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Evidence synthesis on the conditions needed to translate research and drive innovation

Camilla d'Angelo, Anna Knack, Calum MacLure, Jon Freeman

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Preface

The National Academies (the Academy of Medical Sciences, the British Academy the Royal Academy of Engineering and the Royal Society) have recognised the need to better understand the benefits that research and innovation bring to the UK, and the conditions needed to ensure the continued excellence of the UK's outstanding research and innovation base. Rather than simply refining the case for more investment in research and innovation, the aim is to understand the benefits of this investment across the UK and its population, and to develop new analysis to allow government to spend wisely.

To this end, RAND Europe was commissioned to conduct an evidence synthesis on what is known about: (i) the conditions that enable research and innovation, including that which is publicly supported, across different disciplines, to result in a range of benefits; (ii) how such conditions interact in different environments and throughout the lifecycle of research translation and innovation; (iii) how the effectiveness of different levers used to facilitate research translation and innovation has been measured, and how those measures might be made more robust; and (iv) the barriers to translating research and driving innovation.

This report has been prepared for the National Academies. The intended audience for the evidence synthesis is policymakers and academic professionals.

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For more information about RAND Europe or this document, please contact:

Dr Jon Freeman
RAND Europe
Westbrook Centre
Milton Road
Cambridge CB4 1YG
United Kingdom
Tel: +44 (1223) 353 329
Email: jfreeman@rand.org

Executive summary

The aim of this study is to understand the conditions needed to translate research and drive innovation. As the UK government works towards its commitment to increase investment in research and development (R&D) to 2.4 per cent of gross domestic product (GDP) by 2027,[1] there is a need for better evidence to inform decisions about how and where that investment is made. In this context, RAND Europe was commissioned by the Steering Group of the National Academies to synthesise evidence on:

1. The conditions that enable research and innovation, including that which is publicly supported, across different disciplines, to result in a range of benefits.
2. How such conditions interact in different environments and throughout the lifecycle of research translation and innovation.
3. How the effectiveness of different levers used to facilitate research translation and innovation has been measured, and how those measures might be made more robust.
4. The barriers to translating research and driving innovation.

This study investigated the conditions that support innovation in the UK economy, drawing from four distinct sectors to evidence the conclusions: pharmaceutical and life sciences; defence; financial technology (fintech); and creative economy. The approach to this work consisted of a literature review, an expert workshop and key informant interviews.

There are many interacting conditions needed to enable research and innovation, and these are common for publicly and privately funded research

In order for research to be developed into innovations that can deliver benefits to society, there needs to be an effective translation and innovation system in place. A number of conditions, and their interaction, are deemed critical to the translation and innovation process across sectors. These include: (i) drivers; (ii) input resources; (iii) enabling resources; (iv) institutional factors; and (v) absorptive capacity.

Drivers are the motivations that spur innovation to occur and are, therefore, a key condition for innovation.

Input resources, including knowledge, talent and capital, are the primary resources needed for an actor, organisation or sector to undertake innovation.

[1] The UK currently invests 1.7 per cent of GDP in private and public funds on R&D (OECD, 2018).

Enabling factors, including infrastructure and the formation of networks, facilitate the collaboration of multidisciplinary teams, which are increasingly needed for successful translation and innovation.

Institutional factors, including structures (e.g. regulation, standards) and culture, shape the environment in which translation and innovation take place. Regulation is necessary to ensure safety and fairness, but outdated or maladapted regulatory approaches can often represent a barrier to entry into the market for smaller organisations, and so can act to constrain innovation. Culture encourages and incentivises innovation when it is open, trusting, and conducive to risk-taking and learning from failure rather than avoiding it.

Absorptive capacity is an important aspect of innovation systems. In a number of sectors, a lack of systemic readiness and an emerging skills gap suggest that there could be constraints on the absorptive capacity of the UK innovation system.

There is no 'magic formula' for the conditions needed to enable innovation; all of the conditions are required in different forms across the innovation pathway

Effective translation across all sectors requires an interaction of all of the conditions across the different stages of the translation pathway (from ideation and research through to uptake and diffusion).

While knowledge, talent and capital are necessary at all stages of translation, it is their interaction through enablers, such as networks and infrastructure, which is particularly important. Successful translation in all the sectors relies on extensive networks between a range of actors (e.g. government, academia and industry) as well as disciplines and skills (e.g. arts, humanities, STEM and digital). The need for extensive networking is especially apparent in the creative sector, which is highly multidisciplinary and collaborative, as well as in life sciences R&D, which is increasingly open and outsourced from large companies.

Infrastructure, such as innovation hubs and clusters, plays an important role in bringing relevant knowledge and talent together.

Cultures, and associated institutional structures/processes, can have an impact on innovation at all stages of the translation pathway. In the health sector, research has shown the lack of a widespread innovation culture in the NHS, which slows the uptake and diffusion of innovations in the healthcare system. Therefore, despite many initiatives to support the conditions for translation leading to the development of innovations, the absence of the right culture at later stages can act as a barrier to their widespread adoption. This illustrates that it is necessary for all of the conditions to interact at all stages of the translation pathway, from ideation and research through to adoption and diffusion.

In general, the effectiveness of policy interventions to facilitate research translation is not measured particularly well, as a result of lack of evaluation in some sectors and limited metrics in those that do undertake evaluation

Policy interventions can support the generation and diffusion of innovation by fostering an effective translation system. However, interventions are not equally common in the industry sectors reviewed for this study and can vary significantly in their nature. Furthermore, not all the interventions are evaluated;

it seems that the greatest number of interventions and evaluations is found in the pharmaceutical and life sciences sector.

Evaluations of interventions often use metrics that focus on the economic impacts of the intervention rather than measuring broader social outcomes (e.g. well-being or cultural enrichment). Specifically, evaluations often consider metrics such as: R&D additionality, turnover, employment, additional investment, or product sales. Economic measures are certainly useful at quantifying innovation outcomes in R&D-intensive sectors or sectors in which value propositions are around commercial and economic success. A limitation of current evaluation approaches is that they inadequately capture the variety of benefits from innovation, such as patient well-being or the social and artistic innovation in the creative industry. Metrics also do not always fully capture all the stages of the translation pathway in all sectors (e.g. there is a lack of innovation uptake measures in the health sector). This makes it hard to determine whether interventions have been effective, since evaluations are not capturing the full diversity of benefits from innovation both within and across sectors. A more holistic way of measuring the benefits from investment in R&I (beyond economic benefits) would better capture the ways in which research benefits society, and would facilitate better analysis to make sure investment is targeted towards achieving the full range of these benefits and not just those which are most easily measured.

Challenges to the translation and innovation process are very context dependent; however, lack of clarity about user needs and stable access to capital throughout the innovation process were commonly identified

Funding and continuity of funding is important for translation and innovation and, conversely, the absence of funding and stability of funding can be a barrier to translation and innovation. Access to capital is often most challenging during the middle stages of the translation pathway, which tends to present more risk for private investors, such as venture capitalists. In response to this, initiatives such as NIHR i4i, the Biomedical Catalyst and the Small Business Research Initiative (SBRI) are helping to de-risk research and bridge the so-called 'valley of death'.

There are relatively few demand-side measures to stimulate innovation, such as procurement policies or innovation inducement prizes. There have been several interventions that take a demand-driven approach to promote innovations to address specific unmet needs. For example, a review of the SBRI programme concluded that it has a valuable role to play in the innovation and procurement landscape as it provides 'market pull' to complement the 'technology push' of other policies. It may be that there is room for more demand-side interventions that follow the SBRI model to support innovation in the UK. Missions are another policy tool through which the public sector could actively create demand and steer innovation towards solving major long-term societal challenges.

Careful design of interventions, preferably with evaluations, could help improve the conditions for the translation of research and to drive innovation

Given that an interaction between all of the conditions is important to support an innovation across different stages of the translation pathway, interventions should, where possible, ensure that input, enabling and institutional factors interact in order for the effective translation of research to occur.

The lack of rigorous, independent evaluations, as well as robust innovation metrics, makes it hard to draw evidence-based conclusions as to the effectiveness of policy interventions. Where evaluations exist, the methods and metrics for evaluating the impact of policy interventions often do not adequately reflect the full diversity of benefits (beyond economic) from R&I (as stated above). These limitations make it hard to assess the full range of progress following an intervention, and could lead to sub-optimal policies. While not specifically a barrier to innovation, it does mean that there is little formalised knowledge as to what works to enable innovation. This matters because it means that investments to support innovation may be ineffective and an unproductive use of public (and in some cases private) finance.

Innovation timelines are rarely taken into account in the evaluation of policies. Evaluations often focus on the short-term, commercial impacts of interventions and rarely measure longer-term outcomes and progress (e.g. impacts on patients or the NHS). A limitation of this approach is that the full benefits of an intervention are rarely captured, particularly in sectors in which development timelines are long. Innovation timelines are also important in determining the type of conditions, and hence policies, that might be important.

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Abbreviations

AHSN	Academic Health Science Network
BBSRC	Biotechnology and Biological Sciences Research Council
EU	European Union
Fintech	Financial technology
GDP	Gross domestic product
GVA	Gross value added
IT	Information and communications technology
MOD	Ministry of Defence
MRC	Medical Research Council
MRL	Manufacturing readiness level
NICE	National Institute for Health and Care Excellence
NIHR	National Institute for Health Research
OECD	Organisation for Economic Co-operation and Development
R&D	Research and development
R&I	Research and innovation
SBRI	Small Business Research Initiative
SME	Small and medium-sized enterprise
SRL	Systems readiness level
STEM	Science, technology, engineering and mathematics
TRL	Technology readiness level
UKRI	UK Research and Innovation

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1. Introduction

1.1. Research and innovation are important to the UK's economic growth and because of this they feature strongly in the Industrial Strategy

1.1.1. The UK is increasing public investment in R&D

In 2015, over £10bn of taxpayers' money was spent on publicly-funded research and development (R&D).[2] In its Industrial Strategy,[3] the government has since committed to increasing R&D spending (currently at 1.7 per cent of GDP)[4] to match the 2014 Organisation for Economic Co-operation and Development (OECD) average of 2.4 per cent of GDP by 2027, with a long-term goal of 3 per cent.[5] These significant investments are increasingly justified on the grounds that investing in research can ultimately result in a range of benefits to society and, through the process of innovation, enhance productivity and efficiency. The process of innovation is essential in developing research discoveries into new and improved products, services and approaches, all of which can deliver benefits. As part of the Industrial Strategy, the government aims to stimulate innovation by increasing investment in R&D.[6]

It is worth noting that the government target is for R&D spending. Although the process of innovation often draws on R&D, R&D is not always part of the activity of innovation and does not automatically lead to innovation. The OECD defines R&D as creative work undertaken on a systematic basis in order to increase the stock of knowledge, and the use of this stock of knowledge to devise new applications. It includes basic research, applied research and experimental development.[7] Whereas research involves early-stage generation of new knowledge, development involves maturing that knowledge so that it is more ready to be applied. An innovation is defined as the implementation of a new or significantly improved product (good or service) or process, a new marketing method, or a new organisational method in business practices, workplace organisation or external relations (see Box 1 below for OECD definitions of R&D and innovation).[8] In order for R&D to result in benefits to society through innovation, there needs

[2] Office for National Statistics (2017).

[3] Government strategy for increasing productivity and driving economic growth across the UK.

[4] OECD (2018).

[5] BEIS (2017).

[6] BEIS (2017).

[7] OECD (2015).

[8] OECD/Eurostat (2005).

to be an effective translation system in place. Translation is the process by which ideas and discoveries are developed into new and improved products, services and approaches.

Box 1 OECD definitions of R&D and innovation

R&D: creative work undertaken on a systematic basis in order to increase the stock of knowledge, and the use of this stock of knowledge to devise new applications. It includes basic research, applied research and experimental development.

Innovation: the implementation of a new or significantly improved product (good or service) or process, a new marketing method, or a new organisational method in business practices, workplace organisation or external relations.

Product innovation: the introduction of a good or service that is new or significantly improved with respect to its characteristics or intended uses.

Process innovation: the implementation of a new or significantly improved production or delivery method. This includes significant changes in techniques, equipment and/or software.

Marketing innovation: the implementation of a new marketing method involving significant changes in product design or packaging, product placement, product promotion or pricing.

Organisational innovation: the implementation of a new organisational method in the firm's business practices, workplace organisation or external relations.

1.1.2. There is also significant private investment in R&D

It is well known that there are significant rates of return from investment in R&D, likely in the range of 20–30 per cent.[9] The UK government's strategy for investing in R&D is based on the idea, which has been reinforced by a number of studies,[10] that there is a positive link between levels of public and private spending on R&D. A study for the Department for Business, Innovation and Skills (now the Department for Business, Energy and Industrial Strategy) identified a 'crowding-in' effect, suggesting that every extra £1 of public investment in R&D leads to an increase of around £1.36 in private investment.[11] Another study, which focused on medical research, identified a similar relationship, finding that every extra £1 of public R&D expenditure in that field is associated with an increase of between £0.83 and £1.07 in private expenditure.[12] However, the study also notes that only 44 per cent of additional private expenditure occurs within one year of a public investment, with the remainder occurring over decades.

[9] Haskel & Wallis (2010); Haskel & Wallis (2013); Haskel et al. (2014).

[10] See for example: Economic Insight (2015); Sussex et al. (2016).

[11] Economic Insight (2015).

[12] Sussex, Feng et al. (2016).

1.1.3. Not all research is translated into innovation

While the UK has a strong research base through its world-leading university sector,[13] the same success is not seen in translation and innovation.[14] Stimulating innovation is a key policy aim for government to ensure that public services can be delivered more efficiently and effectively, to help create the conditions for improved productivity and growth in the UK economy, and also to improve health and well-being, as well as cultural and social enrichment.[15] While increases in government investment in R&D are important to increase the stock of new ideas and discoveries, in order for this investment to result in benefits to society, there needs to be an effective translation and innovation system in place. Ensuring that research, where there is a potential for innovation, delivers benefits to society requires a better understanding of the conditions needed to enable translation and innovation, the contexts in which innovation is more or less likely to emerge, and the systems which support it.

1.2. Increasing the translation of research into innovation requires an understanding of the necessary supporting conditions

1.2.1. A number of factors beyond R&D spending influence the translation of research into innovation

Beyond increasing spending on R&D, a number of other factors are deemed critical to the translation and innovation process. Innovation is generally conceptualised as occurring within broad systems that contain a variety of factors.[16] Some of these factors include: access to finance, available skill sets within a society or organisation, access to knowledge and expertise, the surrounding policy environment (e.g. legal and regulatory frameworks), and the demand for innovation.[17] An innovation systems perspective recognises that innovation is the result of highly dynamic system interactions, in which these different factors interact.[18]

1.2.2. Effective policy can promote the conditions needed to enable the translation of research into innovation

Policy interventions can support the generation and diffusion of innovation through fostering an effective translation system.[19] Interventions aim to achieve this by improving the availability and interaction of conditions that support the translation process. There exists a diverse set of innovation policy instruments, which include measures that increase the supply of conditions, measures that increase the demand for

[13] Southwood (2017).

