWeb Satellites to automatically collect large sets of data throughout their manufacturing process. Using machine learning and predictive algorithms, this will allow OneWeb Satellites to not only deal with bottlenecks in a reactive manner, but also to proactively predict production hold-ups and detect faults early on. As more satellites are produced, and more data is collected, the tools will automatically learn, allowing more and more accurate predictions over time. Ultimately, the aim is to use big data analytics not only in the manufacturing process, but throughout the supply chain, as well as to monitor the satellites on orbit in space.

[141] OneWeb (2016). *We All Need Access: Note From Our Chairman*. Available at: http://www.oneweb.net/#need [accessed 2018-06-27];

Figure 52 OneWeb Satellites production line



Note: Infographic used with kind permission of OneWeb Satellites.

Source: *Airbus (2017). OneWeb Serial Production Line Infographic. Available at:* https://www.airbus.com/newsroom/press-releases/en/2017/06/one-web-satellites-serial-production-line-inauguration.html#media-list-image-image-all_ml_0-1 *[accessed 2018/06/27]*

Another major difference between OneWeb Satellites' manufacturing facility and traditional space factories is their production line approach (illustrated in Figure 52). Traditionally, satellites are manufactured in a static way, with engineers coming to the hardware to undertake their work. In OneWeb Satellites' factory, staff are organised around module workstations, with hardware (i.e. satellites in manufacture) being moved between workstations using auto-guided vehicles.

Despite the use of all these technologies, the factory is not a completely automated factory, as one might initially think. Skilled staff are still very much in use, with two engineers working at each workstation. Indeed, OneWeb Satellites only uses one robot in their Toulouse facility; a cobot designed to work alongside humans, helping staff to undertake tasks which require modules to be held completely still in a constrained area which a human is unable to do.

In this way OneWeb Satellites is able to manufacture and test each major module less than eight hours. Final satellite integration is also done within a single eight hour shift. All of the module and system lines are running in parallel, but if the time we laid out serially, the total time to build a whole satellite, including manufacturing and testing, is around one month, with OneWeb Satellites' Florida factory designed to deliver up to 10 satellites per week in single shift/5 day operations with the ability to increase rate in the future. .

However, reducing manufacturing time is only one part of the puzzle. To make manufacturing and operating a large constellation economically viable, OneWeb and OneWeb Satellites also had to drastically cut costs. One way in which OneWeb Satellites achieved this, is by bringing in parts and suppliers from non-space industries.

Moreover, while traditional satellites aim to last many years with extremely high reliability, due to the large capital investments required, OneWeb's satellites are manufactured with a lifetime of around five years. Given the lower capital investment and ability to build and launch multiple/many vehicles for a reasonable investment, the overall approach to life and reliability is transformed for the customers.

Source: (i) Consultation with OneWeb and OneWeb satellites; (ii) OneWeb (2016). We All Need Access: Note From Our Chairman. Available at: http://www.oneweb.net/#need [accessed 2018-06-27]; (iii) Airbus (2017). OneWeb Serial Production Line Infographic. Available at: https://www.airbus.com/newsroom/press-releases/en/2017/06/one-web-satellites-serial-production-line-inauguration.html#media-list-image-image-all_ml_0-1 [accessed 2018/06/27]; (iv) OneWeb (2017). OneWeb Satellites Breaks Ground On The World's First State-Of-The-Art High-Volume Satellite Manufacturing Facility. Available at: http://www.oneweb.world/press-releases/2017/oneweb-satellites-breaks-ground-on-the-worlds-first-state-of-the-art-high-volume-satellite-manufacturing-facility [accessed 2018/06/28]

10 Space Manufacturing challenges and Industry 4.0

In addition to the challenges identified in Section 7, industry experts consulted as part of this study identified a number of key challenges in the Space Manufacturing sector adopting Industry 4.0 technologies. While a range of challenges were identified, detailed in the remainder of this section, five key challenges stand out:

- Often low volumes, relative to other sectors, in traditional space manufacturing
- Resistance to new technologies / materials, for some parts of the sector
- Conservative approach to risk, for some parts of the sector
- Bespoke nature of space manufacturing

- High development costs of satellites, leading to high upfront costs to experiment with new technologies

Figure 53 Space Manufacturing challenges and Industry 4.0

Source: London Economics; based on desk research and consultation of industry experts

10.1 Conservative approach to risk and resistance to new technologies and materials in traditional space manufacturing

The **conservative approach to risk** prevalent within some parts of the sector also presents a challenge to lowering costs and increasing volumes.

On the one hand, there was a sense among industry experts that the **specificity of customer needs** presents a challenge to moving towards more standardised products, as bespoke solutions are often required. Challenges were also raised around obtaining customer acceptance towards adopting mass production over highly customised satellites.

On the other hand, Space Manufacturing companies were identified by industry experts as being **more sensitive about their intellectual property**, partly because of the high development costs, as well as to retain their market share.

Contractual constraints on intellectual property pose a particular challenge to reducing the time-to-market as technology built for one customer cannot be re-purposed for other customers, reinforcing the bespoke nature of the sector.

Acceptance of new materials and technologies within the supply chain was also seen as a challenge for traditional space manufacturing. In particular, a **resistance to** and a lack of availability of commercial off-the-shelf (**COTS**) parts was identified.

Acceptance of new processes was also seen as a challenge for the quality assurance stage, where questions around the **acceptance of batch testing** of satellites and their parts, as opposed to an extensive quality assurance process for each satellite, were raised.

It should be noted, that there are very real economic reasons underlying the sector's conservative approach to risk and resistance to new technologies and materials such as COTS. In particular, the low volume, high cost nature of traditional space manufacturing means that component failure can have catastrophic implications: if a large satellite fails in-orbit, it is very difficult to impossible to repair or replace affected components. As such, failure could mean the loss of years of work as well as millions of pounds in manufacturing and launch costs.

There was also a view that existing technology would need to be improved to meet the challenging space standards before it could be widely adopted within the sector. For example, COTS would need to incorporate technologies such as radiation shielding to be able to withstand the demanding space environment by incorporating. This makes the specification and production of COTS in Space Manufacturing particularly challenging.

In this regard, industry experts also highlighted the challenge of **transitioning** from the current system to a new quality assurance process without negatively impacting quality or cost. The **creation of standards** for new space applications, which are less onerous than current quality assurance practice, but still ensure traceability were also mentioned as a challenge for the sector.

Traceability of requirements as well as other data such as measurements was also seen as a challenge for the quality assurance process as well as along the supply chain. Workshop participants also saw difficulties in tracking parts or subsystems across the supply chain.

Some workshop participants also expressed a wish for more **transparency** throughout the supply chain. This was seen as particularly challenging the larger and more diverse the supply chains are.

10.2 High costs, low volumes and bespoke products

High manufacturing costs and **low volumes** present key challenges in the product development stage. In particular, industry experts identified challenges around the **long time-to-market** of space products, as well as around the especially **challenging space environment** requiring special and expensive production components and limiting possible economies of scale.

For satellites specifically, a **reduction of the time from concept to launch** was seen as a key challenge for the industry. In particular, industry experts pointed towards a need for increased flexibility to launch, enabling launches when they are needed and at shorter notice periods as well as the ability to relaunch relatively quickly after a failed launch.

A number of challenges around **scaling-up** the manufacturing process were also identified. For example, the **highly bespoke nature** of Space Manufacturing was seen as a challenge for cost-effective automation as well as for the design and specification of satellites for mass production. In this regard, a **lack of standardisation**, in some parts of the sector, was also identified as a challenge to the potential adoption of digitalisation technologies.

However, **low volumes** mean that pay-offs of investment in automation and standardisation would be slower to accrue, and raises challenges around the creation of economies of scale. In addition, there was a concern among industry experts that **access to finance** and capital investments is challenging, creating cost barriers towards the adoption of digitalisation technologies.

Finally, there was a worry that the **long lifetime** of space products would make **obsolesce** a challenge as technology keeps advancing rapidly. This was seen as a particular problem when developing new technologies from scratch, which can take a long time. Industry experts therefore saw the challenge around introducing new technologies into current systems and processes and retrofitting older technologies.

Because of the long lifetime and development costs associated with the manufacture of satellites and spacecraft a high level of quality assurance is essential. Not surprisingly, therefore, that **high costs** were also mentioned as a particular challenge in the quality assurance stage.

In particular, because of the **high costs of a failed launch,** manufacturers need to ensure that their products as close to **fail-proof** as possible and can withstand the extreme space environment.

For example, to ensure product safety as well as safety of operation, spacecraft are **individually designed and tested**, which is costly. This makes qualifying space products in a mass production environment particularly challenging.

10.3 Barriers to entry

The traditional production paradigm of low volume, bespoke production systems generate barriers to entry. New market entrants are often faced with the **high development costs** of a sector where products are designed to last for many years, meaning high time and monetary costs during the development and testing process to ensure products do not fail.

In addition to the **long lifetime**, satellites and spacecraft are also often **bespoke products** for one-off space missions. This highly bespoke nature of Space Manufacturing also bears the risks of time delays or cost overruns for the manufacturing and launching of satellites. This means that new and innovative approaches come with a much higher upfront cost compared to other manufacturing sectors, increasing the price of failure. At the same time, **securing investment** was seen as a challenge for young and innovative start-ups or SMEs, making it particularly challenging for new entrants to break into the sector.

New entrants are also faced with a sector that takes a **conservative approach to risk** and is more **hesitant towards new technology**, meaning new entrants face an uphill struggle to convince customers of their innovative approach over tried and tested development processes. Moreover, while workshop participants stressed the importance of cyber security, the **heightened sensitivity for intellectual property** and knowledge of the sector was also identified to be prohibitive for new entrants.

Barriers to entry were also identified as a major challenge for supply chains. For example, start-ups and young SMEs face challenges in **identifying and gaining access to networking clusters.** As a result, the sector was identified to be dominated by large incumbent suppliers, lacking a diverse supply chain.

10.4 Regulatory environment and insurance

A **complicated regulatory environment** was cited as a reason for expensive and complicated quality assurance processes, as well as a challenge for supply chain management. For example, workshop participants pointed to export control regulations on sensitive components, which put a limit on possible cost reductions. Industry experts also saw the convoluted regulatory framework as a particular challenge towards reducing launch times and increasing launch flexibility. In addition to regulatory burdens, industry experts highlighted the lengthy insurance process as a barrier to reducing time to space, as well as for the development of potentially disruptive technologies such as large-constellations. The insurance market was therefore seen as in need of development in order to meet the requirements of the sector and keep pace with disruptive technologies.

10.5 Challenges for receiving technologies

Mass production of innovative receiving technologies, such as flat-panel antennas, face similar challenges to the Space Manufacturing sector. In particular, challenges surrounding **volume** and economies of **scale** are also prevalent on the receiving side, with innovative flat-panel antennas currently still produced at small scales and often customised in order to pass regulations and performance criteria, meaning **high costs**.[142]

In addition to high costs, **performance** is a key challenge holding back further development of flat-panel antennas[143], and therefore widespread adoption. Indeed, according to Northern Sky Research[144], if performance issues can be solved, price will be the main deciding factor in whether flat-panel antennas will be successful or not.

Despite these challenges, mass production is already being trialled on first prototypes by Alcan Systems, a German smart antenna company, with first antennas potentially available in 2019.[145]

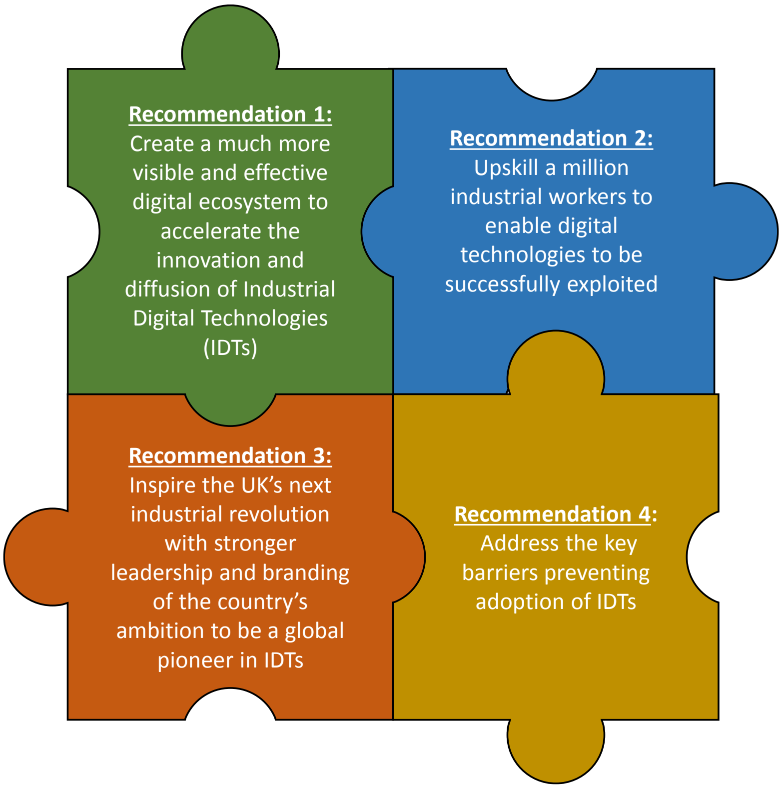
11 Roadmap for the future

The Made Smarter Review[146] provides four recommendations to ensure that the UK will be a global leader in advanced digital technologies by 2030.

Specifically, the authors recommend creating a more visible and effective digital ecosystem; tackling the skills challenge; taking a strong leadership role and clearly branding the UK's ambition to become a global leader in digitalisation technologies; and addressing the barriers which prevent firms adopting these technologies (Figure 54).