[14] Hauser (2010).

[15] BEIS (2017).

[16] Freeman (1987); Nelson (1993); Langlois (2003).

[17] Freeman (1987); Nelson (1993); Langlois (2003).

[18] Freeman (1987); Nelson (1993); Langlois (2003).

[19] Edler et al. (2013).

innovation, and those that combine both approaches.[20] Rationales for these interventions are often based on a de-risking role in the face of market failures (e.g. information and incentive asymmetries) or system failures (e.g. around connectivity or individual and organisational capabilities).[21] Beyond de-risking and failure rationales, innovation policy is also seen as actively creating demand and steering innovation, as seen with the increasing interest in missions and challenges.[22]

1.2.3. Effective measures of innovation are needed to guide policy

Assessing the effectiveness of innovation policy relies on the collection of appropriate data. A limitation of current evaluation approaches is that many types of innovation, and the broad range of benefits these can deliver, are not being captured.[23] For example, investment in organisational innovation, training and skills, product design and branding are not recorded as R&D spend, yet are key sources of increased productivity, particularly in the service sector.[24] Measures of innovation in the UK have typically focused on technological characteristics such as R&D expenditure or number of patents.[25] However, R&D expenditure and patents granted are not necessarily the best measures of innovation, since the former is an input measure and does not automatically lead to innovation, and the latter does not mean that commercialisation of that patent has taken place. At present, there is no single measure of innovation policy that is widely accepted as being useful across strategic through to programme levels. Moreover, metrics for evaluations of innovation policy interventions typically focus on the economic benefits of the intervention, such as productivity (e.g. turnover, employment) and commercial success (e.g. product sales, additional investment). While these are important, there are other highly valuable benefits which go unacknowledged in most of the evaluations reviewed here. These include broader benefits; for example, to well-being, social cohesion, culture and the environment.[26] Therefore, broader measures of innovation could more accurately inform the progress of interventions and ensure these enable different types of innovation.[27]

1.3. Aims and scope of the study

RAND Europe has been commissioned by the Steering Group[28] of the National Academies[29] to complete an evidence synthesis to understand what is known about:

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[20] Edler & Fagerberg (2017).

[21] Edler, Cunningham et al. (2013).

[22] Edler, Cunningham et al. (2013); Mazzucato (2018).

[23] Nesta (2009); OECD (2010).

[24] Goodridge et al. (2012).

[25] Nesta (2009).

[26] RAND Europe study – in preparation.

[27] Nesta (2009); OECD (2010).

[28] Steering Group members: Fresh case for investment in research and innovation: Lord David Willetts PC, FAcSS (Chair); Professor Brian Foster OBE, FRS (Royal Society lead Fellow); Professor Julia Black FBA (British Academy

1. The conditions that enable research and innovation, including that which is publicly supported, across different disciplines, to result in a range of benefits.
2. How such conditions interact in different environments and throughout the lifecycle of research translation and innovation.
3. How the effectiveness of different levers used to facilitate research translation and innovation has been measured, and how those measures might be made more robust.
4. The barriers to translating research and driving innovation.

This study investigated the conditions that support innovation in the UK economy, drawing from four distinct sectors to evidence the conclusions: pharmaceutical and life sciences; defence; financial technology (fintech); and creative economy. The sectors were chosen because they each make important economic and social contributions to the UK in different ways (see Annexes C–F for a more detailed contextualisation of the sectors). The pharmaceutical/life sciences and defence sectors have mature innovation systems with well-established translation pathways, with the former particularly well studied. The creative sector is quite different in nature to defence and pharmaceuticals, with less of a defined translation pathway, and has been less well studied, but the UK is recognised for its arts, gaming and film industries. The fintech sector is nascent but growing rapidly, and financial services are a very important part of the UK economy. The evidence from these four sectors is used to draw out observations about the UK innovation system as a whole.

The study adopted a rapid evidence assessment approach for the literature review to ensure useful information could be gathered in a limited period of time. It is not intended to be a comprehensive review of the innovation literature. It is not a definitive statement of what the innovation system in each sector looks like, nor is it a comprehensive review of every policy intervention. What the study does provide is a rapid evidence synthesis, which aims to draw out some of the key underpinning features within and across each sector, with a focus on extracting and synthesising real-world learning. As such, the approach taken in this study was to focus on breadth rather than depth. Nonetheless, the study aims to provide a useful sense of the scale and nature of the existing work in this space.

1.4. Approach and methods

The approach to this work consisted of the following tasks:

- **Reviewing the existing evidence:** The study team reviewed existing evidence regarding the conditions for translation and innovation, including:

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lead Fellow); David Eyton FREng (Royal Academy of Engineering lead Fellow); Dr Patrick Vallance FMedSci, FRCP, FRS (Academy of Medical Sciences lead Fellow); Professor Sir Drummond Bone FRSE, FRSA; Professor Diane Coyle OBE, FAcSS; Dame Clara Furse DBE; Professor Richard Jones FRS; Dr Fiona Murray; Lord Jim O'Neill; Professor Sir Martin Sweeting OBE, FREng, FIET, FRAeS, FRS; Professor Simon Tavaré CSci, CStat, FMedSci, FRS; Professor John Van Reenen OBE, FBA.

[29] The National Academies are the Academy of Medical Sciences, the British Academy, the Royal Academy of Engineering and the Royal Society.

  - Innovation pathways and conditions that enable this.
  - Policy interventions used in each sector, any evaluations, and remaining barriers.
  - Information on metrics and absorptive capacity.

  This was based on two subtasks: a review of the academic literature and a review of the grey literature.
- **Expert workshop:** The team conducted a workshop with 25 national stakeholders from the life sciences, defence, fintech and creative sectors, as well as general experts in innovation, from government, academia, industry and the charity sector, to harness cross-sectoral wisdom on the conditions which enable innovation. Expert insights from across the four sectors contributed to exploring: (i) innovation pathways in each of the four sectors; (ii) the conditions that enable innovation in each sector and how these change at different stages of the innovation process; and (iii) interventions that have worked well for the translation process in each sector, as well as some of the barriers.
- **Key informant interviews:** To deepen the understanding of the findings from the literature reviews and workshop, the study team conducted interviews with ten sector representatives to test specific points emerging from the evidence or to address apparent gaps in the evidence.
- **Synthesis and reporting:** The team synthesised findings across the tasks and held internal team workshops and discussions to draw out the main findings and insights presented in this report.

More details about the methodology can be found in Annex A.

1.5. Structure of the report

The remainder of the report sets out the findings of the study as follows:

Chapter 2 reviews the concept of translation pathways in an innovation system and describes translation pathways used in different sectors.

Chapter 3 presents the conditions needed to support the translation of research to drive innovation.

Chapter 4 analyses the types of policy interventions used to promote translation and innovation; how they are deployed across different stages of the translation pathway, drawing on examples from different sectors; how they are measured; and how effective they have been.

Chapter 5 concludes with a discussion of further steps that are needed to improve the translation of research and to drive innovation.

More detail on the conditions for innovation, as well as a summary of findings for each of the sectors included in the study, can be found in Annexes B–F.

2. Pathways help to illustrate and manage the translation of ideas into application

This chapter provides an overview of the concept of a translation pathway. It begins by providing an overview of the key stages of a translation pathway. It then describes translation pathways used in the defence and pharmaceutical/life sciences sectors. Finally, it highlights that not all sectors are characterised by formalised translation pathways, including the fintech and creative sectors.

2.1. Innovation pathways are concepts used by some sectors to illustrate the stages involved in the translation process

In order to understand innovation and the conditions that enable it, the notion of translation or innovation pathways are often used to conceptualise the process through which knowledge and ideas are matured into novel products, processes or services. A simplified version of a generic translation/innovation pathway, showing the broad key components, is presented in Figure 2.1. Translation pathways are often conceptualised as consisting of the following broad stages (although these definitions are not universally agreed upon):

- **Early stages**: generally considered to include research (or invention or ideation) and early development.
- **Mid-stages**: generally considered to include development, early demonstration (e.g. of a prototype) and commercialisation.
- **Later stages**: generally considered to include advanced demonstration, integration of the idea into wider systems, application of the idea and its wider adoption and diffusion among users.

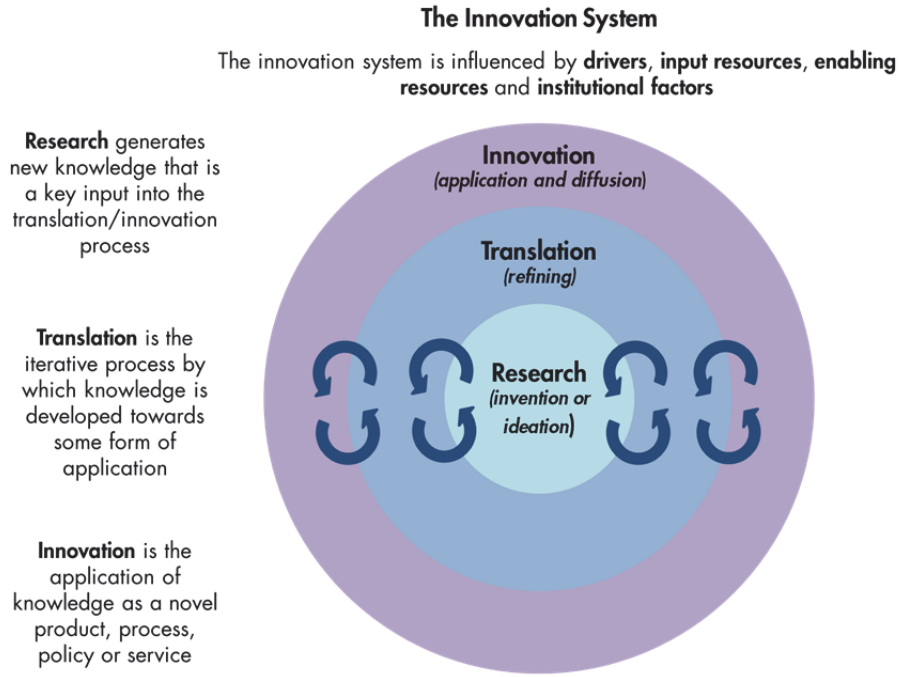
However, there are no 'hard' boundaries between these stages and not all innovation relies on formal R&D. Moreover, although the process of translating research into innovation was once thought to be a linear process,[30] it is now widely recognised that the translation process is an iterative one, consisting of closely interrelated and parallel activities,[31] including interaction with users, incorporation of feedback and

[30] Bush (1945).

[31] Godin (2006).

exploring market opportunities early on.[32] Different sectors employ a range of models to illustrate the stages involved in the translation process.

Figure 2.1 Simplified process of translating research into innovation



Source: RAND Europe.

2.1.1. The translation pathway in defence is Technology Readiness Levels

Technology readiness levels (TRLs) are widely used to describe the development pathway of new technologies.[33] The literature review and expert workshop indicated that the TRL concept is well established in defence and is the main pathway for maturation of technological innovations in this sector.[34] The TRL model consists of nine stages, where TRL1 is basic principles and TRL9 is an actual technology system (see Table C.2 in Annex C for Ministry of Defence (MOD) definitions of TRLs). Progression from one TRL is usually conducted by some form of 'gated' process of business case approval from relevant stakeholders. There are variations on the theme of TRLs that permit a greater focus on different aspects of readiness, for example systems readiness levels (SRLs) which recognises that a technology rarely operates independently of a wider technology system, and seeks to represent the readiness of the system of technologies (or even system of systems). There are also manufacturing readiness levels (MRLs) which assess whether the technology is ready to go into production, which is different to whether the technology has been shown to work within a system.[35] The position of a given

[32] European Commission (2013).

[33] European Commission (2014).

[34] HM Government (2011); NASA (2017).

[35] RAND Europe interview with defence expert, 24 May 2018; Sauser et al. (2006).

technology or solution on the TRL or SRL scale is context dependent and depends on the requirement against which it is being developed; the same technology could have a higher maturity for one requirement but lower for a different requirement. The TRL pathway is, generally speaking, incremental unless there is an urgent requirement in times of operations (e.g. conflict or humanitarian crisis, such as Ebola).

2.1.2. Translation in the pharmaceutical/life sciences sector involve multi-phase, (bi)directional frameworks that span from basic science through to health impacts

The predominant models of knowledge translation in pharmaceutical R&D and the broader biomedical sector view translation as a sequential, multi-phase, (bi)directional continuum leading from basic research through to health impacts.[36] Clinical trials are a key element of knowledge translation in pharmaceutical innovation and would usually feature during the later stages of development. These typically consist of four phases with distinct purposes and progressively larger numbers of participants.[37] Contrary to popular representations, modern therapeutic innovation does not follow a simple linear path. In the context of health, translation is highly distributed, iterative and has the dynamics of an ecosystem. Moreover, the evidence from the literature and workshop highlighted that the life sciences sector is characterised by multiple, unique innovation pathways, including product innovations (e.g. drugs, diagnostics, medical devices, digital products), but also service and process innovations (e.g. novel clinical trial designs).

2.2. Not all sectors are characterised by well-defined translation pathways

A key finding from the literature is that whereas the defence and pharmaceutical/life sciences sectors are characterised by relatively formalised translation pathways, consisting of systematic and sequential stages, the fintech and creative sectors by contrast experience a much more dynamic translation process that is not necessarily characterised by a well-defined pathway. A review of the current literature did not find any attempt to articulate a fintech-specific model of translating research into innovation. Due to the diversity of components within the creative economy, it would be impossible to establish a single translation pathway that encompasses the entire sector. Nonetheless, in relative terms, translation within this sector rarely consists of formalised steps, and innovation in this sector is relatively more spontaneous and 'organic'.[38] It is also a highly iterative process, and co-creation with end-users is seen as fundamental to the various stages of innovation translation, from continuous idea generation, crowdsourcing funding, building networks and ensuring that end products or value creation is supported by end-users. For example, game studios developing online games use iterative processes, whereby developers put out early

[36] Westfall et al. (2007); Trochim et al. (2011); Monitor Deloitte (2016).

[37] Westfall, Mold et al. (2007); Trochim, Kane et al. (2011); Monitor Deloitte (2016).

[38] Miles & Green (2008).

products to gauge consumer reaction and innovate based on feedback from consumers.[39] Among the various industries within the creative economy, the video games industry is sometimes described as the industry whose translation pathway most closely resembles traditional innovation pathways, but it is often seen as atypical for innovation in the creative industries. This illustrates that successful innovation does not necessarily rely on the existence of a formal pathway and that different types of innovation in different sectors have different requirements.

[39] RAND Europe interview with creative sector expert, 23 May 2018.