[142] *Henry C. (2017). German startup takes Kymeta-like LCD approach to flat panel antenna manufacturing. Available at: http://spacenews.com/german-startup-takes-kymeta-like-lcd-approach-to-flat-panel-antenna-manufacturing/ [accessed 14/05/2018]*
[143] Northern Sky Research (2017). *Flat Panel Satellite Antennas, 2nd Edition*
[144] Kasaboski , D. (2017). *Pricing flat panel antennas for success*. Available at: http://www.nsr.com/news-resources/the-bottom-line/pricing-flat-panel-antennas-for-success/ [accessed 14/05/2018]
[145] *Henry C. (2017). German startup takes Kymeta-like LCD approach to flat panel antenna manufacturing.. Available at: http://spacenews.com/german-startup-takes-kymeta-like-lcd-approach-to-flat-panel-antenna-manufacturing/ [accessed 14/05/2018]*
[146] Made Smarter Review: Industrial Digitalisation 2017

Figure 54 Made Smarter Review: Recommendations



Source: Made Smarter Review: Industrial Digitalisation 2017

In order to achieve these goals, the Made Smarter Review sets out a number of more detailed recommendations for each piece of the puzzle. An overview of these more detailed recommendations is provided in Table 13.

Table 13 Made Smarter Review: Detailed Recommendations

Recommendation 1.1:	Invest in a national adoption programme, which will increase both funding and mentoring available to industry, and facilitate focused placements to upcoming talents within university.
Recommendation 1.2:	Create a new national innovation programme to scale the support currently provided by UK innovation centres.
Recommendation 1.3:	Establish large-scale digital transformational demonstrator within the innovation centres, to address challenges faced by specific industries as well as those cutting across industries.
Recommendation 2.1:	Create a national Skills Strategy and Implementation Group. This group would engage with industry, and provide a forum to identify the skills required in the future, as well as synchronise and focus existing initiatives.
Recommendation 2.2:	Establish a digital delivery platform, which would provide scalable, relevant, timely, and easily digestible content helping industry to upskill or reskill their workers.
Recommendation 3.1:	Establish a national campaign aimed at promoting the adoption of digitalisation technologies, and tackling negative preconceptions about them.
Recommendation 3.2:	Establish a Made Smarter UK Commission, which comprises representatives from industry, government, academia, and research/innovation organisations, tasked with developing the UK as a leader in digitalisation technologies.

Recommendation 3.3:	Set up interim Strategy and Support Implementation Groups, accountable to the Made Smarter UK Commission, and tasked with delivering the recommendations set out in the Made Smarter Review.
Recommendation 4.1:	Implement a Standards Development Programme, which would create standards for digitalisation technology and promote greater interoperability.
Recommendation 4.2:	Implement targeted financial incentives aimed at promoting the development and adoption of digitalisation technologies.
Recommendation 4.3:	Develop data trusts tasked to ensure that data exchanges are secure and mutually beneficial.

Source: Made Smarter Review: Industrial Digitalisation 2017

Industry experts consulted as part of this Innovate UK study identified a number of potential actions which they believe could help boost adoption of digitalisation technologies within the Space Manufacturing sector, these are detailed below (Section 11.1). In addition, the consultation also generated a number of further ideas to meet the wider challenges of the Space Manufacturing sector over the next decade (Section 11.2).

11.1 Potential actions to boost adoption of digitalisation technologies

To boost adoption of digitalisation technologies in the UK Space Manufacturing sector, industry experts, consulted as part of this study, suggested a number of potential actions:

- **Potential action 1:** The government should facilitate private funding and access to new technologies both locally, and globally via global government projects. In particular, workshop participants suggested the government should facilitate a venture capital mindset within the UK Space Manufacturing industry to boost private funding within UK space manufacturing.
- **Potential action 2:** The UK space agency should develop a modularity strategy to drive adoption of modular designs and support projects in this area.
- **Potential action 3:** The government should establish a Space Manufacturing Industry 4.0 working group, similar to the Maritime Autonomous Systems Regulatory Working Group.
- **Potential action 4:** A digital space platform should be provided by a neutral party. This platform should help businesses with the adoption of Industry 4.0 technologies by providing access to data, analytics, and tools.
- **Potential action 5:** The government should focus on driving cultural change and facilitate a more digitalisation technology focused mindset among industry leaders and other executives within the UK Space Manufacturing sector by clearly showing the benefits of digitalisation technologies, for example by supporting more technology demonstration projects, and helping companies invest. Moreover, government should also provide clarity on the potential market opportunities to attract new entrants, creating a more diverse sector.
- **Potential action 6:** Facilitate digitalisation of the supply chain and encouraging primes to share their knowledge and experience with other companies within their supply chain, to facilitate investment in digitalisation technologies across the supply chain.

However, experts also warned that the UK needs to be realistic and practical about where it puts its focus within the wider Industry 4.0 vision. In particular, workshop participants felt that a UK Industry 4.0 strategy should be linked to a more global strategy, focusing on collaboration with our European and international partners to bring about the Industry 4.0 revolution. Such a linkage would ensure consistent international standards, for example consistent data formats, such that the UK industry could continue to play a role in global supply and supply into global markets.

Experts also highlighted that such a strategy should be targeted towards all Space Manufacturing companies, not just the big players, and involve not only the Space Manufacturing sector, but other manufacturing sectors such as automotive, aerospace, computer, and food manufacture as well in order to facilitate cross-sector discussions.

11.2 Potential actions to meet the wider challenges of the Space Manufacturing sector

Potential action 1: Encouraging further development and qualification of COTS

Experts saw addressing the challenges around the adoption of COTS as important to reduce costs and development times and allow the space sector to scale up production to higher volumes. Two barriers that could prevent a more widespread adoption of COTS were identified in the consultation:

- The conservative approach to new materials and technologies of the space sector, favouring the tried and tested over new and innovative approaches; and,
- Slow moving national and international bodies, who do not permit accelerated technological development.

These characteristics are unsurprising given the low volume, high cost characteristics of traditional space manufacturing: losing a large satellite in-orbit can have devastating consequences, jeopardising years of work and resulting in the loss of millions of pounds in manufacturing and launch costs. Moreover, the characteristics of the space environment (e.g. space radiation, and the difficulty of repairing or replacing components in-orbit) also provides specific challenges for the adoption of COTS.

Nevertheless, Experts saw addressing the challenges around the adoption of COTS as important to reduce costs and development times and allow the space sector to scale up production to higher volumes. As mentioned in Section 9, the rise of lower cost, shorter lifetime satellites and large-constellations could provide a unique opportunity for the wider use of COTS within the space sector, as the economic costs of failure are reduced significantly: if one small satellite within a constellation of, for example, 900 satellites fails, the resulting loss in capacity could be less than 1% (compared to 100% for a traditional large satellite) and the economic costs of loss are significantly reduced (thousands to hundreds-of-thousands of pounds compared to millions).

In order to overcome the challenges surrounding COTS within the space sector, experts saw the need for involvement of, and collaboration among, all relevant actors, including industry leaders as well as SMEs, national agencies, and government to overcome this challenge. In particular, experts suggested that regulators need to do more to create the right regulatory environment allowing accelerated technological development. Potential actions could include:

- Facilitating collaboration across organisations and the sharing of information with respect to COTS components that have been qualified and demonstrated to be suitable for space.
- Reducing the qualification costs of COTS components, for example by including more parts when testing is performed or by finding other ways to streamline the process.
- Providing additional investment to qualify COTS components and demonstrate suitability of particular components for space.

Experts also suggested taking inspiration from the defence sector, where COTS are already in use, as well as other manufacturing industries such as automotive or aerospace, in order to develop cost effective manufacturing processes which can then be optimised to meet the specific challenges posed by the space environment and to derive best practice.

Potential action 2: Improve virtualisation tools

Experts also saw the further development of effective virtualisation tools for the virtualisation of manufacturing integration and testing as an important step. While virtualisation tools are used in Space Manufacturing, experts suggested that virtual testing environments and models need to be able to better replicate the real-world space environment to allow a more realistic testing environment delivering improved results.

The high cost of virtualisation tools was considered the main barrier hindering the adoption of virtual testing environments. However, experts pointed out that space companies use similar processes for manufacture assembly and integration of similar products so that virtualisation tools could be developed in co-operation, making development more cost-effective.

Experts also saw more traditional operators that are more sceptical towards the adoption of new technologies as potential barriers. The challenge here is to highlight the added value virtualisation tools can bring.

In the longer term, experts painted a vision of the use of digital twins of the whole manufacturing process throughout the Space Manufacturing supply chain. Achieving this vision would require involvement of the whole supply chain, including primes and SME's alike, as well as common tools and standards.

Potential action 3: Promoting a collaborative ecosystem

Experts saw a collaborative ecosystem encompassing the whole supply chain, from primes to small and innovative start-ups or SMEs, as an important step to the advancement of the sector. In particular experts suggested that digital information from the operations of all parties should be collated so that good patterns and best practice can be identified, delivering shared benefits to all.

Achieving this vision requires engagement of all stakeholders including Space Manufacturing companies, government, and facilitators. Experts also saw a common underpinning platform as essential.

Potential action 4: Framing an Industry 4.0 space strategy

Experts suggested the framing of a space strategy around the adoption of Industry 4.0 technologies as essential to boost uptake. They also saw marketing in order to change public perceptions, and the clear definition of targets as crucial to achieving this goal. One tangible action to implement this could be to influence the forthcoming Space Sector Deal to include a strategy on Industry 4.0 technologies.

In the medium term this space strategy will enable a collaborative environment for research, and together with the change in public perceptions, enable easier access to hardware and Industry 4.0 manufacturing facilities. Experts also saw a need for funding/investment events to be held to facilitate investment in Industry 4.0 technologies as well as an active involvement and encouragement from regulatory bodies.

Taken together, these actions would encourage continuous improvement of manufacturing plants, creating, over the next decade, a more competitive Space Manufacturing environment.

However, achieving this vision requires engagement from all stakeholders, including government and regulatory bodies, Space Manufacturing companies, including SMEs as well as big companies, and also investors in order to overcome a number of barriers, identified by experts:

- Facilitating investment in Industry 4.0 technologies.
- Developing the right skills such as data engineers, scientists and developers
- Creating the right regulatory environment
- Facilitating collaboration between large established companies and SMEs
- Adopting the right mindset

Potential action 5: Reducing time to space

Reducing the time to space was seen as a crucial step for the space sector in order to implement the opportunities and benefits identified by experts. In particular, checks prior to space launches were seen as prohibitively lengthy and administratively burdensome.

While, it is crucial to note the importance of these checks in order to mitigate the risks of failure, finding ways to streamline and standardise inspection processes without increasing risk will be an important challenge for the sector.

Lengthy insurance processes as well as insurance that does not meet the needs of new technologies such as large-constellations was also identified as a barrier to reducing time to space by experts.

To achieve this goal, experts suggested that broad engagement from a number of stakeholders was required. This includes national and international bodies, such as the UK and European Space Agencies and the UK Government, as well as space manufacturers and operators, and perhaps insurers.

Experts also saw more flexibility in contracts as well as modular parts as a potential solution to reduce approval burdens.

Establishing a commercial launch site in the UK was also seen as a critical to reduce the time to space.

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ANNEXES

Annex 1 Economic impact assessment

A1.1 Overview of methodology

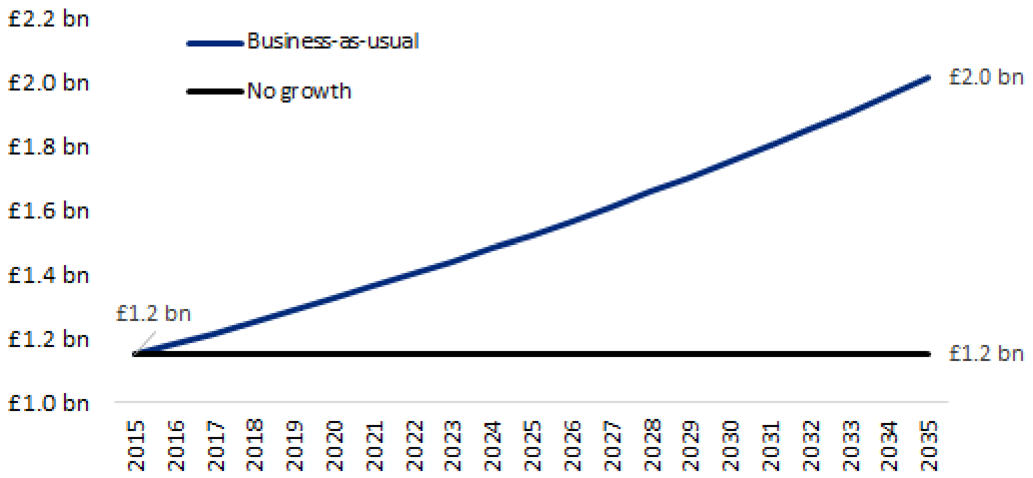
To understand the economic impacts Industry 4.0 technologies could bring to the UK space industry an economic impact assessment was undertaken. Section A1.1.1 provides an overview of the methodology used to estimate benefits to the UK Space Manufacturing sector, while Section A1.1.2 illustrates the estimation of associated effects to the downstream segment.

A1.1.1 Benefits to the UK Space Manufacturing sector

Economic impacts, up to 2030, were estimated relative to two baseline scenarios (Figure 55):

- **Business-as-usual scenario**: Linear projection of past upstream trend – based on Size and Health of the UK Space Industry 2016 data[147]
- **No growth scenario[148]**: No further growth to Space Manufacturing over the next decade, i.e. no further innovations, no large-constellations, etc.