3. A range of conditions are needed to support the translation of research and to drive innovation

This chapter provides an overview of key overarching conditions that are necessary for supporting the effective translation of research into innovation. It begins by describing a range of features relevant to each of the conditions, drawing on examples from four sectors. The chapter then provides observations on how these conditions interact to offer an effective innovation system that supports translation.

3.1. There are a consistent set of conditions that enable the translation of research into innovation

A previous RAND Europe study[40] found a consistent set of conditions critical to driving translation and innovation (see Annex B for a more detailed overview of the conditions), and this was used as a starting point for the analysis of the four sectors reviewed in this study. The present analysis of the four sectors of the UK economy reviewed here (pharmaceutical and life sciences; defence; fintech; and creative economy) has revealed a range of features relevant to each of the conditions and these are outlined below (see Annex C for a more detailed analysis of the conditions for translation and innovation in each sector). The findings relating to the conditions below are additional to and build on the analysis from the previous study.

3.1.1. Drivers

Drivers are the motivations which spur innovation to occur and are, therefore, a key condition for innovation.[41] The key drivers for innovation are often different in each sector, depending on the incentives and perceived benefits of innovation within the discipline in question.

Overall, all the sectors reviewed can be characterised as having both supply and demand-side drivers. For example, for defence, the main driver is enhancing military capability. For the pharmaceutical industry, key drivers include the pressure of (dynamic) competition between companies and external factors such as the extent and nature of hitherto unmet clinical need.[42] In the fintech sector, demand-side drivers include

[40] Freeman et al. (2015).

[41] Nataraj et al. (2012).

[42] Academy of Medical Sciences & ABPI (2017).

a maturing consumer base and a younger demographic more open to mobile banking, whereas supply-side drivers include incumbent financial institutions' desire to cut costs and streamline processes.[43] In the literature reviewed, the creative sector is rarely portrayed as mission-oriented (i.e. it rarely aims to solve complex or long-term societal challenges), though some sections of it can be (for example, urban planning and architecture, design, and education through the arts, heritage, and digital means).

3.1.2. Input resources

Input resources are the primary elements required for an organisation to innovate. The analysis by the previous RAND Europe study identified three input resources: knowledge assets, talent and capital, which we have applied to the four sectors studied in this report.

Knowledge assets are a primary input into the innovation process across all sectors, although the nature of this knowledge varies across sectors. The life sciences and defence sectors rely in significant part on highly institutionalised R&D inputs, with strong links to a well-established knowledge base in the higher education sector. Although the creative sector relies on research, it draws relatively less on formal development, as translation in this sector rarely involves maturing an idea against a set of standards (e.g. TRL phases or clinical trial phases). The creative sector also relies on knowledge from a very broad range of disciplines, including the arts, humanities and STEM.[44] For the fintech sector, there seems to be a degree of spontaneity, with little evidence of a high-level innovation strategy among incumbent institutions, which instead follow a more opportunistic model in their uptake of ideas.[45] There does not appear to be a single structure that describes how knowledge feeds into the innovation process across all sectors; it is very context dependent. Nonetheless, where the R&D process is quite capital intensive (e.g. natural sciences and engineering), there seems to be stronger connections between higher education institutions and the industries that exploit that knowledge.

Talent is an essential component of a functioning innovation system across all of the sectors. Across sectors, it is apparent that multidisciplinary teams with diverse skills are a key input resource for innovation.[46] The importance of interdisciplinary research was also highlighted in the Triennial and Nurse reviews of the UK Research Councils (now part of UKRI).[47] For example, the pharmaceutical/life sciences sector is increasingly collaborative and interdisciplinary, moving towards an open and outsourced approach for access to expertise.[48] Similarly, the creative sector is highly interdisciplinary, relying upon creative talent, but also digital, STEM and business/entrepreneurial skills. For example, a game project typically requires producers, game designers, sound engineers, composers and actors.[49] The creative sector

[43] BNY Mellon (2014); BNY Mellon (2015); Deloitte (2016); Schindler (2017); Yeandle (2017).

[44] Miles & Green (2008); Nesta (2013); The Brighton Fuse (2016).

[45] BNY Mellon (2015).

[46] Marjanovic et al. (2015).

[47] BEIS (2014); Nurse (2014).

[48] Academy of Medical Sciences & ABPI (2017).

[49] Miles & Green (2008).

has also changed rapidly with the advent of digital, leading to demand for a range of skills, such as computer programming skills.[50] The importance of maintaining a balance between different skills was demonstrated by the Arts and Humanities Research Council's Brighton Fuse project.[51] In many sectors, managerial and business skills for innovation are vital but often neglected.[52] Although the UK has a well-educated population (even in comparison to other developed countries)[53] and some of the most highly rated higher education institutions,[54] a 2014 international benchmarking report by the Department for Business, Innovation and Skills (now the Department for Business, Energy and Industrial Strategy) indicates that the UK scores relatively poorly in its supply of talent.[55] Specific gaps identified included: relatively low basic skills (numeracy, literacy, ICT); insufficient domestic human capital to exploit science and innovation (domestic STEM talent and Masters/PhD graduates working in research); and below-average management skills.[56]

The availability of **capital** is a key enabler of innovative performance across sectors. Access to funding, in particular for small and medium-sized enterprises (SMEs), can be a barrier to innovation across sectors.[57] This is especially the case for the creative sector, as creative businesses are typically small and face various resource constraints.[58] Though it is worth noting that in certain contexts, when interdisciplinary teams are tasked with solving important problems, limited resources can act as a spur to innovation across sectors.[59] Both the life sciences and defence sectors have faced difficulty accessing funding in the middle stages of the translation pathway (the 'valley of death'). For example, venture capital funding (which is one element in the financial ecosystem for entrepreneurial firms), has been relatively low in the EU compared to other countries such as the US[60]; however, the situation is changing in the UK, with an increase in venture capital funding observed in the pharmaceutical/life sciences and fintech sectors.[61] Investors are interested in the timeframe in which they can expect a return on investment, which can influence the type of capital needed. In R&D-intensive industries such as defence and life sciences, lags in the process of developing new technologies are typically much longer, outcomes are uncertain and development costs are high.[62]

[50] Nesta (2013).

[51] The Brighton Fuse (2016).

[52] Freeman, Hellgren et al. (2015); Jordan et al. (2014); Mastroeni et al. (2017); Granados et al. (2017).

[53] Southwood (2017).

[54] Southwood (2017).

[55] Allas (2014).

[56] Allas (2014).

[57] RAND workshop, 18th April 2018; MOD (2017a); EKOS Limited (2017).

[58] RAND Europe interview with creative economy experts, 29 May 2018; EKOS Limited (2017).

[59] Williams & Triest (2009); Gupta (2010); Ray & Ray (2010); Christensen (2013); Radjou & Prabhu (2015).

[60] Moncada-Paternò-Castello et al. (2014).

[61] Shaughnessy (2015); ABPI (2017).

[62] Frontier Economics (2014).

3.1.3. Enabling resources

Enabling resources allow actors within the wider innovation system to strengthen their knowledge, talent and capital assets through interaction with other actors in their external environment. The previous RAND Europe study identified two such resources: connectivity and infrastructure, both of which we have applied to the four sectors studied in this report.

Connectivity, in its broadest sense, is a key condition that supports translation across sectors. Innovation across the four sectors was found to rely on extensive networks and collaborations. Networks are particularly important for the creative industries characterised by a large self-employed and freelancing workforce,[63] but also for pharmaceutical and life sciences research, which increasingly relies on outsourcing and open research.[64] Public–private partnerships play an important role in facilitating open research in the life sciences sector by: pooling resources such as knowledge or expertise; distributing risk across multiple partners; or creating research infrastructure.[65] In the fintech sector, the development of connections between incumbent financial institutions and innovative fintech companies is helping to shape the development of new products and bring them to market.[66] Interactions with end-users play a key role in shaping the innovation process in the creative sector,[67] and patient and public involvement is increasingly a feature of the pharmaceutical/life sciences sector.[68]

Infrastructure helps to foster translation across all sectors. Physical infrastructure, such as incubators, technology transfer centres, joint innovations laboratories and science parks are particularly important in R&D intensive industries such as the pharmaceutical/life sciences and defence sectors,[69] and are increasingly important in fintech.[70] Clusters are important in the creative sector, which is highly dependent on networks.[71] There is an increasing need to develop adequate IT infrastructure across sectors.[72]

3.1.4. Institutional factors

The analysis by the previous RAND Europe study identified two institutional factors that influence the resources in the innovation system: culture and structures.

Structures, in particular regulation, strongly shape the speed of innovation, but this varies by organisation and sector. For example, regulation is necessary to ensure the safety and efficacy of new life science

[63] ECIA (2018).

[64] Academy of Medical Sciences & ABPI (2017).

[65] Morgan Jones et al. (2014); Academy of Medical Sciences & ABPI (2017); Academy of Medical Sciences (2018).

[66] PwC (2017c); Shaughnessy (2015); World Economic Forum (2017).

[67] RAND Europe interview with creative sector expert, 23 May 2018.

[68] Academy of Medical Sciences & ABPI (2017).

[69] Freeman et al. (2015)

[70] BNY Mellon (2015).

[71] Creative Industries Council (2014).

[72] BNY Mellon (2015); PwC (2017c); Romero-Torres et al. (2017).

innovations.[73] The impact of regulation on biomedical innovation is often positive; by providing information on drug quality, regulation contributes to the value of new drugs and can encourage innovation.[74] However, outdated regulatory approaches can often represent a barrier to entry into the market for smaller organisations, and so can act to constrain innovation.[75] Smart regulatory approaches can open up opportunities for smaller companies by streamlining and speeding up approvals for new innovations.[76] Regulation in the financial services sector is also necessary to protect consumers and ensure fairness; however, regulation can also serve to constrain fintech innovation. For example, innovative lending services are subject to regulations that did not foresee their development.[77] By contrast, there is a relatively low degree of regulation in the creative sector. Structures can also refer to rules, processes and the design of organisations, which can frustrate or enable innovation.

Culture strongly impacts the innovation process across sectors, at different stages of the translation pathway. For example, risk-averse organisational cultures in the defence and fintech sectors were found to limit the sharing of knowledge and the formation of collaborations.[78] Within the NHS, cultural resistance to innovation by practitioners can limit the adoption and diffusion of innovations (e.g. digital innovations).[79] However, it should be noted that the NHS faces a number of well-acknowledged structural pressures, meaning that innovation can be hampered because the funding, staff time or skills necessary to stimulate change are not always available.[80] Moreover, risk-aversion to guarantee patient safety may also contribute to some of the resistance to innovation. In the creative sector, one report found that there exist cultural barriers across the diverse range of disciplines and industries in the sector, which create practical barriers to collaborations of mixed teams and disciplines.[81]

3.1.5. Absorptive capacity

Absorptive capacity is an important aspect of innovation systems. It is often described as the ability to recognise the value of external knowledge, assimilate this knowledge, apply it commercially and then transform this knowledge.[82] It refers to the capacity – whether that be in terms of skills, attitude or access to knowledge – to build and capitalise on the benefits of new thinking or evidence produced in the UK, but also the wider learning from colleagues, collaborators and innovators internationally. Absorptive capacity relies on the availability and interaction of input resources, enabling resources and institutional factors.

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[73] Mittra et al. (2011).

[74] Katz (2007).

[75] Mittra, Tait et al. (2011).

[76] Mittra et al. (2011).

[77] Knight (2018).

[78] RAND workshop, 18 April 2018; PwC (2017c).

[79] HM Government (2016a).

[80] Robertson et al. (2017).

[81] ECIA (2018).

[82] Cohen & Levinthal (1989); Cohen & Levinthal (1990).

Some of the findings on talent and institutional readiness to adopt new ideas suggest that there could be constraints on the absorptive capacity of the UK innovation system. While the UK has access to significant knowledge assets, having a world-leading university sector[83] and an important creative workforce,[84] there is also an emerging skills gap across all sectors.[85] Regarding institutional readiness, some have argued that, despite a wealth of scientific knowledge, the pharmaceutical and life sciences sector currently suffers from a relatively low uptake of readily available technologies, due to a lack of systemic readiness.[86] In fintech, there is a lack of a coherent innovation strategy, and banks' strategies for digital innovation are fragmented or opportunistic.[87] Absorptive capacity is also potentially impacted when there are structural barriers to SMEs being able to access the market, which is notably the case in heavily regulated sectors, such as financial services or the life sciences.[88] Therefore, investment may need to be targeted towards increasing the capacity of institutions, such as the NHS or large financial institutions, to absorb innovations.

3.2. An interaction of all the conditions is needed across different sectors and across the translation pathway

The evidence indicates that effective translation across all sectors requires an interaction of all of the conditions outlined in Section 3.1 across the different stages of the translation pathway (early, mid and late).

All the sectors reviewed require inputs such as knowledge, talent and capital at all stages of the translation pathway (see Section 3.1 above). However, the translation of research across these sectors relies on the interaction of these conditions through enabling resources. Successful translation in all the sectors relies on extensive networks between a range of actors, including government, academia and industry. However, there is some evidence that the nature of networks may differ, depending on the sector. Thus, whereas the defence sector tends to rely on established actors (e.g. large defence companies or certain universities with a history of working in the defence sector), the pharmaceutical/life sciences and creative sectors rely extensively on multiple and diverse collaborations between many disciplines.[89] The nature of pharmaceutical R&D has shifted to an open innovation model, in which early-stage R&D is often outsourced from large companies and involves collaboration between large pharmaceutical firms and

[83] Southwood (2017).

[84] Bakhshi et al. (2013).

[85] Bakhshi et al. (2013); Walport (2015a); Academy of Medical Sciences & ABPI (2017).

[86] Dubow & Marjanovic (2016).

[87] BNY Mellon (2015).

[88] Mittra, Tait et al. (2011); Knight (2018).