Figure 55 Baseline scenarios - Space Manufacturing



Source: London Economics

For each baseline scenario, three cases, based on estimated productivity improvements in other sectors (see beginning of Section 6) and validation with industry experts, were estimated:

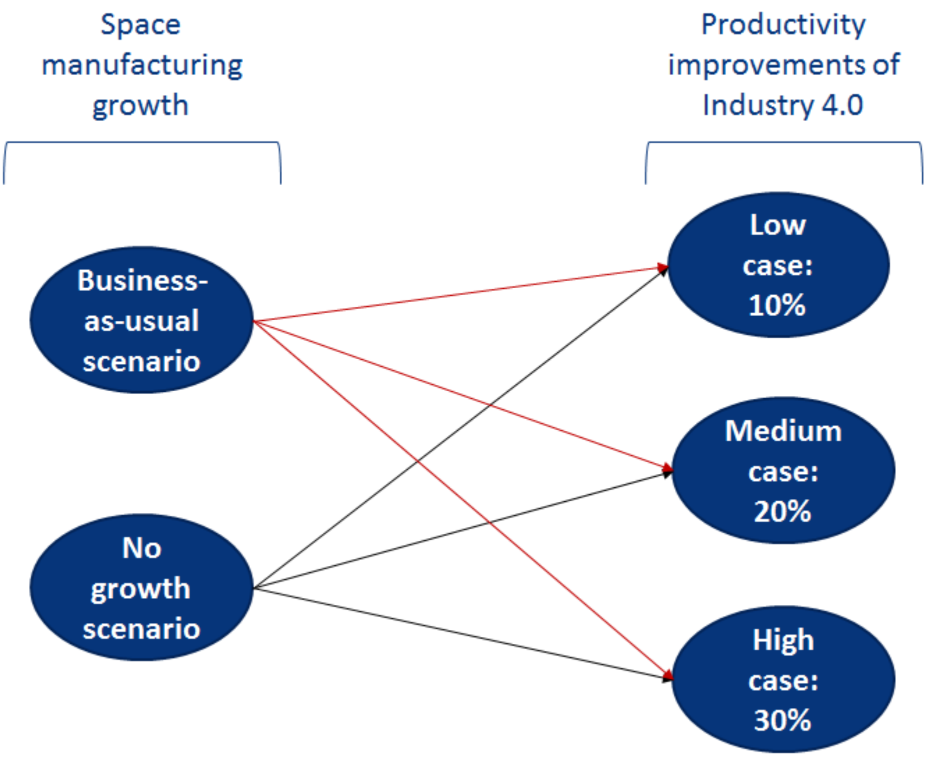
- **Low case:** Industry 4.0 could deliver productivity improvements of **10%**
- **Medium case:** Industry 4.0 could deliver productivity improvements of **20%**
- **High case:** Industry 4.0 could deliver productivity improvements of **30%**

147 Size and Health of the UK Space Industry 2016, a report for the UK Space Agency by London Economics https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/575769/Size_and_Health_summary_report_2016.pdf

148 Failure of adoption of Industry 4.0 may put the UK Space Manufacturing sector at a disadvantage relative to countries that do adopt. This may result in a contraction of the UK Space Manufacturing sector. However, whether such a contraction will occur, and, if it does, how sizable this contraction may be is very difficult to predict.

A visual overview of these nine scenarios is provided below (Figure 56):

Figure 56 Impact assessment: Overview of scenarios



Source: London Economics

For the reasons outlined in Section 7.1, 20% and 30% productivity improvements were judged are the most likely cases for the UK Space Manufacturing sector. Results for these two cases are detailed in Section 7.2.2, for the business-as-usual scenario, and 7.2.3 for the no-growth scenario. Results for 10% productivity improvement are presented in Section A1.3.

To estimate economic benefits, assumptions regarding the adoption process of Industry 4.0 technologies have to be made. The following assumptions regarding current and future use, in terms of Space Manufacturing revenue[149], of Industry 4.0 technologies in the Space Manufacturing sector were made:

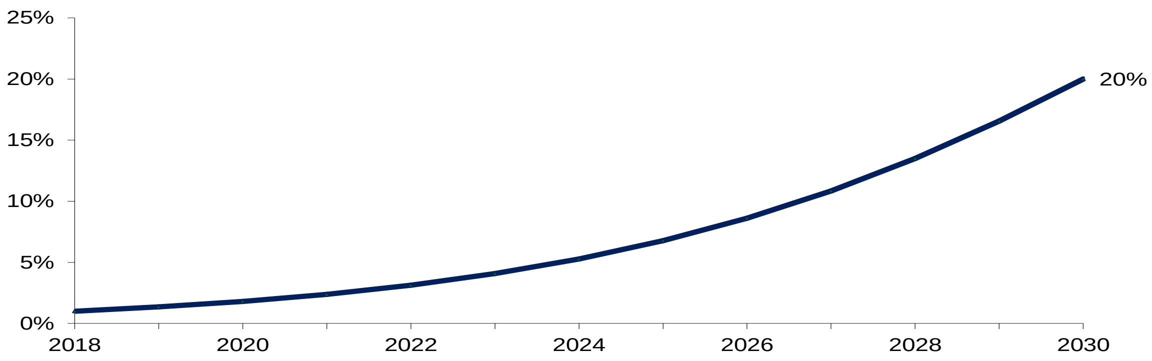
- Current adoption: 1%
- Adoption by 2030: 20%
- Adoption potential[150]: 50%

Assumptions made were based on previous experience of the UK space sector, consultations with industry experts and comparison of assumptions and the resulting adoption process with the literature (see Section A1.3 for an evaluation of assumptions).

[149] I.e.: By 2030, Industry 4.0 technologies could support 20% of Space Manufacturing revenue and could ultimately support up to 50% of Space Manufacturing revenue.
[150] Note that the model implies that the full potential of Industry 4.0 technologies in the UK Space Manufacturing sector is not reached until the mid-2040s. This is consistent with other estimates as well as well as with historical data from other technologies, for example the Boston Consulting Group estimates that a full shift towards Industry 4.0 in manufacturing could take 20 years. For further discussions see Annex 1.

Given these assumptions, an adoption process, depicted in Figure 35, was derived. Further details about the derivation of this this process can be found in Annex A1.2.

Figure 57 Estimated adoption of Industry 4.0 technologies in the UK Space Manufacturing sector



Source: London Economics

Given these three elements, potential benefits were derived as follows:

Potential benefit in t =

Baseline Income in t *
Potential productivity improvements delivered by Industry 4.0 *
Potential adoption rate of Industry 4.0 technologies in t

A1.1.2 Associated benefits to the UK downstream space segment

Associated benefits to the downstream segment were based on an econometric analysis of the relationship between the UK upstream and downstream segments.

Specifically, an OLS regression of UK downstream revenue growth on UK upstream revenue growth and lagged UK downstream revenue growth over the period 1999/00 to 2014/15 was estimated. Upstream and downstream revenue data was obtained from the 2016 Size and Health of the UK Space Industry 2016[151].

Table 14 Downstream revenue growth regression results

Variable	Coefficient	P-Value
UK upstream revenue growth	0.16**	0.027
UK downstream revenue growth (lagged)	0.67***	0.000
Adjusted R-Squared	82.5%	

Notes: Significance levels: * 10%, ** 5%, *** 1%

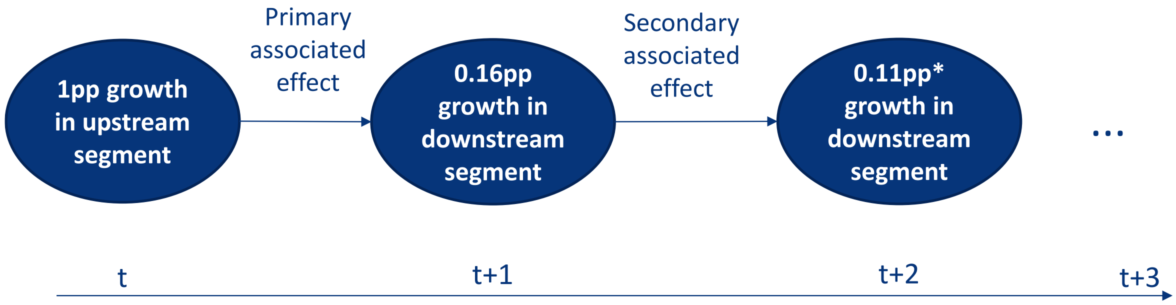
Source: London Economics

Regression results, shown in Table 14, imply that: A one percentage point (pp) shock to UK upstream growth in time t - e.g. due to adoption of Industry 4.0 technologies allowing higher production volumes or due to increased demand from the UK downstream for more satellites (data), leading to

[151] Size and Health of the UK Space Industry 2016, a report for the UK Space Agency by London Economics https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/575769/Size_and_Health_summary_report_2016.pdf

growth in upstream segment to meet this demand - is associated with a 0.16pp shock to UK downstream growth in t+1 (primary associated effect). Moreover, increased downstream growth is associated with further associated effects in following periods (secondary associated effect). (Figure 58 and Figure 59)

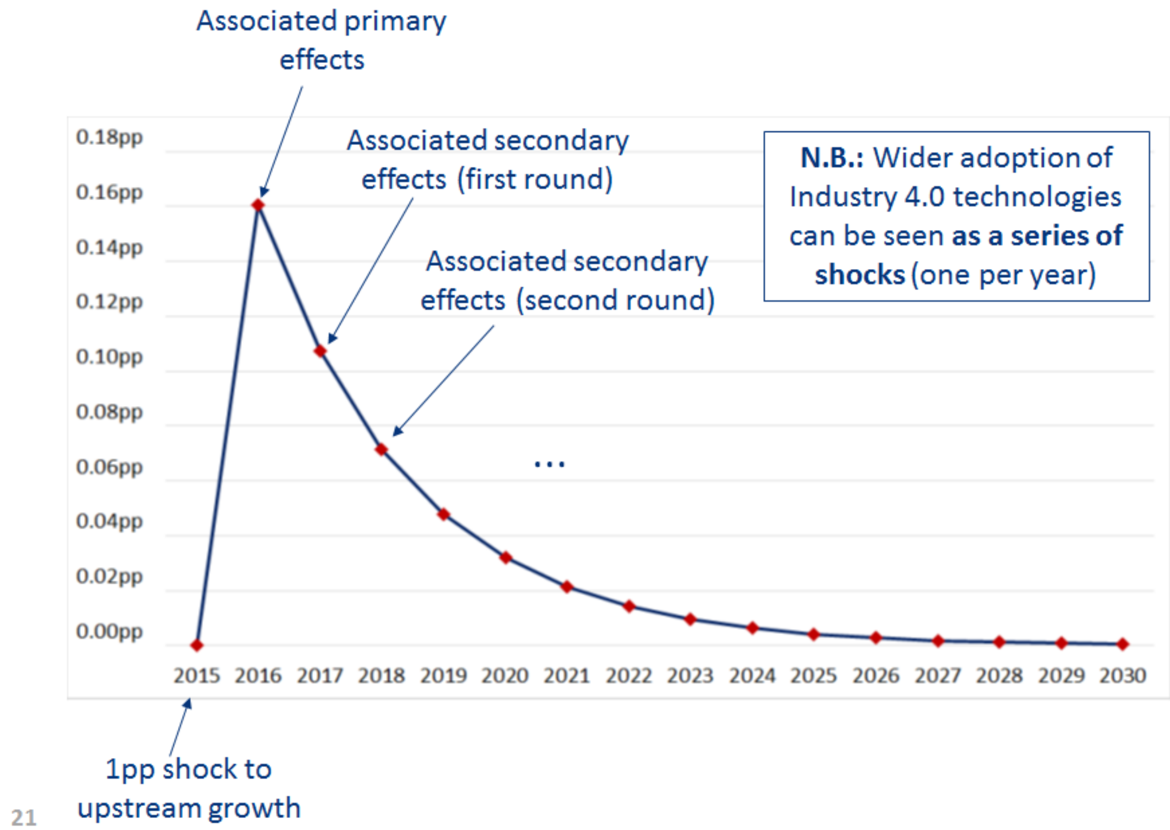
Figure 58 Associated effects to downstream segment



Notes: (*) Primary associated effect (0.16pp) * coefficient on lagged downstream revenue growth (0.67pp) = 0.11pp

Source: London Economics

Figure 59 Associated effects to downstream segment: Example of 1 percentage point shock to upstream growth



Source: London Economics

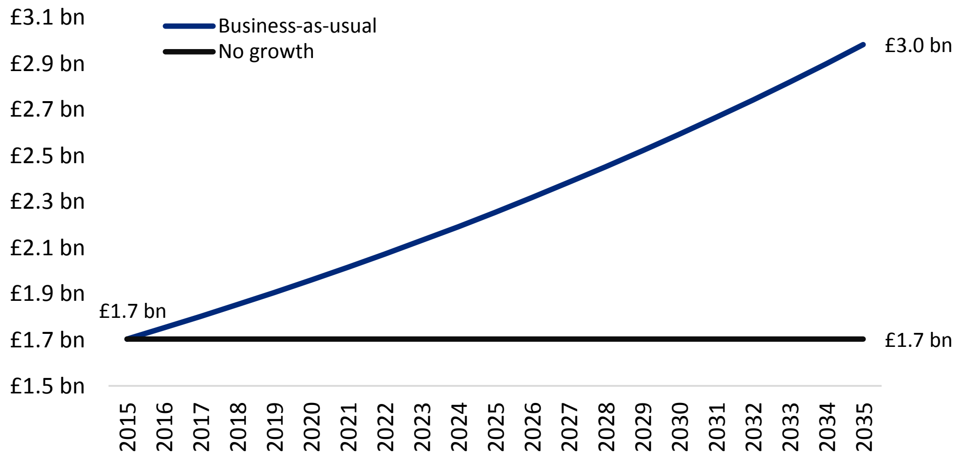
To estimate associated effects, estimated UK Space Manufacturing benefits were converted to corresponding changes in UK upstream revenue growth. The estimated relationship between the upstream and downstream segments was then used to estimate associated changes in downstream revenue growth. Lastly, estimated changes in downstream revenue growth were converted back to £-values.

To convert £-values to changes in growth rates, assumptions on the future development of the upstream and downstream segments have to be made. Assumptions made mirror the Space Manufacturing baselines:

- **Business-as-usual scenario**: Linear projection of past upstream and downstream trends – based on Size and Health of the UK Space Industry 2016 data
- **No growth scenario**: No further growth to upstream and downstream over the next decade, i.e. no further innovations, no large-constellations, etc.

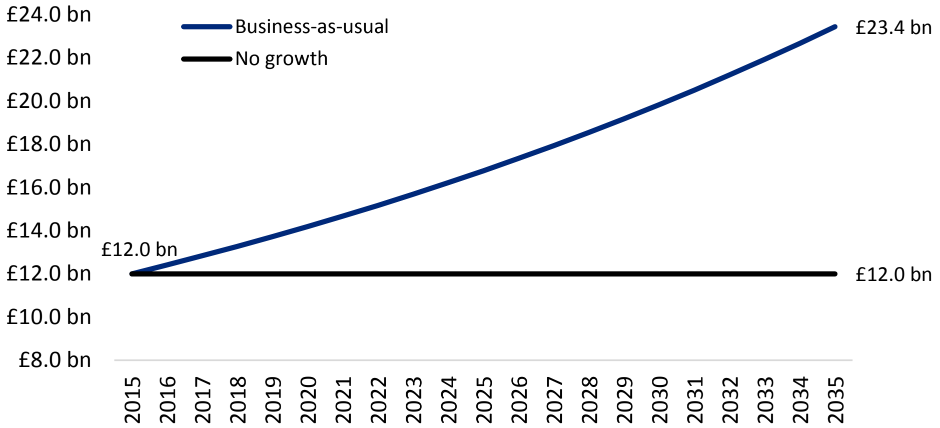
Baselines for the upstream and downstream segments are shown in Figure 60 and Figure 61, respectively.

Figure 60 Baseline scenarios – Upstream segment



Source: London Economics

Figure 61 Baseline scenarios – Downstream segment



Source: London Economics

A1.2 Adoption of Industry 4.0 technologies

To estimate economic benefits, assumptions regarding the diffusion (adoption process) of Industry 4.0 technologies have to be made. Diffusion (adoption) of new products (innovations) typically follows an S-shaped curve[152] and many models have been developed to estimate this process. This study employed a Bass Diffusion Model to estimate the adoption of Industry 4.0 technologies.

This section is structured as follows. Section A1.2.1 outlines the reason for this choice as well as some recent examples. Section A1.2.2 provides a short introduction to the model. Section A1.2.3 explains the application of the model to the adoption of Industry 4.0 technologies in the Space Manufacturing sector.

A1.2.1 Reasons for model choice

The reasons for choosing the Bass Diffusion Model were as follows:

- It is the most widely used mixed influence model and is backed up by a wide range of research and management applications[153] – see Table 15 for a small number of examples of recent applications.
- To illustrate the previous point: Bass's original paper was named, by the Institute for Operations Research and Management Sciences, as one of the top ten most influential papers in management science[154] and, in 2006, was the most widely cited model for diffusion of innovation growth[155]- as of November 2018 the paper had 8,502 citations on Google Scholar.
- The model is also simple and easy to understand, yet sophisticated enough to yield a realistic adoption process that "provides a good fit to the S-shaped curve"[156]
- It considers both external (factors influencing the adoption choice coming from external sources) and internal (factors influencing the adoption choice coming from internal sources). It is intuitive that adoption of Industry 4.0 technologies would be influenced by both external and internal sources. For example:
  - Official sources - e.g. space strategy regarding adoption of Industry 4.0 technologies- promoting adoption of Industry 4.0 technologies (external source)
  - Smaller or more cautious firms imitating larger or more innovative firms who adopt earlier (internal source)
- This consideration of external and internal sources also gives the model an intuitive interpretation in terms of innovators, who first adopt the technology, and imitators, who imitate first adopters (see Section A1.2.2).
- Lack of data – while more complicated models may capture more subtleties in the innovation process, however, these models also require the estimation of further parameters, adding further uncertainty.
- Explanatory power – the Bass model fits almost as well as much more complex models[157]

[152] See, for example: Golder, P. N., Mitra, G., D. (2018). *Handbook of Research on New Product Development: Edward Elgar Publishing*
[153] Boyle (2010). *Some forecasts of the diffusion of e-assessment using a model*. Innovation Journal. Vol. 15:1-30
[154] Hopp, W. J. (2004). *Ten most influential papers of management science's first fifty years*. Management Sci., Vol. 50:1763–1893
[155] Meade N., Islam T. (2006). *Modelling and forecasting the diffusion of innovation—a 25-year review*. *Int Forecasting.* Vol. 22(3):519–45
[156] Chandrasekaran and Tellis (2007). *A Critical Review of Marketing Research on Diffusion of New Products*
[157] Golder, P. N., Mitra, G., D., (2018). *Handbook of Research on New Product Development*: Edward Elgar Publishing

Table 15 Recent applications of the Bass Diffusion Model, selection of examples

Source	Application
Grimm et. al. (2018). *Estimating Future Health Technology Diffusion Using Expert Beliefs Calibrated to an Established Diffusion Model*. Value in Health	Used the bass model to estimate **future health technology diffusion**, calibrated using expert beliefs
Hernandez and Zhang (2017). *Comparing Adoption of Breakthrough and "Me-too" Drugs Among Medicare Beneficiaries: a Case Study of Dipeptidyl Peptidase-4 Inhibitors.* Journal of Pharmaceutical Innovation. Vol. 12(2):105-109	Used a Bass model to compare adoption of **breakthrough drugs** and new pharmaceuticals ("Me-too" drugs), which provide the same mechanism of action as existing drugs drugs
Ntwoku, Negash, and Meso (2017). *ICT adoption in Cameroon SME: application of Bass diffusion model*. Information Technology for Development. Vol. 23(2):296-317	Used a Bass diffusion model to study SME adoption of **information and communications technology** (ICT) in low-income countries using the example of Cameroon
Yoon and Yoon (2017). *An estimation of offset supply for the Korean emissions trading scheme using the Bass diffusion model.* International Journal of Global Warming. Vol. 12(1):99-115	Applied the Bass model to estimate the possible **carbon offset supply** in the Korean emissions trading scheme
Lai (2017). *Modelling the Technology Diffusion by Using Bass Model.* Proceedings of AC 2017. Academic Conferences Association. pp. 169-195	Use the Bass model to explore technology diffusion in **precision machinery industry**
Wang et. al. (2017). *Managing component reuse in remanufacturing under product diffusion dynamics*. International Journal of Production Economics. Vol. 183(B):551-560	Use a use the Bass model to model the product diffusion process of **component reuse and remanufacturing**
Zhu et al. (2014). *Forecasting Mobile Internet Diffusion Trend Based on Optimized Bass Model.* International Journal of Multimedia and Ubiquitous Engineering. Vol. 9(9):351-356	Used a modified Bass model to forecast **mobile Internet diffusion**
Wong et al. (2011). *Predicting the Diffusion Pattern of Internet-Based Communication Applications Using Bass Model Parameter Estimates for Email*. Journal of Internet Business. Vol. 9(2):1-25	Used a Bass model to predict the diffusion pattern of internet-based communication applications based on **email.**
Turk and Trkman (2011). *Bass Model Estimates for Broadband Diffusion in European Countries.* Technological Forecasting and Social Change. Vol. 79(1):85-96	Used a bass model to estimate **broadband** diffusion for European OECD member countries
Chuang and Hsu (2010). *Applying Bass model and KK model to forecast multinational diffusion in LCD TV industry: empirical evidence from Asian and North America*. Scientific Research and Essays, 5 (18) (2010), pp. 2608-2614	Applied Bass model model to forecast multinational diffusion in **LCD TV** industry (data from Asia and North America).
Boyle (2010). *Some forecasts of the diffusion of e-assessment using a model. Innovation Journal. Vol. 15:1-30*	Used a Bass model to forecast diffusion of e-assessment in **GCSE qualifications** in England
Michalakelis et al. (2008). *Diffusion models of mobile telephony in Greece. Telecommunications Policy. Vol. 32:234-245*	Applied the Bass model to examine diffusion of **mobile telephony** in Greece

Note: This list provides a non-comprehensive selection of a small number of recent examples of the Bass Diffusion Model.

Source: London Economics

A1.2.2 The Bass Diffusion Model

The fundamental assumption of the Bass Model is that "the probability of adopting by those who have not yet adopted is a linear function of those who had previously adopted"[158]:

$$P(Adoption\ in\ t\ |\ not\ adopted\ yet) = \frac{f(t)}{1-F(t)} = p + \frac{q}{M}F(t)$$

Where:

f(t) = portion of the market that adopts at t
F(t) = the portion of the market that has already adopted at t
p = the coefficient of innovation representing influences from external sources
q = the coefficient of imitation representing influences from internal sources
M = the ultimate market potential representing the maximum possible adoption rate

The model is driven by two types of adopters:

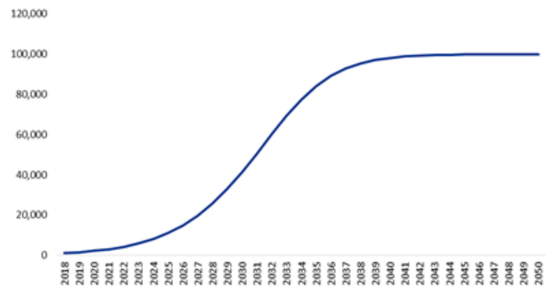
- Innovators who are the first to seek out and adopt a new innovation
- Imitators who are more cautious and wait to see the experiences of others until choosing whether to adopt or not

In each year there are a fixed number of potential innovators (p), and a number of further potential adopters influenced by internal sources, i.e. imitating the innovators, (q/M · number of previous adopters). Each year a certain number of these potential adopters decide to actually adopt.[159]

As more and more organisations adopt the new technology, more and more organisations are tempted to jump on the bandwagon, and more of those tempted do actually adopt. Therefore, the number of imitators increases over time while the number of innovators decreases.

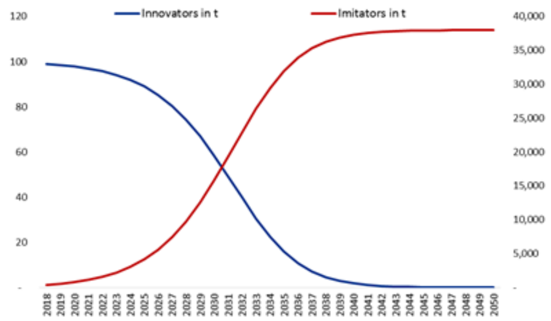
The ultimate market potential (M) imposes an upper limit on the potential number of adopters (adoption rate).

Figure 62 Total number of adopters by t



Notes: Graph based on an example process to illustrate the Bass diffusion model. ***Source: London Economics***

Figure 63 Number of innovators (blue) and imitators (red) adopting in t



Notes: Graph based on an example process to illustrate the Bass diffusion model. ***Source: London Economics***

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158 Bass, F. M. (1969*). A New Product Growth Model for Consumer Durables*. Management Science 15: pp. 215-227
159 Adopters in t = p(M - all previous adopters) + q · (1-1/M) · all previous adopters = Innovators in t + Imitators in t.

A1.2.3 Estimation of the adoption of Industry 4.0 technologies in the Space Manufacturing sector

To estimate the adoption of Industry 4.0 in the UK Space Manufacturing sector, the Bass Diffusion Model was calibrated using the following assumptions regarding current and future use, in terms of Space Manufacturing revenue[160], of Industry 4.0 technologies in the Space Manufacturing sector:

- Current adoption: 1%
- Adoption by 2030: 20%
- Adoption potential (M): 50%

Assumptions made were based on previous experience of the UK space sector, consultations with industry experts and comparison of assumptions and the resulting adoption process with the literature (Section A1.3).

An adoption process fitting these assumptions was then derived. However, as the Bass Model has three parameters, more than one process may fit these assumptions. Therefore, the coefficient of innovation (p) was fixed to 0.001, the mean value for developed countries in other studies. Sensitivity of estimated impacts to this assumption is explored in Section Figure 76.

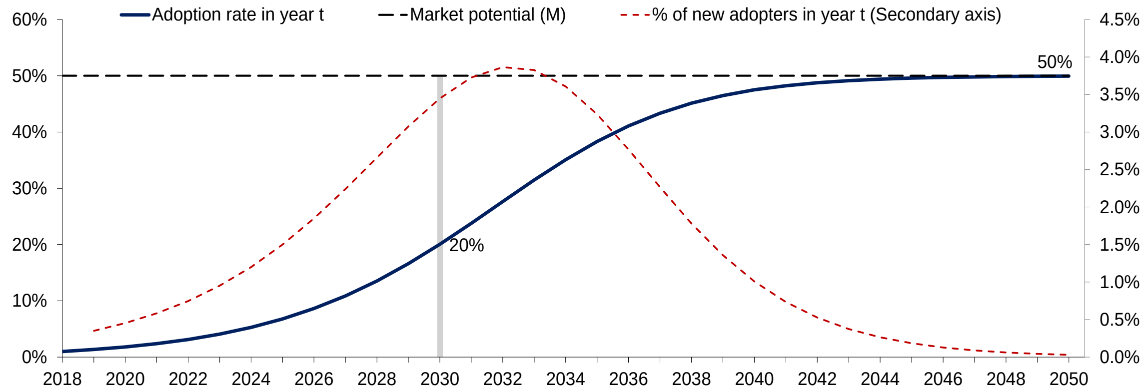
Given these assumptions, the corresponding adoption process was derived by finding a value for the coefficient of imitation (q) that resulted in a process that fits the above assumptions. That is, the question the estimation sought to answers was: *What does q need to be for the model to deliver an adoption process that fits the above assumptions?*

The implied coefficient of imitation (q) derived in this way was estimated to be, approximately, 0.31. The estimated model parameters of the Bass Model employed in this study were thus as follows:

- Coefficient of innovation (p): 0.001
- Coefficient of imitation (q): 0.31
- Market potential (M): 50%

The resulting adoption process, based on these parameters, is shown below (Figure 60).