[89] Academy of Medical Sciences & ABPI (2017).

smaller biotech start-ups, but also many other actors, including academia, the NHS, regulators and patients and the public.[90]

Similarly, all sectors were found to benefit from infrastructure that facilitates the convergence of knowledge, talent and facilities, at all stages of translation. In the case of the pharmaceutical/life sciences sector, during the early stages of translation there are a number of precompetitive collaborations between pharmaceutical firms and public partners that support drug discovery (e.g. the Structural Genomics Consortium[91]) or enable data sharing by providing researchers access to deprioritised compounds (e.g. the MRC-Industry Asset Sharing Initiative[92]). In the middle stages of the translation pathway, collaborations help to bridge the gap between early-stage research and the later stages of commercialisation.[93] At later stages of the pathway, various collaborations aim to facilitate the uptake and diffusion of innovations (e.g. the Academic Health Science Networks,[94] AHSNs). In the creative sector, infrastructures such as clusters are essential to connect multidisciplinary teams, support cross-sectoral relationships, and stimulate knowledge transfer.[95]

Institutional factors, such as regulation and culture, shape the environment in which the above conditions operate and have a strong influence on the innovation process. For instance, regulation is necessary to ensure the safety and efficacy of new medicines or financial products. However, regulation can also sometimes unnecessarily constrain the speed at which certain innovations reach the market, particularly in the case of digital innovations in the pharmaceutical/life sciences sector.[96] Culture interacts with input and enabling factors at all stages of the translation pathway. In the health sector, culture has an effect at the later stages, whereby innovations often face resistance to adoption and diffusion by the NHS.[97] Although, as acknowledged in Section 3.1.4, concern over patient safety, as well as resource constraints, also contributes to the resistance to innovation. This interaction between culture and other conditions is also evidenced in the creative sector, in which cultural barriers across different industries in the sector create practical barriers to collaborations of mixed teams and disciplines.[98] These examples illustrate that it is necessary for input, enabling and institutional factors to interact at all stages of the pathway (from research through to adoption and diffusion) for effective translation. Box 2 below offers a detailed illustration of how the conditions for innovation evolve throughout the translation pathway in the defence sector.

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[90] Academy of Medical Sciences (2018).

[91] Morgan Jones, Castle-Clarke et al. (2014).

[92] MRC (2015).

[93] Marjanovic, Krapels et al. (2015); Ipsos MORI (2016); Lichten et al. (2017).

[94] Leaver (2017).

[95] New Factory (2017); ARS Electronica (2018).

[96] Lutter (2017).

[97] HM Government (2016a).

[98] ECIA (2018).

Box 2 Innovation translation in the defence sector

As a solution matures, different actors provide different kinds of finance and expertise at the different stages of the TRL pathway. At the earliest TRLs, actors are often universities backed by research council funding, producing new knowledge and cutting-edge science. Small companies also operate in this space with the backing of private capital (e.g. venture capital). At the low-mid TRLs, actors evolve to include Innovate UK, to help bridge the transfer from universities to industry and/or government. As the middle TRLs are approached, there can be an increasing role for MOD actors, such as the Defence Science and Technology Laboratory (Dstl) or Defence Equipment & Support, who are looking for technologies that have undergone some degree of lab demonstration and may have application to particular defence requirements. At this stage, the technology may be moving away from solely academia and under the leadership of industry and the MOD (often in partnership). Progress from here will be associated with development against various defence capability requirements.

The early TRL stages can broadly be characterised as being relatively cheap and progress can be quite quick. The later TRL stages, however, are generally much more expensive and time-consuming, with the need to rigorously test the technology against a range of standards and requirements, and to ensure integration into a system can be achieved. The increased number of actors and requirements to be complied with increases the number of interactions and complexity of the pathway. For this reason, the later TRLs are often dominated by larger defence companies (the so-called 'primes'), who have the finances and liquidity to support long-term commitments, supported by the talent that is experienced at navigating the compliance with standards and expectations of the customer. It was observed that assured funding was the key to driving an innovation through the whole journey of the innovation pathway.

Source: RAND Europe workshop, 18 April 2018.

4. There are various policy interventions that aim to improve the conditions for innovation, but there is limited application and evidence as to what works

This chapter provides an overview of the types of policy interventions that have been used to stimulate translation, and evidence of their effectiveness. The chapter begins by outlining a typology of innovation policy instruments. It then proceeds to highlight examples of interventions that have been used at various stages of the translation pathway, as well as evaluations of some of these across the four sectors reviewed in this study. Finally, the chapter concludes with a discussion of the metrics that have been used in evaluations and how they could be made more robust.

4.1. Policy interventions may help to stimulate the innovation process

Policy interventions can support the generation and diffusion of innovation through fostering an effective translation system.[99] Policy interventions to stimulate innovation can either promote the supply of key conditions needed for innovation (supply-side measures); create more requests for innovation (demand-side measures); or affect both supply and demand (for example challenges can supply finance against a specific need).

Supply-side actions help improve the ability of actors and organisations to innovate and thus influence innovation generation. These instruments focus on: (i) the creation of new knowledge through financial support to R&D, using grants and loans as well as fiscal incentives (e.g. tax relief); (ii) supporting the development of skills to generate and commercialise innovation; and (iii) stimulating various forms of collaboration at the national and/or regional level, with clusters as a particularly notable example.[100]

Demand-side measures aim to shape the context in which organisations operate, to encourage more requests for innovation. These can take the form of instruments geared towards creating public demand, most notably public procurement policies, and those that encourage private demand.[101] Those stimulating private demand can be separated into two additional categories: those that offer financial support and

[99] Edler, Cunningham et al. (2013).

[100] Edler & Fagerberg (2017).

[101] Edler & Fagerberg (2017).

those that do not.[102] Those that offer financial backing help improve the competitive edge of the innovation and include subsidies as well as various forms of tax instruments. Non-financial instruments aim to reduce information asymmetries and enable an environment receptive to innovation.

Finally, there are also measures that combine both approaches, including pre-commercial procurements, innovation inducement prizes, regulation, standardisation, and technology foresight exercises. Missions, which focus on solving specific (often complex and long-term) societal problems, are policy tools that can help to influence the direction of, and the demand for, innovation.[103]

Table 4.1 Typology of innovation policy instruments

Innovation policy instruments	Supply	Demand
Supply side interventions		
Fiscal incentives for R&D	***	
Direct support to firm R&D and innovation	***	
Policies for training and skills	***	
Entrepreneurship policy	***	
Technical services and advice	***	
Cluster policy	***	
Policies to support collaboration	***	
Innovation network policies	***	
Supply & demand side interventions		
Pre-commercial procurement	*	***
Innovation inducement prizes	**	**
Standards	**	**
Regulation	**	**
Technology foresight	**	**
Demand side interventions		
Private demand for innovation		***
Public procurement policies		***

Notes: ***= major relevance, **= moderate relevance, *=minor relevance to the overall orientation of the listed innovation policy instruments. Source: Adapted from Edler and Fagerberg, 2017.[104]

[102] Edler (2013).

[103] Mazzucato (2018).

[104] Edler & Fagerberg (2017).

4.2. Different interventions have been used at different stages of the translation pathway; evaluations help identify which are effective

Across the sectors reviewed in this study, a range of policy interventions have been used to stimulate each of the conditions outlined in Section 3.1 at different stages of translation, from research/ideation through to the middle stages of development, until the later stages of uptake and diffusion. Some conditions are addressed more often than others and, unsurprisingly, any single intervention often simultaneously promotes more than one condition. The literature identified a number of evaluations of policy interventions, particularly in the pharmaceutical and life sciences sector (some of these are outlined below). The evidence indicates that several interventions in this sector have broadly been successful in terms of commercial or economic outcomes (see below). Evaluations have rarely considered whether a given intervention led to social benefits (e.g. benefits to patients or the NHS), although some evaluations acknowledge that this would require a longer-term study.[105] Interventions in the other sectors studied have been the subject of fewer evaluations and therefore it is harder to draw evidence-based conclusions on their success. Nonetheless, there is some evidence that different policy measures have broadly been effective at addressing the different conditions and stages of translation. Examples of policy interventions used at different stages of translation, and evaluations of their effectiveness, are presented below (for a detailed overview of interventions and evaluations in the different sectors, see Annexes C–F). A striking finding from the review of the defence sector is the lack of evaluations, reviews or impact assessments that are publicly available.

4.2.1. Interventions at the early stages

Interventions at the early stages often focus on providing capital, developing talent and de-risking R&D

Interventions used to support research and development include early-stage translational funding initiatives, as well as a variety of tax incentives. In the pharmaceutical/life sciences sector, there are many early-stage translational funding initiatives, usually government or charity initiated, and examples include: the NIHR Invention for Innovation (i4i) programme[106]; the SBRI Healthcare programme[107]; the Wellcome Trust Health Innovation Challenge Fund[108]; Pathfinder Awards[109]; Translational Fund[110]; and the Biotechnology and Biological Sciences Research Council's (BBSRC) Follow on Fund scheme.[111] These interventions often focus on supporting small companies, or on supporting specific categories of innovations such as medical technologies or therapeutics. Some initiatives, such as the Biomedical

[105] Lichten, MacLure et al. (2017); Cox et al. (2018).

[106] NIHR (n.d.).

[107] SBRI Healthcare (2018).

[108] Department of Health and Wellcome Trust (n.d.).

[109] Wellcome Trust (n.d.-a).

[110] Wellcome Trust (n.d.-b).

[111] BBSRC (n.d.).

Catalyst, jointly run by the Medical Research Council and Innovate UK, provide both early and late-stage funding.[112] Beyond the health sector, the SBRI programme overall, which is funded by a number of UK government departments, takes a demand-driven approach and promotes the development of innovations to address specific unmet needs in the public sector, which then acts as the lead customer for the products developed.[113]

As access to funding at early stages is particularly challenging in the creative sector, there are a number of schemes that either seek to provide access to grant funding or that provide tax reliefs. The UK Department for Digital, Culture, Media & Sport and the Department for Business, Energy & Industrial Strategy launched a £150m fund to support cultural and creative businesses.[114] The UK Games Talent and Finance CIC was established to help the UK games sector at early stages of development.[115] The Arts and Humanities Research Council has allocated £80m to support eight new creative research and development partnerships as part of the Government's Industrial Strategy Challenge Fund.[116] Innovation vouchers have also been used to promote R&D in creative sector SMEs. Thus, the City of Manchester piloted the Creative Credits scheme, during which 150 SMEs received £4,000 worth of credits to purchase a range of services.[117] In Baden-Württemberg in Germany, the government launched innovation vouchers for SMEs, with one category specifically allocated for the creative sector called innovation voucher C (Kreativgutschein).[118] The scheme provided €5,000 for microbusinesses and self-employed individuals in the cultural and creative sector to access research and development services.[119]

There is an increasing amount of venture capital funding available in the UK, and several pharmaceutical companies have created corporate venture investment arms with the intention of overcoming the translational gap.[120] However, venture capital funding still remains below countries such as the United States[121] and, overall, some argue that venture capital has not been a successful source of funding for early-stage research in the UK.[122] Indeed, figures from the British Private Equity and Venture Capital Association indicate that total venture capital funding in the UK has been inconsistent over time.[123] The government's target of 2.4 per cent includes corporate R&D but does not include venture capital. There are mixed opinions about the utility and suitability of venture capital funding in the innovation system. Some argue that venture capital and private equity can be important sources of funding in the innovation

[112] Ipsos MORI (2016).

[113] Manchester Institute of Innovation Research (2015); Connell (2016).

[114] HM Government (2018a).

[115] UK Game Fund (2018).

[116] AHRC Creative Economy Programme (2018).

[117] Coletti (2014).

[118] Coletti (2014).

[119] Coletti (2014).

[120] Academy of Medical Sciences & ABPI (2017); ABPI (2017); Academy of Medical Sciences (2018).

[121] Moncada-Paternò-Castello, Vezzani et al. (2014).

[122] Jones & Wilsdon (2018).

[123] British Private Equity and Venture Capital Association (2017).

system, particularly for SMEs.[124] Public support of venture capital financing can help to reduce the risk associated with financing start-ups and can encourage private investors to focus on early-stage companies. A report by the European Investment Fund found that its investments effectively crowd-in venture capital funding.[125] However, a recent report by Nesta considered that venture capital funding for risky, science-based enterprises had failed in the UK and suggested that public funding would be better used for R&D grants and contracts to support early stage companies.[126]

A large number of interventions aim to foster links between industry, academia and the public sector, to promote knowledge exchange for R&D. In the pharmaceutical/life sciences sector, there are a number of precompetitive collaborations between pharmaceutical firms and public partners that support drug discovery (e.g. the Structural Genomics Consortium[127]) or enable data sharing by providing researchers access to deprioritised compounds (e.g. the MRC-Industry Asset Sharing Initiative[128]). A number of incubator and accelerator initiatives have been established to provide early-stage innovation support in fintech. Examples include the global FinTech Innovation Lab, which seeks to build relationships between start-ups and big banks, and Barclays' Accelerator Progamme, which gives start-ups office space and access to data from Barclays.[129]

Certain sectors have developed initiatives to develop specific skills. In the creative sector, there have been several interventions to develop entrepreneurial skills. For example, in Liège, Belgium, the ID Campus facilitates project collaborations between industry and creative students.[130] Les Réalisateurs in Nantes, France, is an art program that seeks to create opportunities for artists to produce artwork in partnership with businesses.[131] The UK's Creative Enterprise Programme by Nesta[132] and the British Council Creative Economy[133] involve face-to-face workshops aimed at equipping creative entrepreneurs with the skills and confidence required to translate the commercial value of their ideas. In the defence sector, skills interventions have tended to focus on supporting the development of STEM skills, as these are at the heart of much of traditional defence innovation. Lately, there has been a particular focus on the skills needed for cyber security.[134]

[124] Kraemer-Eis et al. (2016).

[125] Kraemer-Eis, Signore et al. (2016).

[126] Jones & Wilsdon (2018).

[127] Morgan Jones, Castle-Clarke et al. (2014).

[128] MRC (2015).

[129] BNY Mellon (2015).

[130] ID Campus (2018).

[131] Les réalisateurs (2018).

[132] Nesta (2018a).

[133] British Council (2014).

[134] Pozniak (2017).

Evaluations find that early-stage funding initiatives broadly help to de-risk R&D

Evaluations indicate that early-stage funding initiatives show evidence for success in a number of sectors. Evaluations conclude that the NIHR i4i, Biomedical Catalyst and SBRI Healthcare programmes fill a crucial gap in the innovation finance system by providing funding at an earlier stage than alternatives such as venture capital.[135] An independent review of the SBRI programme overall (beyond the health sector) concluded that the programme has a unique and valuable role to play in the innovation and procurement landscape.[136] By taking a demand-led approach, SBRI stimulates the development of innovations in response to needs identified by the public sector, which then acts as the lead customer.[137] Within the creative sector, the evaluation of Manchester's Creative Credits scheme found that the award of a Creative Credit increased the likelihood of SMEs and creative businesses working together by about 84 per cent.[138] There is some qualitative evidence that the video game tax relief has enabled the production of more innovative and better quality games, and has improved the retention of talented developers in the UK.[139]

Public-private partnerships in the life sciences sector have also shown some success in reinvigorating the innovation process in the sector. Evaluations indicate that interventions such as the EU Innovative Medicines Initiative and the Structural Genomics Consortium have helped to de-risk early-stage research.[140] Nonetheless, the UK's pharmaceutical and biotechnology sectors still suffer from poor productivity and will require a fundamental reappraisal of research priorities, cultures and incentives to improve the conditions for innovation.[141]

4.2.2. Interventions in the mid-stages

Interventions in the mid-stages often focus on providing enabling resources to promote development and commercialisation

The Catapult Network supports the middle stages of translation across multiple sectors.[142] The Catapult Network consists of ten technology centres set up by Innovate UK. The first centre was set up in 2011. The Catapults aim to promote translation and commercialisation of new and emerging technologies by bridging the gap between academia and industry. They aim to provide support and de-risk opportunities in the middle stages of the technological readiness scale. Catapults provide infrastructure and sector expertise, and aim to connect universities and research institutions with businesses and public bodies. In this way, Catapults aim to stimulate demand for innovation. A 2017 evaluation of the Catapult Network

[135] Marjanovic, Krapels et al. (2015); Ipsos MORI (2016); Lichten, MacLure et al. (2017).