Figure 64 Estimated adoption of Industry 4.0 technologies in the UK Space Manufacturing



Source: London Economics

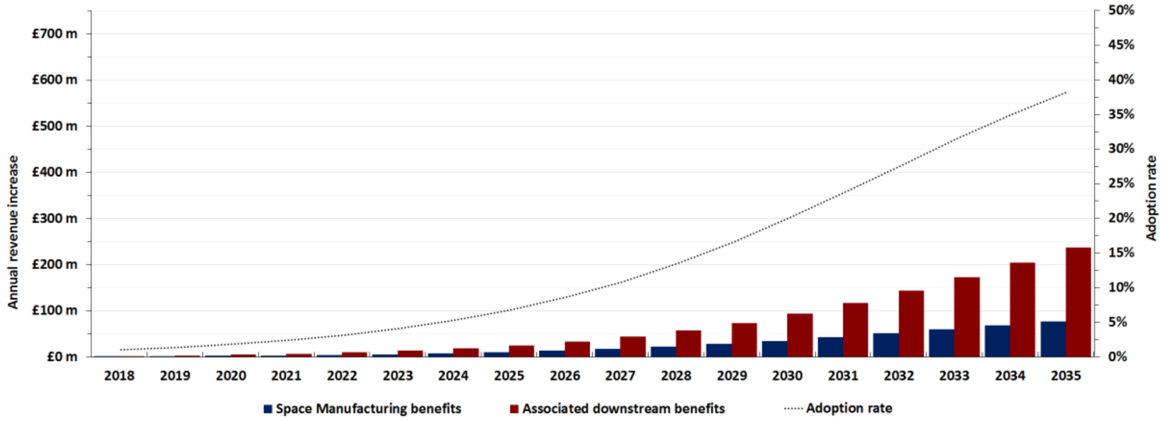
[160] I.e.: By 2030, Industry 4.0 technologies could support 20% of Space Manufacturing revenue and could ultimately support up to 50% of Space Manufacturing revenue.

A1.3 Estimated benefits – 10% productivity case

Annual benefits of wider adoption of Industry 4.0 in UK Space Manufacturing, in the 10% productivity case, are estimated to be, approximately, **£80 million**, by 2035, to UK Space Manufacturing, if the UK Space Manufacturing continues to grow as indicated by past trends.

Associated downstream benefits of wider adoption of Industry 4.0 in UK Space Manufacturing, in the 10% productivity case, are estimated to be, approximately, **£240 million**, if both the UK upstream and downstream segments continue to grow as indicated by past trends.

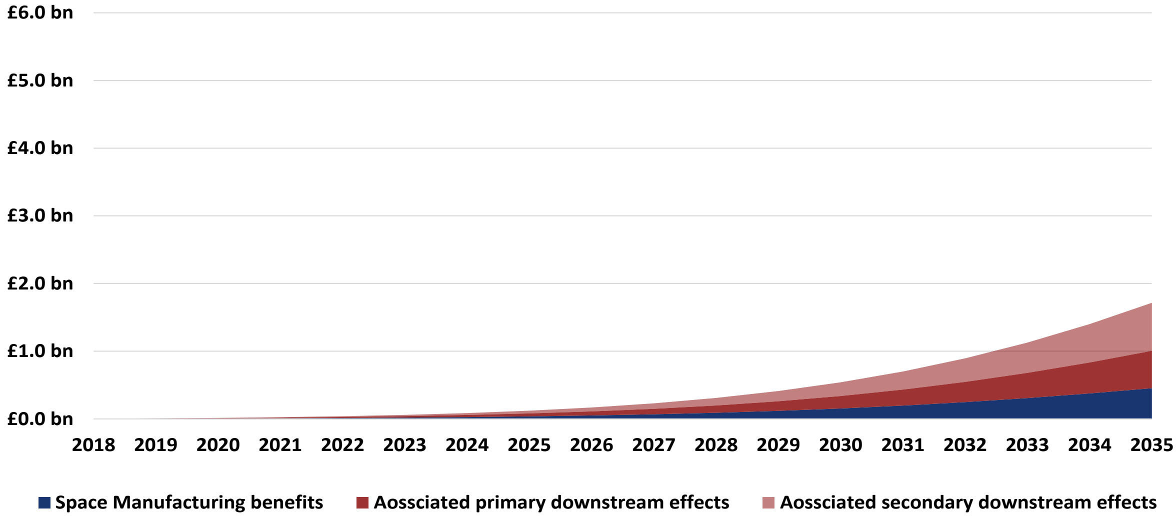
Figure 65 Estimated annual revenue increases, UK Space Manufacturing and UK downstream – business-as-usual scenario, 10% productivity improvements



Source: London Economics

Cumulative revenue increases are estimated to be, approximately, **£0.5 billion** in the UK Space Manufacturing sector, and **£1.3 billion** in the UK downstream segment (**£0.6 billion** through associated primary downstream effects, and the remainder, **£0.7 billion**, through associated secondary downstream effects).

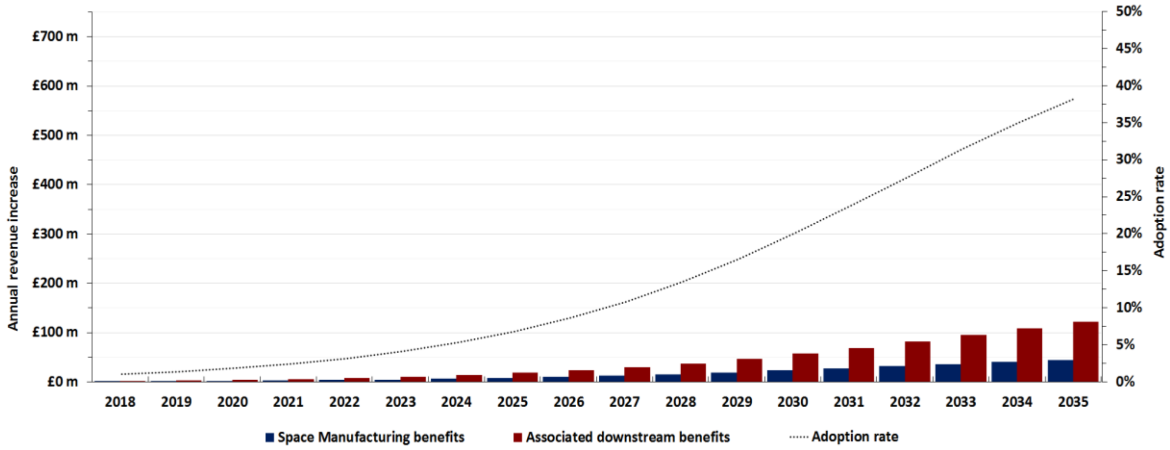
Figure 66 Estimated cumulative revenue increases, UK Space Manufacturing and UK downstream – business-as-usual scenario, 10% productivity improvements



Source: London Economics

In the scenario where the UK Space Industry sees no further growth, annual benefits are estimated to be, approximately, **£40 million** for the UK Space Manufacturing sector, by 2035. Associated downstream benefits, in the no-growth scenario, are estimated to be, approximately, **£120 million**, by 2035.

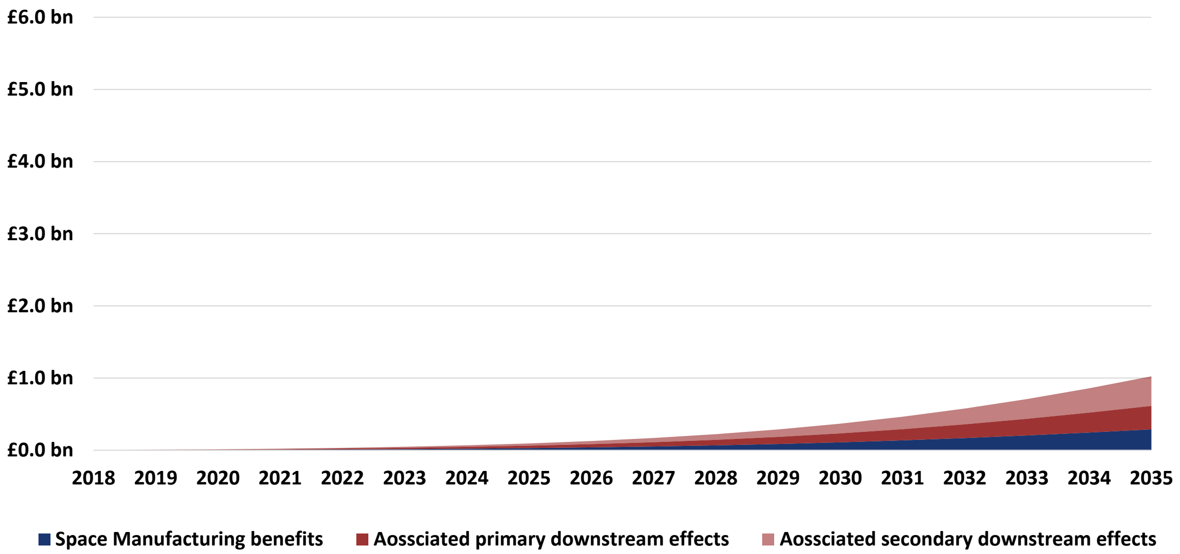
Figure 67 Estimated annual revenue increases, UK Space Manufacturing and UK downstream – no-growth scenario, 10% productivity improvements



Source: London Economics

Cumulative revenue increases in the no-growth scenario are estimated to be, approximately, **£0.3 billion**, by 2035, for the UK Space Manufacturing sector. A further **£0.7 billion** is estimated to accrue through associated benefits to the UK downstream segment.

Figure 68 Estimated cumulative revenue increases, UK Space Manufacturing and UK downstream – no-growth scenario, 10% productivity improvements



Source: London Economics

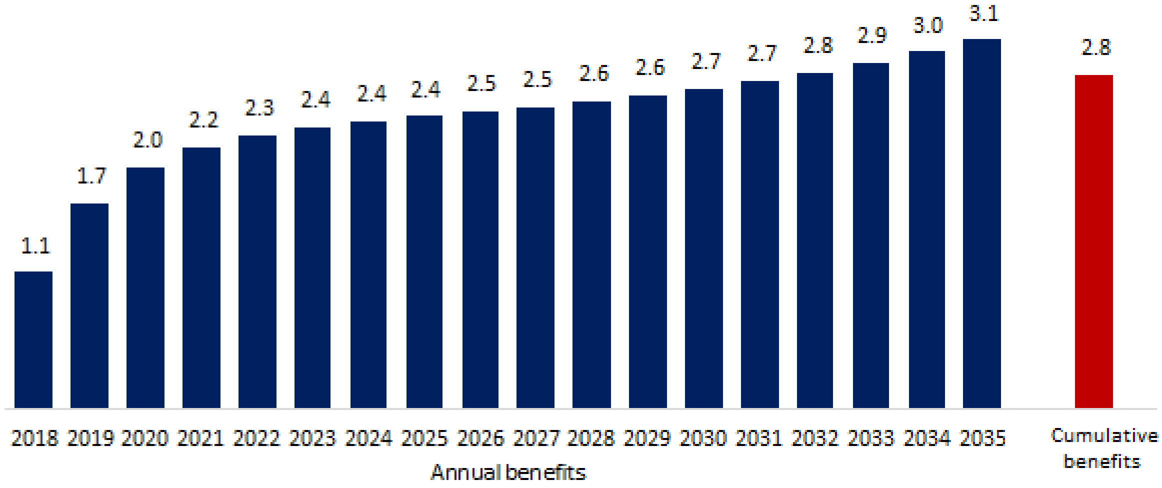
A1.4 Size of associated downstream effects relative to Space Manufacturing benefits

While, the Space Manufacturing segment is comparatively small - it accounts, based on 2014/15 income data, for approximately 8% of total UK space industry income and 0.5% of the global space economy[161] - adoption of Industry 4.0 in UK Space Manufacturing is also expected to be associated with further benefits to the UK downstream segment, for example by enabling new or improved space applications.

In this study we found that the relationship between benefits to the UK Space Manufacturing sector and associated benefits to the UK downstream segment is in the order of 2.8. That is, every £1 in higher revenue accruing to UK Space Manufacturing sector, over the study period (2018-2035), due to wider adoption of Industry 4.0 technologies, is estimated to be associated with an additional increase in downstream revenues of £2.8, based on the business as usual-scenario.

However, the size of associated downstream benefits relative to benefits accruing to the Space Manufacturing sector is not static, but changes in line with adoption, as Figure 69 and Figure 70 show.

Figure 69 Estimated relationship between UK Space Manufacturing and UK downstream benefits – business-as-usual scenario

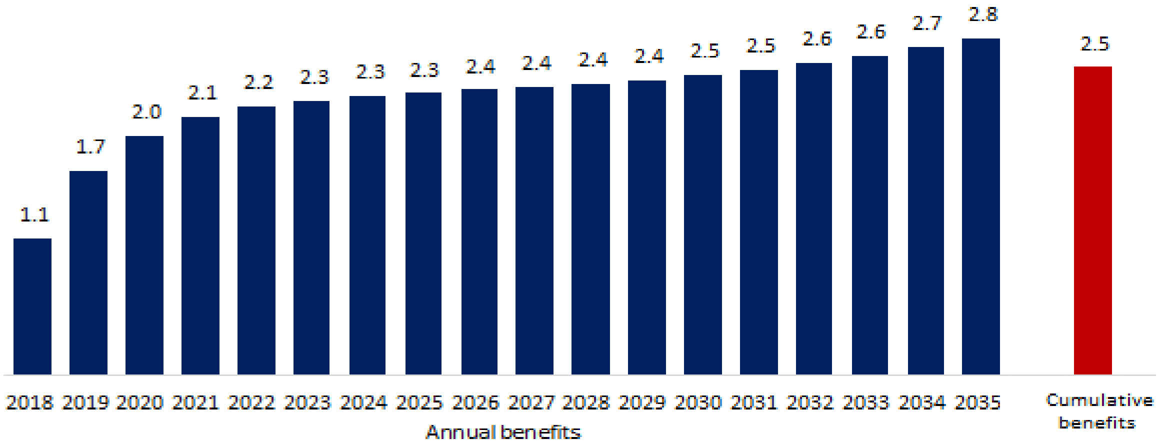


Note: Graph shows the ratio of associated UK downstream benefits to UK Space Manufacturing benefits, for each year and over the whole study period.

Source: London Economics

[161] Size and Health of the UK Space Industry 2016, a report for the UK Space Agency by London Economics https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/575769/Size_and_Health_summary_report_2016.pdf and The Space Foundation (2016) *The Space Report 2016*. Overview of the report is freely available online at: http://www.spacefoundation.org/sites/default/files/downloads/The_Space_Report_2016_OVERVIEW.pdf

Figure 70 Estimated relationship between UK Space Manufacturing and UK downstream benefits – no growth scenario



Note: Graph shows the ratio of associated UK downstream benefits to UK Space Manufacturing benefits, for each year and over the whole study period.

Source: London Economics

A1.5 Size of benefits relative to total space industry

This section evaluates the size of the estimated benefits of adoption of Industry 4.0 in UK Space Manufacturing relative to the potential size of adoption of Industry 4.0 in the whole UK space industry (upstream + downstream) for the case of the business-as-usual scenario. In order to do this, the calibrated model for UK Space Manufacturing was applied to the whole space industry, using the same assumptions that were made for Space Manufacturing (detailed in Annex A1.1).

Important: As space industry characteristics differ from those of the Space Manufacturing sector, assumptions would have to be validated separately for the whole space industry. In particular, potential benefits of Industry 4.0 in non-manufacturing sectors likely differ from benefits Industry 4.0 could bring to Space Manufacturing. Therefore, estimated benefits presented here are not indicative of the potential benefits of adoption of Industry 4.0 in UK space overall (upstream + downstream). Rather, estimated benefits presented here are only illustrative of the relative size of model outputs if a different baseline (upstream + downstream) is used.

Assumptions:

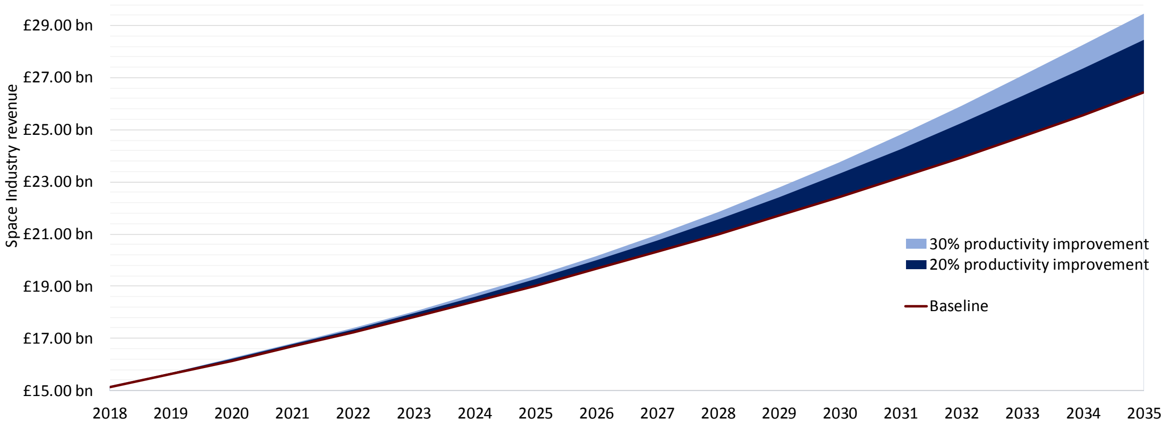
- Both upstream and downstream grow as indicated by past trends (upstream CAGR: 2.8%, downstream CAGR: 3.4%) – this is the business-as-usual scenario. This corresponds to an assumed baseline growth of space industry revenue from £13.7 bn in 2015, to £26.4 bn in 2035.
- Current adoption rate: 1%
- Adoption rate by 2030: 20%
- Market potential: 50%

Calibrating the Bass Diffusion model using these assumptions, annual benefits are estimated to be between £2 billion (20% productivity gains) and £3 billion (30% productivity gains) in 2035.

Cumulative space industry benefits, given the above assumptions, are estimated to be between £11.7 bn (20% productivity gains) and £17.5 bn (30% productivity gains) between 2018 and 2035.

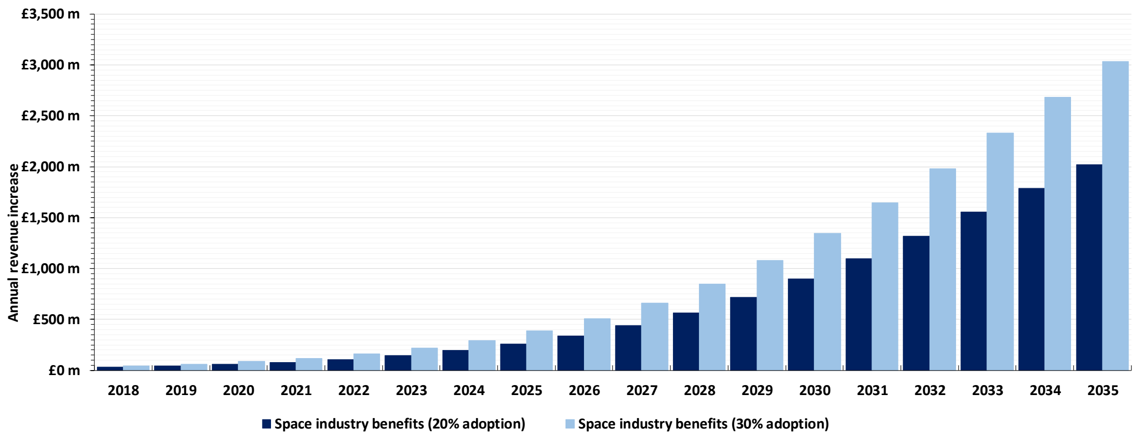
Important: As mentioned above, the Space Manufacturing assumptions may not hold for the space industry as a whole (e.g. ancillary services may only have limited or no benefits from industry 4.0 technologies). Therefore, the adoption rate and ultimate market potential should likely be lower than those assumed for Space Manufacturing to take account of this. The numbers presented here are only meant to be indicative of the difference in scale between benefits estimated for Space Manufacturing alone and benefits estimated for the whole space industry. Further study would be required to derive reasonable assumptions for the whole space industry.

Figure 71 Estimated revenue compared to baseline, total UK space industry (upstream + downstream), business-as-usual scenario



Source: London Economics

Figure 72 Estimated annual revenue increases, total UK space industry (upstream + downstream), business-as-usual scenario



Source: London Economics

A1.6 Evaluation of assumptions and model parameters - sensitivity analysis

This section evaluates assumptions made and resulting model parameters as well as the sensitivity of the estimated adoption process and space industry benefits to these assumptions.

A number of meta-studies analysing diffusion behaviour across a range of different innovations, countries, and disciplines and seeking to draw potential generalisations about the diffusion process of new innovations have been undertaken.

However, most of these are somewhat outdated so that generalisations drawn may not necessarily hold for new innovations such Industry 4.0 technologies. The majority of these meta-studies also focuses on the marketing literature, and, in particular, on the diffusion of consumer goods and so may not be directly applicable. Despite these drawbacks the literature can at least provide some guidance whether estimated parameters are within a plausible range.

As the majority of meta-studies reports ranges which are fairly similar, the discussion in this section will focus on one of the most recent such studies undertaken by Chandrasekaran and Tellis[162]. The meta-study reviews twenty studies and meta-studies, covering hundreds of product categories, including consumer durables as well as industrial products and other applications, across the world. Their generalisations regarding model parameters are detailed below and compared to the parameters and assumptions used in this study.

In addition to sense-checking estimated model parameters, the following section will also provide a discussion on the impact that varying the assumptions made, based on the ranges suggested in the literature, has on the benefits of wider adoption of Industry 4.0 technologies in the UK space industry.

As all three baseline scenarios are based on the same adoption process, sensitivity of estimated impacts is explored for the business-as-usual scenario only. Sensitivity of other scenarios is proportional to the relative baselines.

A1.6.1 Coefficient of imitation (q)

While the coefficient of imitation was not chosen directly in this study, ranges provided in the literature provide a guideline against which estimates of this parameter, implied by the assumptions chosen, can be judged.

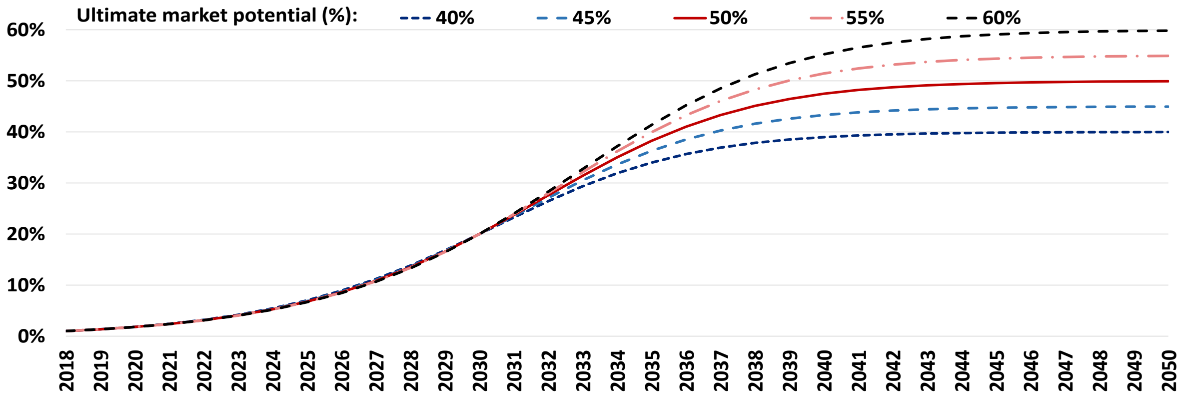
The mean value of the coefficient of imitation (q) lies 0.38 and 0.53, although industrial and medical innovations were found to have a higher coefficient of imitation than consumer durables and other innovations. The mean value for developed countries was found to be 0.51. The estimate of 0.31, implied by the assumptions made in this study, is slightly below this range.

A1.6.2 Ultimate Market potential (M)

The mean value of the ultimate market potential was found to be 52% for developed countries, which is very close to the 50% assumed in this study. Sensitivity analysis further showed that, while choice of the ultimate market potential has significant implications for the shape of the adoption curve post 2035, the adoption process prior to 2035 is only marginally affected (Figure 73).

[162] Chandrasekaran and Tellis (2007). *A Critical Review of Marketing Research on Diffusion of New Products*

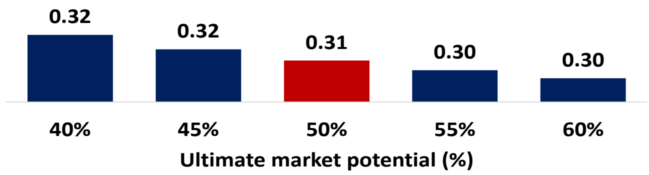
Figure 73 Sensitivity of the adoption process to changes in the ultimate market potential



Notes: Adoption rate refers to the proportion of Space Manufacturing revenue supported by Industry 4.0 technologies.

Source: London Economics

Figure 74 Sensitivity of implied coefficient of imitation to changes in the ultimate market potential

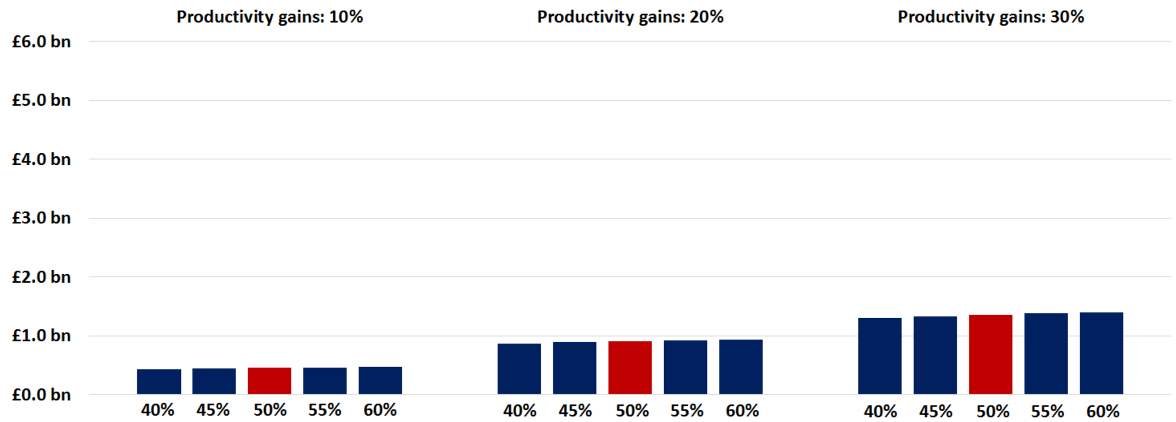


Source: London Economics

The coefficient of imitation (q) implied, keeping all other assumptions unchanged, is also robust to changes in assumptions regarding the ultimate market potential (Figure 74).

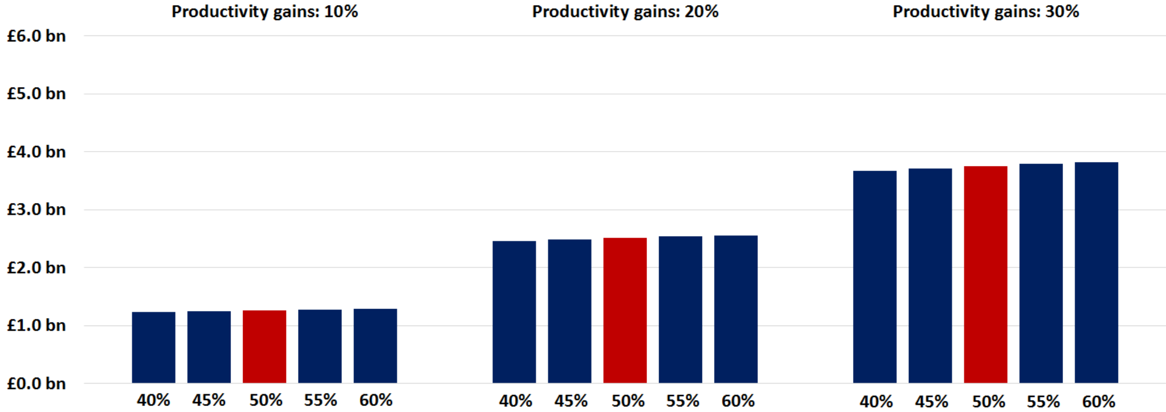
This is reflected in the response of estimated impacts to changes in the ultimate market potential (Figure 75 and Figure 76). As these figures demonstrate both Space Manufacturing benefits as well as associated effects to the downstream sector are only marginally affected by changes in the assumed ultimate market potential.