[136] Connell (2016).

[137] Manchester Institute of Innovation Research (2015).

[138] Bakhshi, Edwards et al. (2013).

[139] HM Revenue & Customs (2017).

[140] Morgan Jones, Castle-Clarke et al. (2014); Syrota et al. (2017).

[141] Jones & Wilsdon (2018).

[142] Catapult (2018).

by Ernst & Young[143] found that the Catapult concept has delivered some positive impacts. The longer-established Catapults have been successful in establishing themselves in their sectors, have formed relationships with academia, SMEs, government and industry, have generated commercial and collaborative R&D funding streams, and have established cutting-edge infrastructure for use in the innovation system.

The Catalyst programme is another example of a mid-stage intervention that also spans multiple sectors. Catalysts consist of partnerships between Innovate UK and various public sector bodies. They provide funding to innovative businesses and researchers working in priority areas with the aim of accelerating research into new or improved commercial processes and products. The Biomedical Catalyst, jointly run by Innovate UK and the MRC, is the longest running programme and was established in 2012. The scheme provides funding to bioscience companies and universities for the translation of scientific ideas into products and therapies for patients. The programme aims to bridge the 'valley of death' by de-risking innovative science and accelerating the translation of novel products to market, enabling them to attract onward investment.

The Regulatory Sandbox,[144] set up by the UK Financial Conduct Authority, allows innovators to conduct testing in a regulated space and is aimed at: reducing the time needed to exploit and commercialise ideas; attracting investment due to the reduction of regulatory uncertainty for investors; and facilitating the integration of products into the market according to appropriate standards and regulations.

The defence sector quite regularly has interventions designed to stimulate innovation in a specific field related to a particular challenge that needs a solution (e.g. the urban warfare grand challenge[145]), or the desire to build the knowledge and supplier base in a particular technology or military capability area (e.g. the synthetic environment Tower of Excellence[146]). Some interventions include regular calls for particular challenges, currently delivered through the Defence and Security Accelerator[147] (and previously the Centre for Defence Enterprise). The Defence and Security Accelerator seeks to promote collaboration between industry, government defence and security departments, and academia, to speed up the development of innovative solutions to the most pressing security challenges.[148]

Evaluation evidence regarding the effectiveness of mid-stage interventions is mixed

Evidence indicates that the Biomedical Catalyst is a successful intervention. For example, a 2015 report by the UK BioIndustry Association highlighted that the Biomedical Catalyst is a successful government intervention supporting translation at the middle stages of the technological readiness scale.[149] The

[143] EY (2017b).

[144] FCA (2017).

[145] MOD (2008).

[146] Dstl (2018b).

[147] Defence and Security Accelerator (n.d.).

[148] Defence and Security Accelerator (n.d.).

[149] BioIndustry Association (2015).

programme is seen to fill a crucial structural gap at earlier stages of the investment pathway where private sector investors will not venture alone. It has helped to bridge the 'valley of death' by de-risking opportunities to a stage that venture capital and other forms of financing will come in. An evaluation of the Biomedical Catalyst published in 2016 indicated that it has successfully provided support to both academically and commercially led R&D.[150] The evaluation found early evidence that: there is positive R&D additionality; projects awarded funding have accelerated their technological progress; and turnover and employment rose more rapidly among successful applicants compared with non-successful applicants. However, the evaluation noted that at the stage of the evaluation it was too early to be confident about attributing all of these findings to the Catalyst.

By contrast, the evidence is mixed in the case of the Catapult Network. An evaluation of the Catapults concluded that overall they have not delivered as much impact as anticipated due to a lack of robust governance. However, individual Catapults, such as the Cell and Gene Therapy Catapult, have likely delivered positive economic impact.[151] The evaluation also noted that similar programmes in other countries have been successful at supporting innovation, citing the longevity of their existence and continued public funding as evidence of this. This suggests that stability of, and commitment to, public funding might have a positive impact.[152]

There is early evidence that the Financial Conduct Authority Regulatory Sandbox (which aims to speed up the commercialisation of fintech innovations) has been successful in meeting its objectives.[153] For example, 40 per cent of the first companies who tested their innovation in the sandbox received investment.[154]

The absence of independent evaluations of defence interventions (at least in the public domain) makes it challenging to identify what works for stimulating innovation in the defence sector and whether the conditions needed for innovation are being developed to ensure an optimally favourable environment for innovation.

4.2.3. Interventions in the later stages

Interventions in the later stages often focus on promoting cultural change

There are relatively fewer examples of policy interventions that target the later stages of the translation pathway. In the pharmaceutical/life sciences sector, there are several initiatives that aim to address challenges at later stages of the process, specifically around the uptake and diffusion of innovations in the NHS.[155] AHSNs, regional networks that connect the NHS, academic organisations, local authorities, the third sector and industry, have developed programmes in partnership with NHS England to identify and

[150] Ipsos MORI (2016).

[151] EY (2017b).

[152] EY (2017b).

[153] FCA (2017).

[154] FCA (2017).

[155] Marjanovic et al. (2017).

drive the adoption and diffusion of innovative ideas and technologies in the NHS.[156] Other initiatives that focus on promoting cultural change and innovation uptake include the NHS Innovation Accelerator,[157] which supports delivery of the NHS Five Year Forward View[158] and the Next Steps on the NHS Five Year Forward View.[159] More recently, the Accelerated Access Review proposes an Accelerated Access Pathway for strategically important and innovative products to deliver patient benefit as soon as possible.[160] However, it is expected that only around five to ten innovations per year will receive the transformative designation and travel down the Accelerated Access Pathway.

Evaluation evidence regarding the effectiveness of interventions to stimulate cultural change in the NHS is mixed

A first phase evaluation of the UK government's Innovation, Health and Wealth (IHW) strategy, which was a national strategy to embed innovation into the NHS, found that IHW has not been sufficiently informed by an overall strategic sense of direction, has not been effectively communicated and is not grounded in learning and emerging evidence.[161] It also found that progress towards IHW's objectives has been variable. A study in innovation as a driver of UK healthcare found that so far there is not much evidence for progress in culture change in the NHS.[162] However, other measures have been more successful. For example, a 2017 Impact Report indicated that AHSNs have created effective regional networks able to deliver innovation and improvement within the NHS.[163] There is also early evidence that demand-side interventions, such as the NHS Innovation Accelerator, have helped to stimulate greater uptake of healthcare innovations in the NHS.[164]

4.3. Using more diverse metrics could help to improve understanding of the effectiveness of interventions

Measuring innovation accurately is important in order to ensure policy interventions are effective at enabling different types of innovation. This can thus help to guide innovation policy to ensure that UK society truly benefits. A potential limitation of the evaluations considered in this study is that they often use metrics that focus on economic outcomes rather than measuring broader social outcomes (e.g. well-being or cultural enrichment). Evaluations often consider economic metrics such as: R&D additionality, turnover, employment, additional investment, or product sales. These metrics are certainly useful at

[156] Leaver (2017).
[157] NHS England (n.d.-b).
[158] NHS England (2014).
[159] NHS England (2017).
[160] HM Government (2016a).
[161] Bienkowska-Gibbs et al. (2016).
[162] Marjanovic, Sim et al. (2017).
[163] Leaver (2017).
[164] Institute for Employment Studies (2018).

quantifying innovation outcomes in a number of sectors; however, they inadequately capture the wide diversity of innovation that exists across sectors or the wide diversity of impacts that innovation achieves, particularly the non-market impacts. For example, unlike in other sectors where knowledge creation is often a product of formal R&D, knowledge inputs in the creative economies are sometimes, but not always, the result of purposeful R&D.[165] Capturing information on innovation in the creative economy is also challenging due to the various informal, small-scale transactions that contribute to innovation, but are not captured in a systematic manner.[166] Innovation surveys currently do not measure the value creation that takes place in the creative sector because questions focus on the activities of large organisations and downplay non-technological innovation.[167] Evaluations also indicate that there is a lack of metrics that adequately capture different stages of the translation pathway, which makes it hard to capture progress in a given intervention. For example, it has been argued that the health sector lacks adequate metrics to capture the adoption and diffusion of medical innovation in the NHS.[168]

4.3.1. Metrics should go beyond economic impacts

A study by RAND Europe on measuring the benefits of research and innovation found that economic approaches to measuring research may not fully capture some of the harder-to-measure benefits from R&I across society, including benefits to culture, public engagement, social cohesion and the environment.[169] The report developed an 'impact index' that illustrates the wider societal benefits (beyond economic and commercial) that come from investment in research and innovation (see Table 4.2 below). It outlined that many of these benefits from R&I are not well measured or, in many cases, not well understood. The report concluded that a more holistic way of measuring the benefits from investment in R&I would better capture the ways in which research benefits society, and would facilitate better analysis to make sure investment is targeted towards achieving the full range of these benefits, and not just those which are most easily measured.

[165] EKOS Limited (2017).

[166] EKOS Limited (2017).

[167] Miles & Green (2008).

[168] Bienkowska-Gibbs, Exley et al. (2016); Marjanovic, Sim et al. (2017).

[169] RAND Europe study – report in preparation.

Table 4.2 Examples of the potential types of impacts from R&I

Impact category	Examples
Impact on the economy	Increased productivity; GDP gains; attracting capital investment; improving resilience and diversification of the economy
Commercial impact	Generating revenue; improving processes; opening up new markets; creating employment in industry
Impact on public policy and services	Informing policy debate within the general public, in a government body, or at a non-governmental organisation; increasing public engagement with the policy process; improving efficiency of or access to public services; improving the equity of public service provision
Impact on health and well-being	Improving health outcomes; changing healthcare practice; improving health equity; increasing patient/user choice; increasing access to health services; improving the management of healthcare performance; improving patient/user satisfaction
Impact on education and training	Changing curricula; improving training materials, text books or other teaching resources; creating materials for specialised teaching contexts; changing the structure of a course; increasing access to education; improving educational outcomes
Impact on public engagement, awareness and perceptions	Shaping the nature of public debate; increasing public engagement with research findings; increasing public awareness; creating publicly available tools or resources; increasing public curiosity about science, technology, the arts or other disciplines
Cultural impact	Preserving cultural heritage; increasing accessibility of culture; improving artistic/cultural methods; improving the quality of cultural events/activities
Impact on social cohesion	Reduced inequality; reduced bias and intolerance; improved social integration; increased social capital
Impact on safety and security	Improving infrastructure security/resilience; improving policing practices; creating new tools for policing; improving safety in the workplace, at home or in other settings; increased regional security
Impact on the environment	Reducing pollution levels; improving measures of environmental condition; contributing to conservation; improving waste management, environmental efficiency or environmental management; reducing the depletion of a natural resource; developing adaptations to environmental conditions/changes

Source: Evidence synthesis on measuring the distribution of benefits of research and innovation. RAND Europe study – in preparation.

5. Further steps are needed to assist translation and drive innovation

This chapter highlights: (i) a number of challenges to the translation process; and (ii) how the translation of research could be improved.

5.1. There are a number of challenges to the translation process

5.1.1. There is limited application of policy interventions and a lack of continuity of funding

Funding and continuity of funding is important to successful translation and innovation

The workshop identified that funding and continuity of funding is important for successful translation and innovation and, conversely, that the absence of funding as well as stable funding can be a barrier to translation and innovation.[170] Access to capital is often most challenging during the middle stages of the translation pathway, which tends to present more risk for private investors, such as venture capitalists. However, the financing of different stages of translation has improved; for example, initiatives such as NIHR i4i, the Biomedical Catalyst and SBRI are helping to de-risk research and bridge the 'valley of death.'[171] An evaluation of the UK Catapult Network also noted that similar programmes in other countries have been successful at supporting innovation, citing the longevity of their existence and continued public funding as evidence of this. This suggests that commitment to, and stability of, public funding might have a positive impact.[172]

There are relatively few demand-side interventions to stimulate innovation

The analysis indicates that the majority of interventions used to stimulate innovation in the sectors reviewed are supply-side measures and supply/demand-side measures, including policy measures to provide funding, support the development of skills and stimulating various forms of collaboration. From the examples identified in this study, there were notably fewer demand-side measures, such as procurement policies or innovation inducement prizes. An exception is the UK SBRI programme, funded

[170] RAND Europe workshop, 18 April 2018.

[171] Marjanovic, Krapels et al. (2015); Ipsos MORI (2016); Lichten, MacLure et al. (2017).

[172] EY (2017b).

by a number of UK government departments, which takes a demand-driven approach and promotes the development of innovations to address specific unmet needs in the public sector, which then acts as the lead customer for products developed.[173] Interventions to stimulate cultural change in the NHS have been increasingly used to address the poor uptake of innovations, and these include the AHSNs, the NHS Innovation Accelerator and the recent Accelerated Access Review strategy.[174] In the defence sector, demand-side measures are typically procurements; however, these are not necessarily presented as innovation interventions. Moreover, since the financial crash there has been a significant reduction in defence spending, which has reduced funds available, including for procurement.[175] Challenges, such as innovation inducement prizes, have been used in the creative sector and the health sector.[176] Some have suggested that prizes should play a more significant role in the UK health R&D system than they have to date, as they more directly link reward with motivation.[177] However, one report finds that the evaluation evidence on the impacts of prizes on innovation and economic output is very limited.[178] In addition, the literature is in consensus that prizes are not a substitute for other innovation policy instruments and in certain circumstances can (or should) be complementary.[179] It may be that there is room for more demand-side interventions to support innovation in the UK. In addition, it is increasingly recognised that the public sector can go beyond merely incentivising innovative activity in the private sector and can take on a leadership role that sets the direction of travel for innovation in a particular area.[180] By setting missions, the public sector can actively create demand and steer innovation towards solving major long-term societal challenges.[181]

5.1.2. Evaluations are limited, often lack effective metrics and do not consider innovation timelines

A lack of evaluations and metrics makes it hard to determine what works in a range of sectors

The literature identified a number of evaluations for policy interventions in the pharmaceutical and life sciences sector. By contrast, few interventions in the defence, fintech or creative sectors have been publically evaluated, which makes it hard to determine which interventions have been effective and, therefore, where to direct increased government investment. In addition, current methods and metrics for evaluating the impact of policy interventions do not adequately reflect the full diversity of benefits (e.g. non-market impacts) from R&I. This could hinder the design of adequate policies and interventions to

[173] Manchester Institute of Innovation Research (2015); Connell (2016).

[174] HM Government (2016a).

[175] MOD (2017a).

[176] Nesta (2018b).

[177] Ling (2008).

[178] Gök (2013).

[179] Gök (2013).

[180] Mazzucato (2018).

[181] Mazzucato (2018).

stimulate innovation in many sectors, as the costs and benefits of an investment option are not being considered in full. Perhaps the single most important improvement that could be made would be to conduct more rigorous, independent evaluations of interventions in the overall innovation space to ensure robust, evidence-based information on the impacts of policies. To conduct such evaluations would require consideration of 'theory of change' models which would enable suitable input, process and outcome metrics to be developed. Developing more diverse metrics to better capture the full range of benefits from investment in R&I would help to ensure that interventions accurately measure outcomes and progress across sectors, and therefore that investments are targeted towards those interventions that work.

Innovation timelines are often not taken into account in the evaluation of policies

The timeframes for innovation vary depending on the sector. In the defence and pharmaceutical sectors, it can take decades for ideas to be translated into an innovation.[182] Yet despite this, many evaluations considered in this study focus on the short-term impacts of interventions, with few adopting a longer-term view. Nonetheless, a number of evaluations do acknowledge that the full impacts of innovation policies will likely only be apparent over the longer term. A similar lack of longitudinal impact assessments is also evident in studies measuring the benefits of research, as found in a study by RAND Europe on measuring the impacts of R&I.[183] The fact that time-lags are not always taken into account in evaluations could impact on investment decisions. Certain investments may not appear worthwhile, but if more consideration was given to demonstrating the time it takes for returns on investments in different disciplines and areas, then they may be worthwhile. Factoring in the timelines for the translation process also has an impact on the design of interventions to steer the process. For instance, the returns on investment are typically much faster in the creative and fintech sectors than for drug discovery or defence. Innovation in the creative and fintech sectors tends to be driven by novelty and swiftly-changing consumer tastes.[184] As a result, there is more risk associated with R&I in the pharmaceutical sector and therefore initiatives to de-risk the process, such as public-private partnerships and translational infrastructure to fill funding gaps, are particularly important.

5.2. The conditions for innovation, as well as the understanding of effective interventions to support the development of innovation systems in the UK, could be improved

Suggestions are made below for how to improve the conditions for innovation, as well as the understanding of effective interventions to support the development of innovation systems in the UK.

[182] Westfall, Mold et al. (2007); Morris et al. (2011).

[183] RAND Europe study – in preparation.

[184] RAND Europe workshop, 18 April 2018; EKOS Limited (2017).

5.2.1. Interventions should target more than one of the conditions needed to support innovation

As has been outlined in Section 3.2, the interaction of a number of conditions is required for effective translation of research. For example, many of the successful interventions in the pharmaceutical/life sciences sector stimulate multiple conditions simultaneously, such as building networks, sharing knowledge, bringing together talent and leveraging capital. There is also evidence that an interaction between all of the conditions is needed to support an opportunity across different stages of the translation pathway. For instance, interventions in the biomedical sector have been effective at supporting the development of opportunities, but innovations often face difficulty at the uptake and diffusion stages. This illustrates that it is necessary for input, enabling and institutional factors to interact in order for the effective translation of research to occur and for the adoption and diffusion of a resulting innovation.

5.2.2. Pathways can help to identify the conditions needed at each stage and guide the design of policy interventions

For sectors with relatively defined translation pathways, such as the pharmaceutical/life sciences and defence sectors, it is possible to identify the conditions needed at different stages, and therefore design appropriate policies to promote these. The life sciences sector is an example of a sector in which policy interventions were, broadly speaking, more coordinated and found to support conditions across the translation pathway, from idea generation to product development, through to uptake and diffusion. In other sectors, although policies were found to broadly target the full spectrum of conditions for innovation, policies are not necessarily coordinated and often do not cover the complete translation pathway. The evidence from the life sciences sector therefore might suggest that, where appropriate, greater alignment of interventions across the pathway may help to stimulate innovation and release the benefits of research. Nonetheless, even sectors with a defined pathway have considerable real world variation in that pathway as to the conditions that are needed and the interventions that work. For instance, interventions in the pharmaceutical and life sciences sector have shown varying degrees of success. The life sciences sector is also characterised by multiple pathways, which means there is not a one-size-fits-all approach to policy interventions. Therefore, in sectors with no clearly defined pathway, such as the creative sector that has multiple, diverse and dispersed pathways, it is more challenging to design interventions to stimulate innovation. For the creative sector, there have been fewer interventions and fewer still that have been evaluated, but the success of UK gaming and television/films, as but two examples, suggests that tax reliefs that help the overall sector can be effective. Nonetheless, even where there are no formal pathways, there is evidence of successful innovation happening.

6. Summary

6.1. Which conditions enable research and innovation, including that which is publicly supported, across different disciplines, to result in a range of benefits?

6.1.1. There are a consistent set of conditions critical to driving translation and innovation

A number of conditions are deemed critical to the translation and innovation process across sectors. These include: (i) drivers; (ii) input resources; (iii) enabling resources; (iv) institutional factors; and (v) absorptive capacity.

Drivers are the motivations which spur innovation to occur and are, therefore, a key condition for innovation.[185] The key drivers for innovation will often differ between sectors, depending on the incentives and perceived benefits of innovation within the discipline in question. Overall, all the sectors reviewed can be characterised as having both supply and demand-side drivers.

Input resources are the primary elements required for an organisation to innovate. These include: knowledge assets, talent and capital. Sufficient availability of these three conditions was found to be a key enabler of innovative performance across the sectors reviewed in this study.

Enabling resources, including connectivity and infrastructure, allow actors within the wider innovation system to strengthen their knowledge, talent and capital assets through interaction with other actors in their external environment. Innovation across the four sectors was found to rely on the formation of networks and physical infrastructure, which facilitate the collaboration of multidisciplinary teams.

Two institutional factors that influence the resources in the innovation system are culture and structures (e.g. regulation and standards, but also rules, processes and the design of organisations). Regulation is necessary to ensure safety and fairness, but outdated or maladapted regulatory approaches can sometimes represent a barrier to entry into the market, particularly for smaller organisations, and so can act to constrain innovation. Culture encourages and incentivises innovation when it is open, trusting, and conducive to risk-taking and learning from failure rather than avoiding it.

[185] Nataraj, Shatz et al. (2012).

Absorptive capacity is an important aspect of innovation systems and refers to the capacity to build and capitalise on the benefits of new thinking or evidence produced both in the UK and internationally. Some of the findings on talent and institutional readiness to adopt new ideas suggest that there could be constraints on the absorptive capacity of the UK innovation system.

6.2. How do conditions interact in different environments and throughout the lifecycle of research translation and innovation?

6.2.1. Effective translation requires interaction between all of the conditions across the innovation pathway

Effective translation across all the sectors reviewed requires an interaction between all of the conditions, (i.e. input, enabling and institutional factors, as well as drivers and absorptive capacity) at all stages of the pathway (from research through to adoption and diffusion). While all the sectors reviewed require inputs such as knowledge, talent and capital, successful translation in all the sectors relies on the formation of networks between a range of actors, including government, academia and industry, as well as availability of infrastructure that facilitates the convergence of knowledge, talent and facilities. In addition, institutional factors, such as structures and culture, shape the environment in which the above conditions operate and have a strong influence on the innovation process. For example, in the health sector, research has shown the lack of a widespread innovation culture in the NHS, which can slow the uptake and diffusion of innovations in the healthcare system. Therefore, despite a number of initiatives leading to the development of innovations, the absence of the right culture at later stages can act as a barrier to their widespread adoption.

6.3. How has the effectiveness of different levers used to facilitate research translation and innovation been measured, and how could those measures be made more robust?

6.3.1. A lack of evaluations and metrics makes it hard to determine what works in a range of sectors

Whereas there are a number of evaluations for policy interventions in the pharmaceutical and life sciences sector, by contrast, few interventions in the defence, fintech or creative sectors have been publically evaluated. Where evaluations exist, the methods and metrics for evaluating the impact of policy interventions often do not adequately reflect the full diversity of benefits (beyond economic) from R&I. These limitations make it hard to draw evidence-based conclusions as to the effectiveness of policy interventions. While not specifically a barrier to innovation, it does mean that there is little formalised knowledge as to what works to enable innovation. This matters because it means that investments to support innovation may be ineffective and an unproductive use of public (and in some cases private) finance.

6.3.2. Evaluation metrics often focus on economic outcomes rather than on the wider benefits of research and innovation

A potential limitation of the evaluations reviewed in this study is that they often use metrics that focus on economic outcomes rather than measuring broader social outcomes (e.g. well-being or cultural enrichment). Evaluations often consider economic metrics such as: R&D additionality, turnover, employment, additional investment, or product sales. Although these metrics are useful at quantifying innovation outcomes in a number of sectors, they inadequately capture the wide diversity of innovation that exists across sectors or the wide diversity of impacts that innovation achieves (e.g. the non-market impacts). A study by RAND Europe on measuring the benefits of research and innovation found that economic approaches to measuring research may not fully capture some of the harder-to-measure benefits from R&I across society, including benefits to culture, public engagement, social cohesion and the environment.[186] Developing more diverse metrics to better capture the full range of benefits from investment in R&I would help to ensure that interventions accurately measure outcomes and progress across sectors, and therefore that investments are targeted towards those interventions that work.

6.3.3. Innovation timelines are often not taken into account in the evaluation of policies

Many evaluations considered in this study focus on the short-term impacts of interventions, with few adopting a longer-term view. A similar lack of longitudinal impact assessments is also evident in studies measuring the benefits of research, as found in a study by RAND Europe on measuring the impacts of R&I.[187] If more consideration was given to demonstrating the time it takes for returns on investments in different disciplines and areas, then a greater proportion of investment decisions may appear worthwhile. Factoring in the timelines for the translation process also has an impact on the design of interventions to steer the process. Innovation in the creative and fintech sectors tends to be relatively fast, driven by novelty and swiftly changing consumer tastes.[188] By contrast, there is more risk associated with R&I in the pharmaceutical sector, which typically takes many years. Therefore, the type of measures most suited will differ between sectors.

6.4. What are the barriers to translating research and driving innovation?

6.4.1. There is a lack of clarity about user needs and stable access to capital throughout the innovation process

Funding, as well as continuity of funding, is important for successful translation and innovation, and, conversely, the absence of funding and stable funding can be a barrier to translation and innovation.[189]

[186] RAND Europe study– report in preparation.

[187] RAND Europe study – in preparation.

[188] RAND Europe workshop, 18 April 2018; EKOS Limited (2017).

[189] RAND Europe workshop, 18 April 2018.

Although access to capital has traditionally been relatively challenging during the middle stages of the translation pathway, the financing of different stages of translation has improved. For example, initiatives such as NIHR i4i, the Biomedical Catalyst and SBRI are helping to de-risk research and bridge the 'valley of death.'[190]

From the interventions identified in this study, there were relatively fewer demand-side measures, such as procurement policies or innovation inducement prizes, compared with supply-side measures that aim to provide funding, support the development of skills and stimulate various forms of collaboration. There have, nonetheless, been several interventions that take a demand-driven approach to promote innovations to address specific unmet needs. For example, a review of the SBRI programme concluded that it has a valuable role to play in the innovation and procurement landscape as it provides 'market pull' to complement the 'technology push' of other policies.[191]

[190] Marjanovic, Krapels et al. (2015); Ipsos MORI (2016); Lichten, MacLure et al. (2017).

[191] Connell (2016).

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Annex A. Methods

This Annex provides a detailed overview of the methods used in this study.

A.1. Description of methods

A.1.1. Rapid evidence assessment

A rapid evidence assessment was conducted to review existing evidence on: (i) translation pathways and the main conditions needed to translate research and drive innovation; (ii) how these conditions interact and change in different environments; (iii) how these conditions evolve throughout the lifecycle of research translation and innovation; (iv) the levers and barriers of research translation and innovation; and (v) how the effectiveness of the levers of research translation and innovation can be measured, both in economic and societal impacts. In addition, in consultation with the National Academies, four sectors were selected for in-depth analysis regarding these questions: the pharmaceutical and life sciences industry; the defence sector; the creative economy; and the fintech sector. Unlike a full systematic review, which aims to search the entire evidence base comprehensively, the scope and coverage of the rapid evidence assessment was restricted through search and screening criteria to focus on the most relevant literature and ensure that the amount of literature to review is manageable within the scope, resources and timeline available for this study.

A comprehensive search strategy was developed with expert input from RAND Knowledge Services on devising the appropriate search strings, search constraints and capture requirements. One set of search strings was conducted using title and author-supplied keywords in the following databases: Academic Science Complete, Social Sciences Abstracts, Policy File, Scopus and Embase (Elsevier). In order to identify additional articles in the business and management literature, an additional, targeted set of search strings was conducted in Business Source Complete and in Scopus. For all searches, the publication timeframe was 2014 onwards to capture literature from the past five years, and only articles published in English were considered. It was decided that more recent literature would be more relevant as it would capture the most recent developments in the key sectors of interest. Table A.1 shows the final search strings. Additional articles were identified through 'snowballing', to identify articles from reference lists of selected articles, and some additional, targeted searching using the team's existing knowledge.

Articles were screened by title and abstract. Table A.2 shows the inclusion and exclusion criteria. The following types of articles were included: articles that focused on general conditions needed to enable innovation; and articles focusing on innovation in the four key sectors (pharmaceutical; aerospace/defence; creative industry; financial services). The following articles were excluded: articles prior

to 2014; articles exploring innovation conditions in low or middle income countries; and articles focusing on innovation conditions in specific sectors outside of the key sectors of interest. Following the screening stage, articles were read and details were extracted into a Microsoft Excel template covering the following information: sector, translation pathway, specific policy interventions, metrics to measure outcomes of levers, barriers to innovation, and innovation factors (drivers, knowledge, capital, talent, networks, infrastructure, culture and structures).

In total, the search retrieved 3258 articles, of which 62 were finally included and full text reviewed by the research team. Of these 62, 38 were sector-agnostic sources on general conditions for innovation, 15 were on the pharmaceutical sector, 6 on the defence sector, 2 on the creative industries and 1 on health innovation.