Figure 75 Sensitivity of cumulative Space Manufacturing benefits to changes in the ultimate market potential (business-as-usual-scenario)



Source: London Economics

Figure 76 Sensitivity of cumulative associated downstream effects to changes in the ultimate market potential (business-as-usual-scenario)



Source: London Economics

A1.6.3 Coefficient of innovation (p)

The mean value of the coefficient of innovation (p) lies between 0.0007 and 0.03. For developed the mean is 0.001. Based on these results, a value of 0.001 was chosen for the purpose of this study.

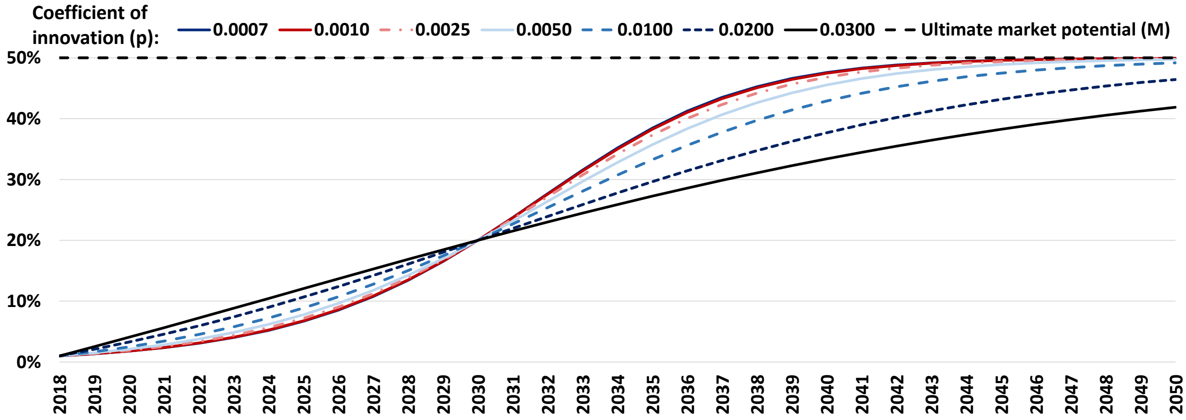
Due to the wide range of likely values that the coefficient of innovation could take, the shape of the estimated adoption process (Figure 77) and the coefficient of imitation implied (Figure 78) are affected significantly by changes in this parameter.

Using the upper end of the range (0.01 - 0.03) implies adoption benefits that are somewhat higher than the benefits implied by the model assumptions used in this study (Figure 79 and Figure 80).

However, these parameters also imply a near linear adoption process, which is unlikely to hold in practice. Moreover, implied estimates of the coefficient of imitation are also significantly below the average ranges provided in the literature (Section A1.6.1).

Other values examined yield adoption processes and benefits that are much closer to those implied by the assumptions used in this study. Estimated benefits are therefore affected only marginally by realistic variation in the choice of the coefficient of innovation.

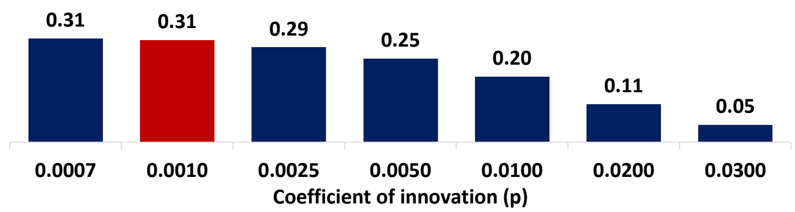
Figure 77 Sensitivity of the adoption process to changes in the coefficient of innovation



Notes: Adoption rate refers to the proportion of Space Manufacturing revenue supported by Industry 4.0 technologies.

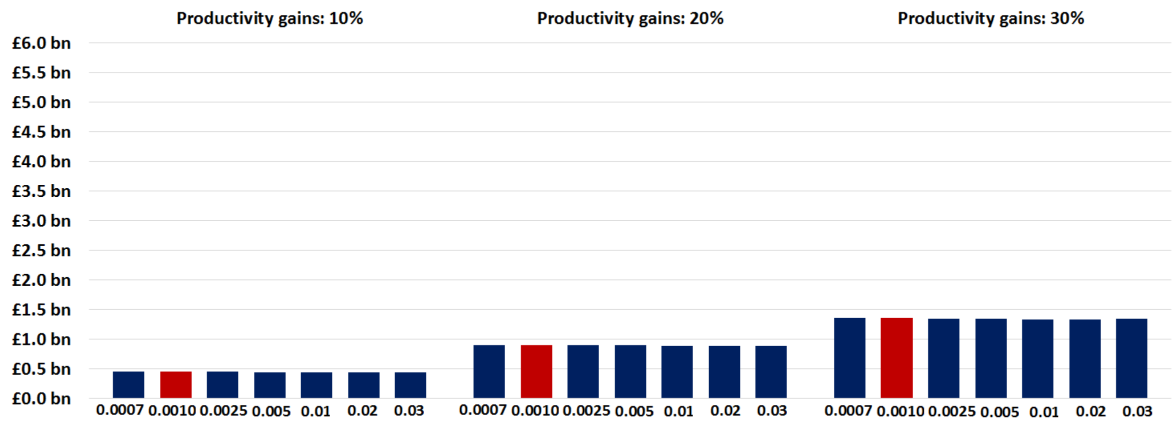
Source: London Economics

Figure 78 Sensitivity of implied coefficient of imitation to changes in the coefficient of innovation



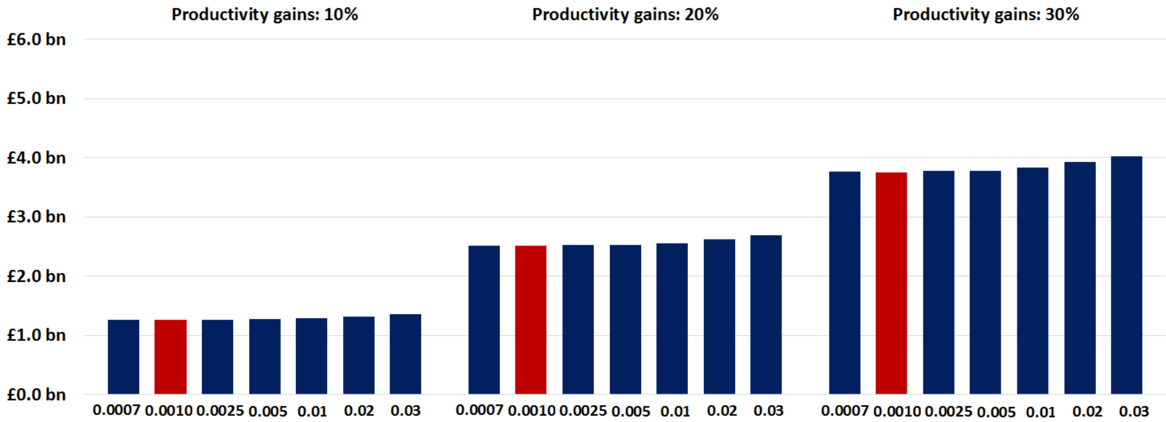
Source: London Economics

Figure 79 Sensitivity of cumulative Space Manufacturing benefits to changes in the coefficient of innovation (business-as-usual-scenario)



Source: London Economics

Figure 80 Sensitivity of cumulative associated downstream effects to changes in the coefficient of innovation (business-as-usual-scenario)



Source: London Economics

A1.6.4 Adoption by 2030

The assumption regarding the adoption of Industry 4.0 technologies by 2030, was chosen based on industry experience of the UK space industry, consultations with industry experts, as well as a comparison with the diffusion of similar technologies.

In particular the assumption implies that less than half of the ultimate market potential of Industry 4.0 technologies will have been realised by 2030, while an adoption rate of close to 50% is reached in the early- to mid-2040s (Figure 81). This is consistent with other estimates as well as with historical data from other technologies, for example:

- Chandrasekaran and Tellis[163] find that it takes about six to ten years for an innovation to take-off and approximately sixteen years for a product to reach peak sales.
- The Boston Consulting Group[164] estimates that a full shift towards Industry 4.0 in manufacturing could take 20 years.
- Cloud computing was first commercialised in the 1990s, yet has still only been adopted by less than 25% of businesses in OECD countries[165].

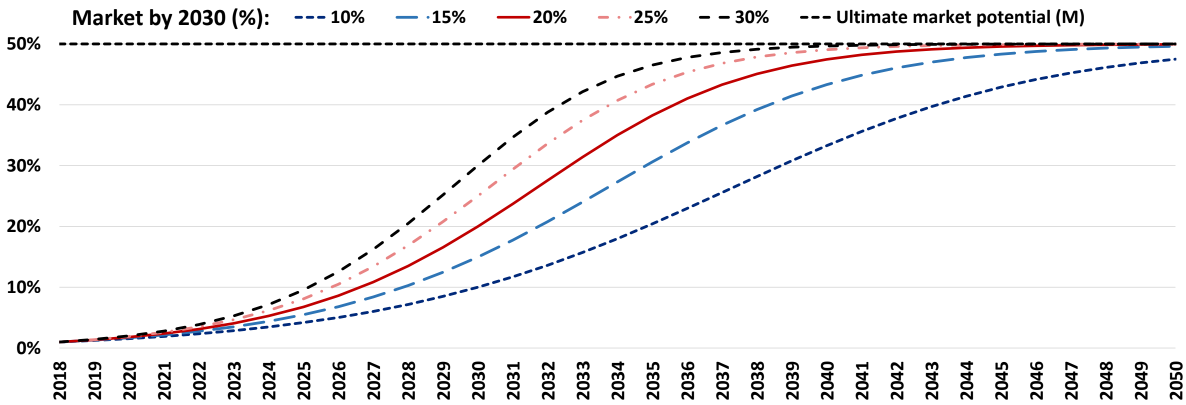
At the high end, an adoption rate of 30%, in terms of Space Manufacturing revenue supported by Industry 4.0 technologies, by 2030 implies a rapid uptake from approximately 7% in 2024 to nearly 45% (in 2034) within the space of a decade. Unsurprisingly, this is estimated to be associated with higher benefits to the UK sector (Figure 83 and Figure 84). However, such rapid adoption is unlikely without significant encouragement of Industry 4.0 uptake, in terms of investment or addressing the barriers presented in this report.

In contrast, a very low adoption rate of 10%, in terms of Space Manufacturing revenue supported by Industry 4.0 technologies, by 2030 implies a coefficient of imitation falling far short of the typical range (see Section A1.6.1) discussed in the literature, with adoption not reaching the ultimate

[163] Chandrasekaran and Tellis (2007). *A Critical Review of Marketing Research on Diffusion of New Products*
[164] Boston Consulting Group (2015). *Industry 4.0: The Future of Productivity and Growth in Manufacturing Industries*
[165] OECD (2017). *The Next Production Revolution: Implications for Governments and Business*

market potential even by 2050. As such, failure of a more widespread adoption of Industry 4.0 technologies is estimated to yield lower benefits to the UK space sector (Figure 83 and Figure 84).

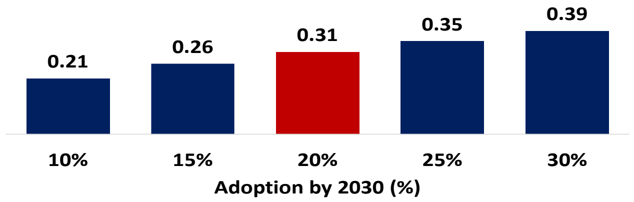
Figure 81 Sensitivity of the adoption process to changes in the rate of adoption by 2030



Notes: Adoption rate refers to the proportion of Space Manufacturing revenue supported by Industry 4.0 technologies.

Source: London Economics

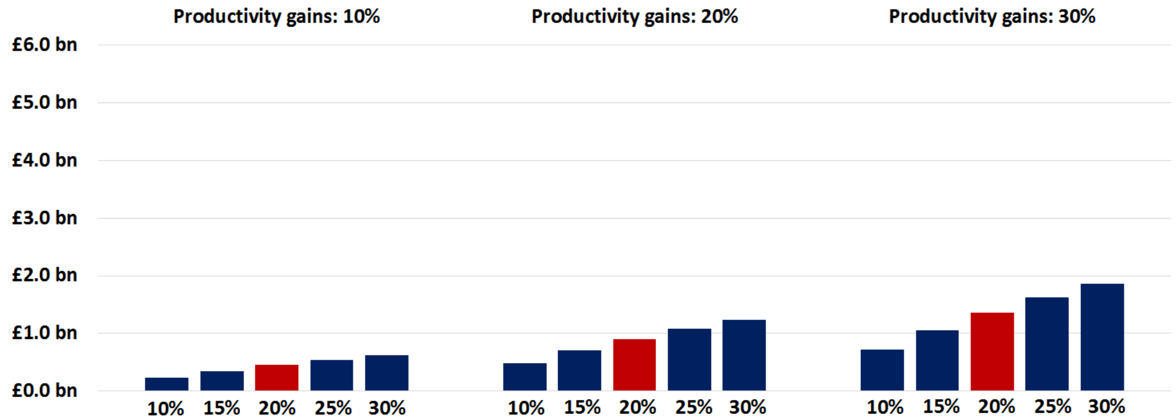
Figure 82 Sensitivity of implied coefficient of imitation to changes in the rate of adoption by 2030



Notes: Adoption rate refers to the proportion of Space Manufacturing revenue supported by Industry 4.0 technologies.

Source: London Economics

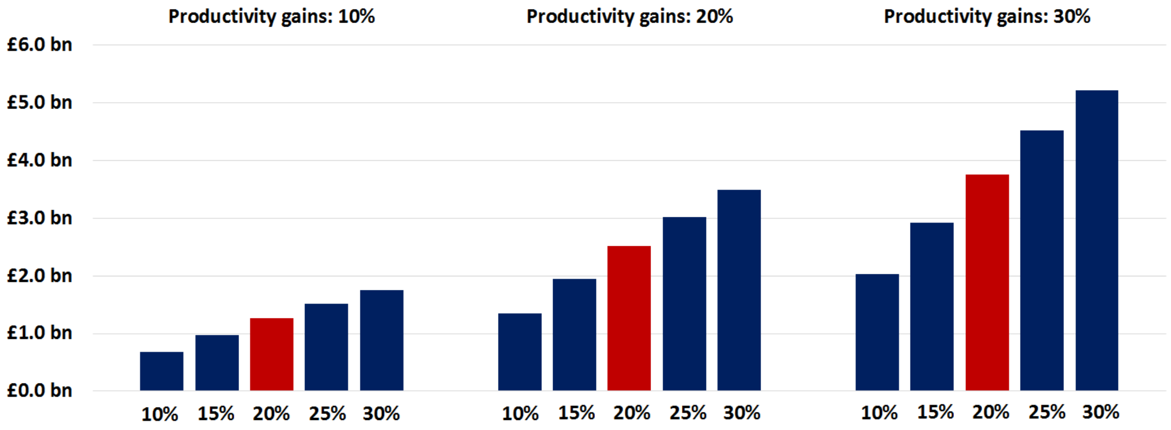
Figure 83 Sensitivity of cumulative Space Manufacturing benefits to changes in the rate of adoption by 2030 (business-as-usual-scenario)



Notes: Adoption rate refers to the proportion of Space Manufacturing revenue supported by Industry 4.0 technologies.

Source: London Economics

Figure 84 Sensitivity of cumulative associated downstream effects to changes in the rate of adoption by 2030 (business-as-usual-scenario)



Notes: Adoption rate refers to the proportion of Space Manufacturing revenue supported by Industry 4.0 technologies.

Source: London Economics

A1.6.5 Current adoption

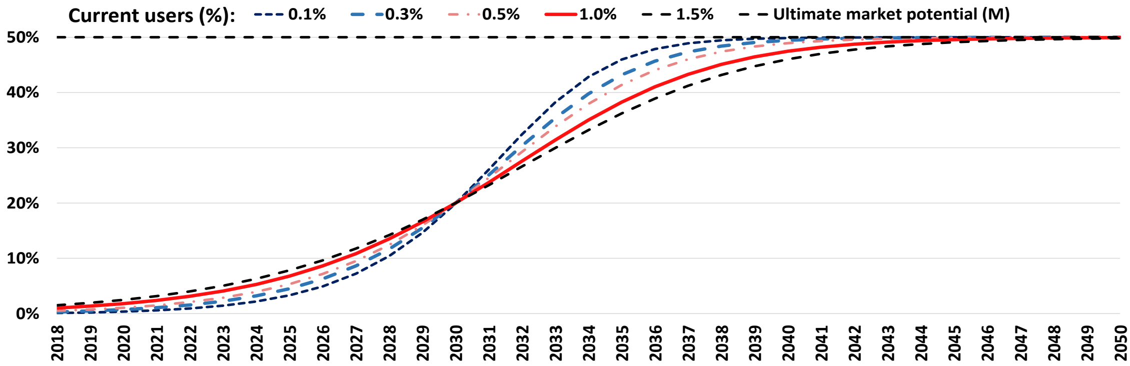
Desk based research regarding current adoption of Industry 4.0 technologies in the UK (Section 5) revealed that the UK manufacturing sector is lagging behind other nations. Desk based research and consultation with industry experts confirmed that Industry 4.0 technologies are also not widely used in the UK Space Manufacturing sector yet. Nevertheless, a number of demonstration and pilot projects are already underway. Current adoption of Industry 4.0 technologies was therefore chosen to be close to, but not exactly, zero.

Figure 85 shows the implied adoption processes for varying proportions of revenue of current users supported by Industry 4.0 technologies, from 0.1% to 1.5%. Figure 86 shows the coefficients of imitation for these adoption processes. Figure 87 and Figure 88 show the estimated benefits to the Space Manufacturing sector, and estimated downstream associated effects, respectively.

A higher proportion of current users, in terms of Space Manufacturing revenue supported by Industry 4.0 technologies, implies a flatter adoption process and therefore faster uptake of Industry 4.0 technologies initially. At the upper end, a proportion of current users of 1% - 1.5% imply coefficients of imitation that are somewhat below the typical range (see Section A1.6.1), and an adoption process that implies higher uptake in the very near future, which remains broadly stable over time.

A lower proportion of current users, in terms of Space Manufacturing revenue supported by Industry 4.0 technologies, implies a more sluggish initial uptake, followed by increased acceleration starting in the mid- to late-2020s. At the low end, a proportion of current users of 0.1% implies a coefficient of imitation at the upper end of the typical range (see Section A1.6.1), and an adoption process exhibiting only limited uptake prior to 2024, but more rapid uptake between 2024 and 2034.

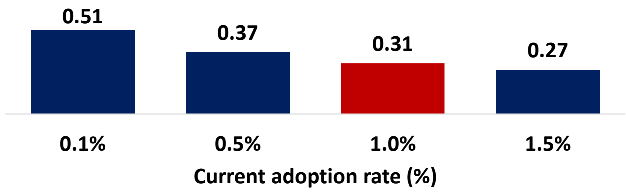
Figure 85 Sensitivity of the adoption process to changes in the current adoption rate



Notes: Adoption rate refers to the proportion of Space Manufacturing revenue supported by Industry 4.0 technologies.

Source: London Economics

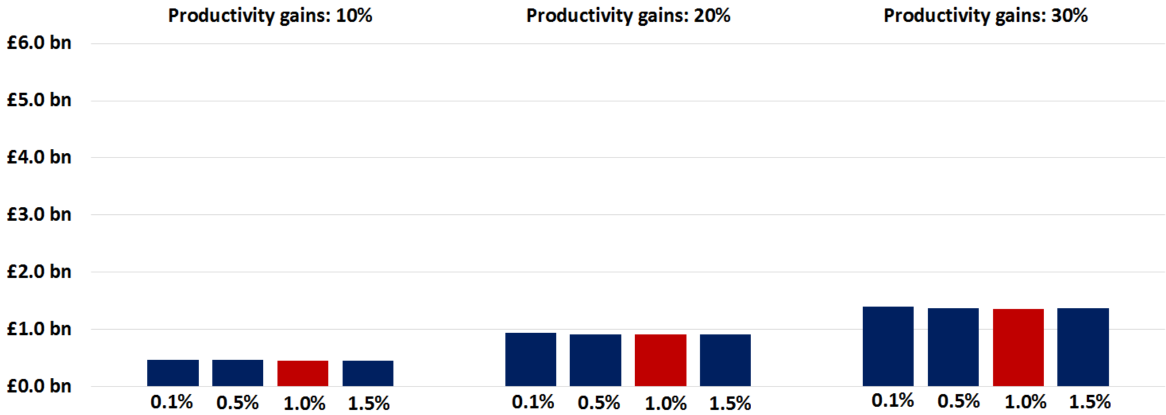
Figure 86 Sensitivity of implied coefficient of imitation to changes in the current adoption rate



Notes: Adoption rate refers to the proportion of Space Manufacturing revenue supported by Industry 4.0 technologies.

Source: London Economics

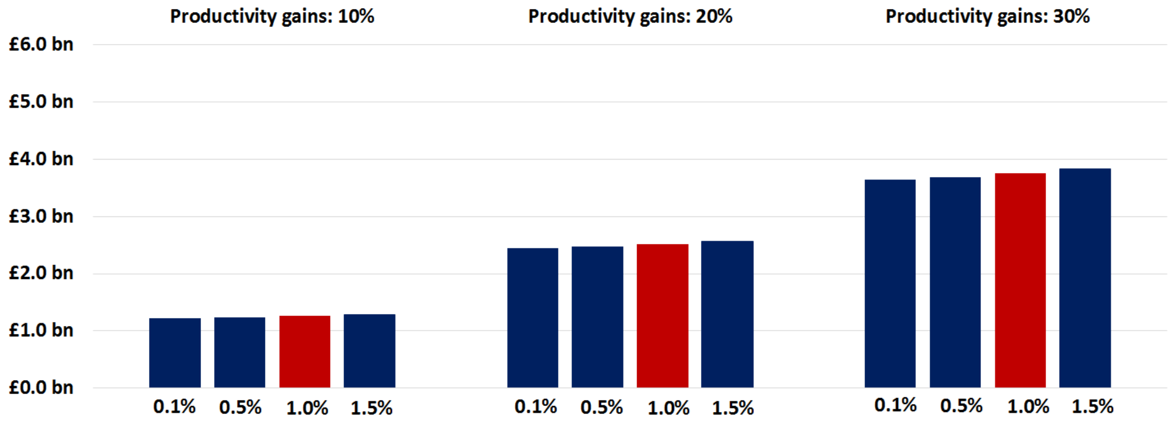
Figure 87 Sensitivity of cumulative Space Manufacturing benefits to changes in the current adoption rate (business-as-usual-scenario)



Notes: Adoption rate refers to the proportion of Space Manufacturing revenue supported by Industry 4.0 technologies.

Source: London Economics

Figure 88 Sensitivity of cumulative associated downstream effects to changes in the current adoption rate (business-as-usual-scenario)



Notes: Adoption rate refers to the proportion of Space Manufacturing revenue supported by Industry 4.0 technologies.

Source: London Economics

A1.6.6 Associated downstream benefits

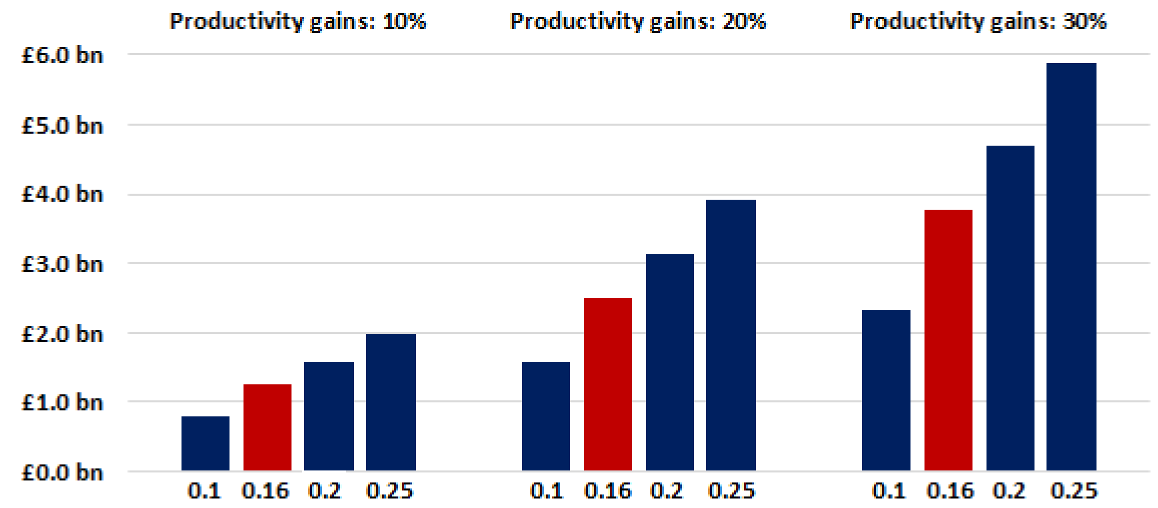
Associated downstream benefits are quantified using a statistical relationship between upstream and downstream growth rates in the past (Section A1.1.2). This section explores the sensitivity of associated downstream benefits to changes in the estimated coefficients.

As Industry 4.0 technologies could potentially have disruptive impacts on the wider space industry, particular attention is paid coefficients that are larger than the historical relationship between the UK upstream and downstream sectors suggest.

Figure 89 shows the effects on cumulative associated downstream effects to changes in the coefficient of UK upstream revenue growth, for the business-as-usual scenario.

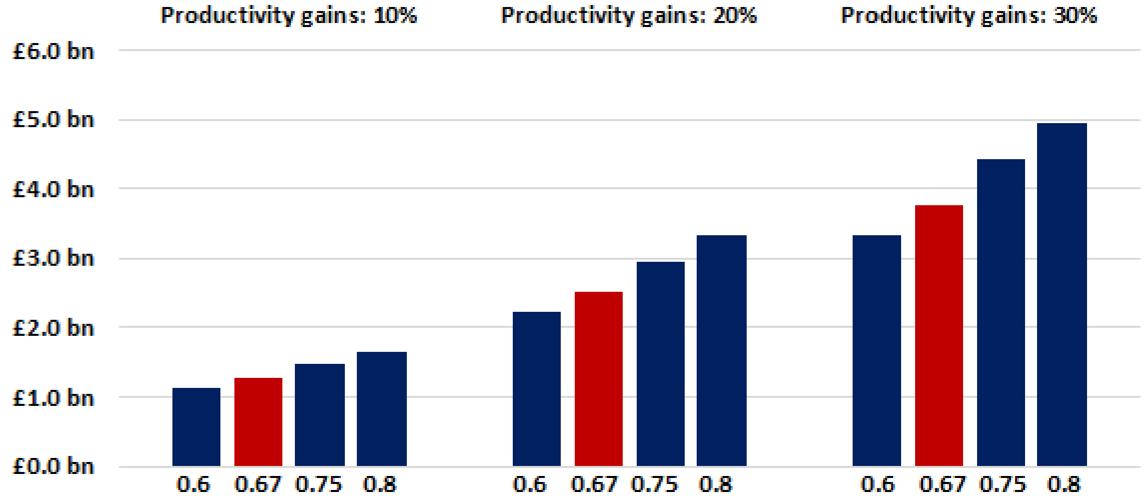
Figure 90 shows the effects on cumulative associated downstream effects to changes in the coefficient of of lagged UK downstream revenue growth, for the business-as-usual scenario.

Figure 89 Sensitivity of cumulative associated downstream effects to changes in the coefficient of UK upstream revenue growth (business-as-usual-scenario)



Source: London Economics

Figure 90 Sensitivity of cumulative associated downstream effects to changes in the coefficient of lagged UK downstream revenue growth (business-as-usual-scenario)



Source: London Economics

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