Table A.1. Search strings used for the rapid evidence assessment

	Search string	Database searched
1	(Conditions OR factors OR contribut* OR variable* OR enabl* OR preconditions OR driver* OR lever* OR requirement OR specification OR barrier* OR challenge OR obstacle OR talent OR skills OR capital OR fund* OR financ* OR investment OR money OR resourc* OR "knowledge asset*" OR "intellectual property" OR patent OR copyright OR infrastructure OR facilities OR network OR connection OR collaborat* OR coop* OR partnership OR culture OR regulation OR "organizational structures" OR "organizational structures") AND TI (Translation OR innovation) AND TI (research OR R&D OR innovation OR R&I OR RDDI OR academ* OR university OR science OR technology)	Academic Science Complete, Social Sciences Abstracts, Policy File, Scopus, Embase (Elsevier)
2	(Framework OR innovation OR organizational OR "public R&D") AND (policy OR "human resource" OR regulation OR conditions OR "social challenges")	Business Source Complete
3	(("innovation systems" OR "innovation process") AND ("changing role" OR "technological change")) OR (("health research" OR ("publicly funded" AND research)) AND (outcomes OR impact))	Scopus

Table A.2. Inclusion and exclusion criteria for the rapid evidence assessment

Included	Excluded
• Publications from 2014 onwards • Articles in English • Articles focusing on the general conditions needed for innovation • Articles focusing on innovation in four sectors of interest (pharmaceutical and life sciences; defence; creative economy; fintech)	• Publications from prior to 2014 • Articles exploring innovation conditions in low or middle income countries • Articles focusing on innovation conditions in specific sectors outside of the key sectors of interest

A.1.2. Review of the grey literature

To supplement the rapid evidence assessment, the study team conducted a review of the grey literature covering the four sectors of interest (pharmaceutical and life sciences industry, defence, creative economy and fintech). While the rapid evidence assessment found relatively more articles relating to the pharmaceutical and defence sectors, there were comparatively fewer papers on the creative industry and the financial services sector. Given the shortage of formal literature, the study team conducted targeted searches of the grey literature to further develop an understanding of translation models and innovation conditions relevant to these sectors. The review focused on policy and strategy reports (particularly relating to interventions to stimulate innovation); evaluations, reviews or impact assessment of interventions and; other relevant documentation from key stakeholders, primarily in the UK but also internationally. As with the rapid evidence assessment, the scope and coverage of the grey literature search was restricted to focus on the most relevant literature and ensure that the amount of literature to review is manageable within the scope, resources and timeline available for the work.

A.1.3. Expert workshop

In order to enrich the findings of the evidence synthesis, the study team held a half-day expert workshop at the Academy of Medical Sciences, with 25 national stakeholders from government, academia, industry and the charity sector from across the four chosen sectors (pharmaceutical, defence, fintech and creative). Table A.3 contains the list of experts invited to attend the workshop. The aim of the interactive workshop was to extend the findings from the rapid evidence assessment and grey literature review. Specifically, expert insights from across the four sectors contributed to exploring: (i) understanding of innovation pathways in each of the four sectors; (ii) the conditions that enable innovation in each sector and how these change at different stages of the innovation process and; (iii) interventions that have worked well for the translation process in each sector as well as some of the barriers. Box 3 below outlines the key sessions covered in the workshop.

Box 3 Outline workshop agenda

Introduction

1) Brief overview of the project and insights to date

2) Four short presentations on the innovation process in four sectors (pharmaceutical, defence, fintech, creative)

3) Understanding innovation pathways in each sector

Interactive group activities

4) Explore the conditions that enable innovation in each sector

5) Cross-sectoral comparison of the innovation pathways and enablers in each sector

Plenary discussion

6) Explore effective interventions and barriers to each sectoral innovation pathway

Table A.3. List of workshop attendees

Name	Organisational affiliation
Dr Tom Livermore	Academy of Medical Sciences
Dr Naho Yamazaki	Academy of Medical Sciences
Alberto Lazari	Academy of Medical Sciences
Alison Evans	Alzheimer's Research UK
Ali Hansford	Association of British Pharmaceutical Industries
Dr Martin Turner	Bioindustry Association
Chinara Rustamova	British Academy
Charmaine Phillips	Department for Business, Energy & Industrial Strategy
Melanie Knetsch	Economic and Social Research Council
David Legg	Innovate UK
Chris Warkup	Knowledge Transfer Network/Innovate UK
Dr Ian Viney	Medical Research Council
Dr Helen Ewles	Royal Academy of Engineering
Zoe Jacob	Royal Society
Dr Elizabeth Surkovic	Royal Society
David Shrier	Said Business School, University of Oxford
Prof Joanna Chataway	Science Policy Research Unit, University of Sussex
Kevin Dean	Smart Health Science
Prof Kirsten Shepherd-Barr	The Oxford Research Centre in the Humanities, University of Oxford
Helen Cross	UK Research & Innovation
Dr Joe Marshall	University College London
Louise Wren	Wellcome

Source: RAND Europe.

A.1.4. Key informant interviews

To deepen the understanding of the findings from the literature reviews and workshop, the study team conducted a limited number of interviews to test specific points emerging from the evidence or to address apparent gaps in the evidence. This was particularly useful for the creative economy and the financial services sector, as the literature was not so available for these areas. A meeting was also held with David Legg from UKRI and Innovate UK to learn about the experiences of those institutions from evaluations of different innovation policies in order to better understand the impact and benefits arising from innovation and research. Table A.3 below indicates the individuals that were interviewed.

Table A.4. List of interviewees

Interviewee name	Organisational affiliation
Dr Sumi David	Arts and Humanities Research Council
Charlotte Ashbrooke	Arts and Humanities Research Council
Matt Cullen	Association of British Insurers
Hasan Bakhshi	Nesta
Philip Oliver	Rebellion
Paul Stein	Rolls Royce
Dr Allan Sudlow	The British Library
Maja Maricevic	The British Library
Dr Louise Beaumont	Freelancer
David Legg	UKRI/Innovate UK

Source: RAND Europe.

A.1.5. Interview protocol

Background

Thank you for agreeing to participate in our study. The work is commissioned by the Academy of Medical Sciences, the British Academy, the Royal Academy of Engineering and the Royal Society, and seeks to understand how research is translated into innovation and what can be done to promote this. As part of that, we are conducting an evidence synthesis on the innovation process (broadly defined) and the conditions needed to enable this. The [fintech/creative sectors] are one area of focus for this.

The project will be written up as a publicly available report which will be on the RAND website and should be completed by September 2018. Do you have any questions about the project?

GDPR statement

With your permission I would like to record this interview, but the recordings, any notes and transcripts will be kept strictly confidential and never be made available to any third party, including the National Academies.

Any quotes included in RAND Europe's final report will not be explicitly or directly attributed to you without your permission. Should we wish to use a quote which we believe that a reader would reasonably attribute to you or your organisation, a member of the RAND Europe project team will contact you to inform you of the quote we wish to use and obtain your separate consent for doing so.

All records will be kept in line with the General Data Protection Regulation (GDPR) 2018. Further information about RAND Europe's data security practices can be provided upon request.

To keep all processes in line with the GDPR 2018, we would like to ask you to confirm a few data protection statements:

1. Do you agree that the interview can be recorded by RAND Europe and that these recordings can then be transcribed for the purpose of providing an accurate record of the interviews?
   Yes ☐ No ☐

2. Do you agree that RAND Europe can store this data securely on password-protected computers and its servers for the duration of the project?
   Yes ☐ No ☐

3. Do you agree that RAND Europe can destroy the recordings and all notes and transcripts after the project has been completed?
   Yes ☐ No ☐

4. Do you agree to us recontacting you if we wish to use a quote which we believe that a reader would reasonably attribute to you or your organisation?
   Yes ☐ No ☐
5. Do you agree to us listing you, and your affiliation, within our final project report as a named individual that we interviewed?
   Yes ☐ No ☐

Interview questions

A. The depth of knowledge that exists of the innovation system in your sector
    1. What constitutes an 'innovation' in your sector?
    2. How does innovation happen in your sector?
        i. Are there different processes which lead to these innovations, or is there a generalisable way in which innovations come to market in your sector (e.g. for gaming?)
        ii. Is there a clear 'translation pathway' for your sector? Does this vary across different types of innovations?
    3. What is the availability of different conditions in your sector to support innovation?
    There are many ways of thinking about all the conditions needed to support innovation. We have started with a set of seven, though know there will be many more. Could we talk through each in turn, and can you describe the nature of that condition for your sector? So, for the first one (knowledge), what kind of knowledge is needed for innovation in the creative sector and do we currently have enough of it in the UK?
    What is the nature and availability of:
        - Knowledge
        - Talent
        - Capital
        - Networks/connections
        - Infrastructure
        - Structures
        - Culture
    4. Are there other conditions that are important in your sector?
    5. Do the conditions vary over the course of the innovation process? E.g. during development versus uptake?
    6. What are some of the drivers and barriers of innovation in your sector?

B. Policy interventions to promote innovation in your sector
    1. What types of interventions have been used to promote innovation in your sector?

C. The effectiveness of policy interventions in your sector
    1. Have there been any evaluations of policy interventions? If yes, what are the outcomes?
    2. Do the evaluations reveal any barriers to innovation that remain?
    3. Thinking about innovation metrics:
        i. How is innovation measured in your sector? How is the effectiveness of interventions measured in your sector?
        ii. How could metrics to measure the effectiveness of interventions be made more accurate or robust?

D. Absorptive capacity in your sector
    1. We're also thinking about absorptive capacity in each sector. Absorptive capacity refers to an organisation or a sector's ability to acquire, assimilate, transform and exploit new knowledge. If we think about each of these four dimensions:
        i. Do you have a sense of the capacity, or 'ability' of your sector to innovate? Where is it lacking in capacity? Is it related to acquisition, assimilation, transformation or exploitation?

A.1.6. Internal workshops

A key part of the evidence synthesis process, especially when that synthesis was across different evidence sources such as the literature, workshops and interviews, and when this covered four sectors, was to use internal workshops to analyse the evidence and rigorously test assumptions and emerging findings. These workshops were used to highlight the similarities and differences in the conditions needed to drive innovation in each of the sectors (for example reliance on an extensive university infrastructure, or organic innovation less reliant on formalised institutional support) and across the four sectors. During the workshops, the study team brought together key observations from the analysis conducted in terms of the overall evidence base for the conditions for innovation in the UK and interventions used to support this, including any trends and gaps. Observations were clustered and key emerging themes were identified, discussed and analysed.

A.2. Limitations of the analysis

The study team adopted a rapid evidence assessment approach for the literature review to ensure useful information could be gathered in a limited period of time. This means that there may be relevant studies and documents that were not identified or included in the analysis. Nonetheless, it was ensured searches were as broad and comprehensive as possible, through snowballing and carrying out some targeted searches based on our own knowledge of the topic. The final report consists of a summary, and consequently there are likely many interventions and pieces of evidence that were not included or discussed in detail. Nonetheless, the evidence synthesis is intended to provide an overview of key findings and interventions for each sector within the scope of the timeframe for this work, and hopefully provides a useful sense of the scale and nature of the existing work and some direction for future work in this space.

Annex B. Overview of conditions that enable translation and drive innovation

B.1. There are a consistent set of conditions that enable the translation of research and drive innovation

A previous RAND Europe study[192] found a consistent set of conditions critical to the innovation process and this was used as a starting point for the analysis in this study. These factors can provide a structured understanding of the conditions driving innovation and translation; however, their realisation and relative importance will vary greatly depending on the actor and sector in question, and at different stages of an innovation as it progresses to greater maturity.[193] Each of the factors is described briefly below.

B.1.1. Drivers

Drivers are the motivations which spur innovation to occur.[194] The key drivers for innovation are often different in each sector, depending on the incentives and perceived benefits of innovation within the discipline in question. For example, for defence, drivers include enhancing military capability, whereas for the pharmaceutical industry key drivers include the pressure of (dynamic) competition between research-based companies and external factors such as the extent and nature of hitherto unmet clinical needs. From a societal perspective, drivers for innovation could include the need to respond to important challenges, such as environmental issues, health and an ageing population,[195] whereas for private companies, the motivation to innovate stems from profits generated by introducing new ways of doing things and achieving competitive advantages.[196]

B.1.2. Input resources

Input resources are the primary elements required for an organisation to innovate. The analysis by the previous RAND Europe study identified three input resources: knowledge assets, talent and capital.

[192] Freeman, Hellgren et al. (2015).

[193] Allas (2014); Drezner (2009); Levy & Brinkley (2013); Penny et al. (2013, 15-6).

[194] Nataraj, Shatz et al. (2012).

[195] Foray et al. (2012).

[196] Amable et al. (2009).

- **Knowledge** is required to discover the new ideas that spur innovation and to adopt new methods and technologies.
- **Talent** refers to the technical and managerial expertise necessary to support the successful implementation of novel applications, as well as education and skills provision.
- **Capital** is required to fund the different stages of the innovation pathway, including R&D relevant to a particular sector. This can include research grants, loans, private equity, venture capital, crowd funding or incentives such as tax relief.

B.1.3. Enabling resources

Enabling resources allow actors within the wider innovation system to strengthen their knowledge, talent and capital assets through interaction with other actors in their external environment. The framework identified two such resources[197]:

- **Infrastructure** includes facilities and research hubs that provide a physical space for innovation, such as universities, science parks, test facilities, research and technology organisations and demonstration facilities.
- **Networks and connections** encourage the exchange of knowledge (including novel ideas), the mingling and connection of talented individuals, investors, and the connection of suppliers to end users, including in the UK and internationally.

B.1.4. Institutional factors

In this framework there are two **institutional factors** that influence the drivers and resources in the innovation system: culture and structure.[198]

- **Culture** encourages and incentivises innovation when it is open, trusting, and conducive to risk-taking and learning from failure rather than avoiding it.
- **Structures** can be organisational, managerial and/or bureaucratic. These can include, for example, regulations or standards. Bureaucracy and formal rules, including regulation, may act to constrain innovation by restricting knowledge exchange or productive partnerships; in other cases, structures, including regulation or standards, can encourage innovation by setting new boundaries within which to innovate.

[197] Freeman, Hellgren et al. (2015).

[198] Freeman, Hellgren et al. (2015).

Annex C. The pharmaceutical and life sciences sector

This Annex provides detailed evidence on the conditions needed to translate research and drive innovation in the pharmaceutical and life sciences sector.

The pharmaceutical and wider life sciences industry makes a significant contribution to the UK economy and to the health and well-being of the population. According to one analysis, the sector contributed £30.4bn to the economy in 2015 and supports 482,000 jobs,[199] generates approximately £63.5bn of annual turnover and employs 233,400 people.[200] The importance of life sciences has been recognised in the 2017 Life Sciences Industrial Strategy (see Box 4 below).[201] However, the pharmaceutical and wider biomedical sector is facing a well-established decline in productivity and R&D investment.[202] Understanding the conditions and interventions that support innovation in life sciences could help to reinvigorate this sector.

[199] PwC (2017a).

[200] HM Government (2016d).

[201] Report that provides recommendations to government on the long-term success of the life sciences sector. Office for Life Sciences (2017).

[202] Jones & Wilsdon (2018).

Box 4 Life Sciences Industrial Strategy

The Life Sciences Industrial Strategy (LSIS), published in August 2017, provides recommendations for the government and the life sciences sector on how to build on the UK's existing strength in life sciences to increase the pace of economic growth in this sector. It was written in collaboration with industry, academia, charity and research organisations. The LSIS was followed by the publication of the first phase of the Life Sciences Sector Deal on 6 December 2017.[203] The life sciences sector is the first to publish an industrial strategy, which shows its importance to the future of the UK's economic success.

The strategy puts forward recommendations under five key themes:

- Science: Sustaining and increasing funding for basic science to match international competition.
- Growth: Ensuring the fiscal environment (including tax credits, grants, loans and capital allowances) supports growth and attracts manufacturing investment.
- NHS: Adopting the Accelerated Access Review to secure faster patient access to innovative new treatments and technologies.
- Data: Improving the collection of health data and streamlining access.
- Skills: Developing and delivering a skills action plan, including a migration system that allows for the recruitment and retention of highly skilled workers.

C.1. The depth of understanding of the innovation system

The pharmaceutical and life sciences sector in the UK is perhaps the most thoroughly investigated of the four sectors in this study, with a wealth of academic literature, grey literature and other sources from which to draw evidence. The sector can be considered to be well-established with extensive networks and connections between industry, academic, public and charity sectors. Actors within these sectors range from large, established pharmaceutical multinationals and large charities to small biotech companies and disease-specific charities. The translation pathway is well-understood for conventional drug development but is evolving to adapt to new technologies and advances in knowledge. Although regulation is necessary to ensure the safety and efficacy of new products for the public, some would argue that regulatory processes are struggling to keep up with advances in knowledge. There is evidence of innovation in the approvals processes, although it remains to be seen how effective these are. The sector has been the subject of numerous interventions, with a mix of both supply and demand side tools, largely from the public sector, as well as a large number of public–private partnerships. The latter interventions show some evidence of helping to reinvigorate the pharmaceutical industry, which despite increases in R&D investment, has experienced a high attrition rate of compounds, and rising overall costs of drug development.[204] There is a recognised process of evaluating interventions to understand how effective these have been.

[203] Department for Business Energy & Industrial Strategy and Office for Life Sciences (2017).

[204] Jones & Wilsdon (2018).

The key conditions for innovation

This section describes some of the key drivers and conditions identified as stimulating innovation in the pharmaceutical and life sciences sector.

There are both demand-side and supply-side drivers of pharmaceutical and life sciences innovation

A key demand-side driver of innovation in the pharmaceutical and life sciences sector is unmet clinical need in patients. This is fuelled by an ageing population and the associated burden of complex multi-morbidity, including neurodegenerative diseases (e.g. dementia).[205] The threat of antimicrobial resistance and potential re-emergence of infectious diseases also presents a major challenge, and there have been many high profile measures to address this, namely the UK Review on Antimicrobial Resistance,[206]and government actions in response to this.[207] In more recent years, patient demand (due to patient empowerment) has also been an important driver of product and service innovation, with healthcare services increasingly becoming more person- and patient-centred.[208]

On the supply-side, pharmaceutical firms' desire to find ways to increase their productivity and reduce the rising costs of drug development contribute to organisational innovation. [209] For example, firms are experimenting with process innovation in new clinical trial designs to reduce the costs of clinical trials, but also to adapt to the rising trend of personalised medicines and advanced therapeutics,[210] and provide healthcare providers 'real-world' evidence about the value of medicines.[211] Another supply-side driver is the pressure of (dynamic) competition between research-based companies.

Regulation plays a crucial role in shaping the life sciences innovation system

Regulation has a significant impact on R&D-driven industries, such as pharmaceuticals and biotechnology.[212] Regulation is necessary to ensure the safety and efficacy of new life science innovations. The impact of regulation on biomedical innovation is often positive – by providing information on drug quality, regulation contributes to the value of new drugs and can encourage innovation.[213] However, in some instances, existing regulators in a number of countries have been slow to adapt to changes in the medical innovation landscape.[214] As such, regulatory systems are often closely aligned with pharmaceutical multinationals rather than small, innovative companies, and are often not designed for novel and

[205] Corbett et al. (2017).
[206] O'Neill (2016).
[207] HM Government (2016c).
[208] Corbett, d'Angelo et al. (2017).
[209] Mittra, Tait et al. (2011).
[210] ABPI (2014).
[211] HM Government (2016a).
[212] Mittra, Tait et al. (2011).
[213] Katz (2007).
[214] Mittra, Tait et al. (2011).

disruptive therapies that have no established route to market.[215] As a result, this can present a high barrier to entry for smaller companies that are developing disruptive technologies.[216] Smart regulatory approaches can open up opportunities for smaller companies by streamlining and speeding up approvals for new innovations.[217]

Patents are an important part of life sciences innovation

The use of patent laws to protect and commercialise investments is a vital part of the UK's innovation system. Patents are often considered necessary for pharmaceutical drug innovation due to the costly nature of R&D in this sector.[218] Although the intellectual property system is not the only mechanism to encourage innovation, it is argued that the absence of such laws would significantly affect innovation in the pharmaceutical industry, unlike some other sectors.[219] Patents grant innovators a temporary monopoly and therefore a limited period during which they can enjoy potentially significant returns on an innovation, which provides an incentive to innovate. However, the current drug patent system has its limitations, as setting high drug prices to recoup costs restricts access and certain aspects of the patent system increase the cost of discovering novel therapies, decrease sales revenues and thus reduce the financial incentive to innovate.[68] Alternative solutions include 'push' programs, which subsidise the cost of drug discovery, or 'pull' programmes, such as impact-based and royalty-based rewards for new drugs. [68]

Public–private partnerships facilitate open research

The health innovation system is increasingly collaborative and interdisciplinary, moving towards an open and outsourced approach for access to expertise.[220] Public-private partnerships (PPPs) play an important role in facilitating open research by: pooling resources such as knowledge or expertise; distributing risk across multiple partners or; creating research infrastructure. Pre-competitive collaborations are an important tool for supporting early stage discovery and notable examples include the Structural Genomics Consortium (see Box 5 below),[221] the Innovative Medicines Initiative[222] and the Medical Research Council (MRC)-Industry Asset Sharing Initiative.[223] However, there are a range of uncertainties associated with PPP design such as stakeholder incentives, network size, governance models and intellectual property/ownership arrangements.[224]

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[215] Mittra, Tait et al. (2011).

[216] Mittra, Tait et al. (2011).

[217] Mittra, Tait et al. (2011).

[218] Grootendorst et al. (2011).

[219] IPO (2018).

[220] Academy of Medical Sciences & ABPI (2017).

[221] Structural Genomics Consortium (2018).

[222] Innovative Medicines Initiative (n.d.).

[223] Medical Research Council (2018).

[224] Pigott et al. (2014); Academy of Medical Sciences (2018).

Box 5 Structural Genomics Consortium

The Structural Genomics Consortium (SGC) is an international public-private partnership established in 2004 in response to concerns about the drop in productivity of pharmaceutical R&D. The SGC uses a unique open access model to speed up drug discovery by conducting pre-competitive research in less well-studied areas of structural biology and placing the results of that research in the public domain. Work is carried out by researchers based at the University of Oxford in the UK, the University of Toronto in Canada, the Universidade Estadual de Campinas (Unicamp) in Brazil, the University of North Carolina at Chapel Hill in the USA, the Karolinska Institutet in Sweden and Johann Wolfgang Goethe Universität in Germany. The SGC is funded by a combination of pharmaceutical companies, public bodies and non-profit organisations in the UK, Canada and Brazil.

The SGC's main remit is to determine 3D protein structures on a large scale and cost-effectively. Its activities also include developing chemical probes and antibodies. In a unique open science model, the SGC foregoes patent claims and provides open access to findings. The SGC places all solved structures in the Protein Data Bank without IP restriction on use until later stages of clinical trials. In this way, the SGC aims to remove the legal and financial barriers that prevent a more diverse range of actors from engaging in drug discovery work.

An evaluation[225] of the SGC initiative indicates that it:

- Provides collaborative research opportunities and access to a global network in core areas of structural biology expertise.
- Helps to 'de-risk' new areas of science.
- Enables rapid and efficient research processes.

Translation pathways

The predominant models of knowledge translation in pharmaceutical research and the broader biomedical sector view translation as a sequential, multi-phase, (bi)directional continuum leading from basic research through to health impacts.[226] However, contrary to popular representations, modern therapeutic innovation does not follow a simple linear path. In the context of health, translation is highly distributed, iterative and has the dynamics of an ecosystem.

Biomedical innovation is characterised by complex and multifaceted translation pathways

Technologies such as personalised medicine, new biologics-based therapies, and digital innovations have emerged to challenge the conventional blockbuster drug development business model and innovation pathway. Today, the health sector is characterised by multiple, unique innovation pathways, including product innovations such as drugs, diagnostics, medical devices and digital products, but also service and process innovations (e.g. novel clinical trial designs). Biomedical innovation is also an increasingly interdisciplinary endeavour, combining expertise from the physical sciences as well as the

[225] Morgan Jones, Castle-Clarke et al. (2014).

[226] Monitor Deloitte (2016).

life sciences.[227] The diversification and interdisciplinary nature of the health innovation system thus requires a much broader group of actors to generate innovation than traditional, chemistry-based drug development pathways.

Box 6 100,000 Genomes Project

The importance of personalised medicine has increased significantly in the last decade. There are currently over 5,600 active products in the global industry research pipeline, of which 60 per cent are personalised medicines.[228] Genomics, which enables the study of the complete set of DNA within an individual, is paving the way for the establishment of personalised medicine.[229] The UK is in a strong position internationally in the field of genomics.[230]

The 100,000 Genomes project is a UK government initiative launched in 2013 by Genomics England, [231] a company wholly owned by the Department of Health. The initiative, the largest of its kind in the world, aims to put the UK at the forefront of transforming healthcare through genomics. Specifically, it aims to sequence 100,000 human genomes and put in place the infrastructure, training and systems to enable the NHS to offer genomic medicine. Genomics England is working with NHS England, Health Education England and Public Health England to deliver the project. There are 13 NHS Genomic Medicine Centres across England to recruit patients, take the samples and provide medical information to the project.

Biomedical translation is characterised by a disconnect between supply and demand

Some have argued that scientific progress in the biomedical sector is outpacing society's readiness to harness it.[232] The diversity of innovative technologies that are emerging challenge existing regulatory systems as well as established healthcare pathways, reimbursement systems and clinical practices. Thus, cultural, institutional and economic barriers are inhibiting successful translation of scientific knowledge and findings into viable clinical products.[233] In response to these challenges, translational medicine first emerged as an approach to encourage the adoption of the range of new technologies emerging from life sciences, and foster communication and sharing of knowledge between the bench and the bedside.[234] More recently, implementation research is increasingly seen as a mechanism to increase the uptake and diffusion of innovation in the healthcare system. Academic Health Science Networks (AHSNs) have been established to facilitate the translation of research into clinical practice and the adoption of innovations.[235]

[227] Bell (2017).
[228] ABPI (2014).
[229] Deloitte (2015).
[230] Deloitte (2015).
[231] Genomics England (n.d.).
[232] Dubow & Marjanovic (2016).
[233] Mittra (2013).
[234] Mittra (2013).
[235] Leaver (2017).

Co-creation with patients and the public is increasingly important

There is growing recognition that a sustainable and effective health innovation system needs to involve patients and the public throughout the innovation pathway.[236] The shift towards open innovation in the life sciences requires knowledge from multiple sources, including from users of knowledge, such as patients. A second stage evaluation of the UK Department of Health's Innovation, Health and Wealth strategy[237] found that patient and public involvement is widely accepted as an essential part of health innovation pathways, yet it is still particularly underrepresented.[238] The Accelerated Access Review[239] has made patient involvement throughout all stages of the innovation pathway one of its priorities.[240]

Absorptive capacity

There is evidence that greater engagement by clinicians and healthcare organisations in research has a positive impact on healthcare performance.[241] This is thought to partly be due to increased absorptive capacity within that institution, due to improvements in infrastructure and positive changes in human capital (e.g. acquisition of new skills).[242] However, within the biomedical sector overall, some argue that scientific progress has outpaced the institutional advances needed to uptake new innovations.[243] There is some uncertainty around the ability of institutions and actors to access, assimilate, translate, integrate and use new knowledge for further, targeted downstream R&D, effective health innovation and healthcare delivery models. [244] This is thought to be due to a number of reasons, including: a lack of evidence of the cost-effectiveness of novel and disruptive therapies; the uncertainty around regulation; the high costs of investment and potentially unattractive rates of return; concerns over consent, privacy and other legal and ethical issues (this is particularly the case for sharing of patient data to develop personalised medicines); and the unpreparedness of healthcare systems and workforce to integrate new technologies into clinical practice. [245] Moreover, although the UK currently has a strong research base in the life sciences,[246] there is an emerging skills gap that could impact on the success of the sector in the future.[247] There are already a number of shortages in several disciplines, including clinical pharmacology, bioinformatics and data

[236] HM Government (2016a).

[237] This was a government strategy to promote the spread of innovation in the NHS. See: Liddell et al. (2011).

[238] Marjanovic, Sim et al. (2017).

[239] Government strategy report that sets out recommendations to speed up access to innovative healthcare and technologies in the NHS. See: HM Government (2016a).

[240] HM Government (2016a).

[241] Hampson et al. (2017); Hanney et al. (2013).

[242] Hanney, Boaz et al. (2013).

[243] Dubow & Marjanovic (2016).

[244] Dubow & Marjanovic (2016).

[245] Dubow & Marjanovic (2016).

[246] ABPI (2017).

[247] Academy of Medical Sciences & ABPI (2017).

science.[248] This could be magnified by the UK's withdrawal from the EU, which could impact on the mobility of researchers, an essential factor in maintaining the skills base.[249]

C.2. Measuring impacts from research and innovation

As was identified in another study by the National Academies on the impacts of research and innovation, a significant body of literature has attempted to measure the impacts of R&D in health.[250] The Payback Framework is one of the most widely used frameworks in studies looking at the impacts of biomedical and health research on health and well-being.[251] The framework has two main components: a set of payback categories for classifying impacts and a logic model of the research process. Using a Payback approach, a study by RAND Europe found that achieving impact from research relies on a number of factors, including: diverse skills, non-academic stakeholder engagement, international collaboration, and diverse impact metrics, among others.[252] Evidence suggests that investments in R&D have led to significant benefits in terms of health and well-being. For example, the economic returns series of studies suggest that the health benefits from research investment across a number of fields are equivalent to returns of around 7–10p per year, forever, for every £1 invested.[253] Moreover, public research investments 'crowd in' further private sector R&D investments. Thus, for every £1 of additional public research expenditure, there was an associated £0.87–1.07 of private sector R&D in the UK.[254] A potential limitation identified by the report is that evaluations of health research are often focused on health gain and economic outcomes rather than taking a broader perspective on potential outcomes from research, such as improved health equity or improved well-being in society.

C.3. Understanding of interventions to support innovation

Interventions in the biomedical sector include a mix of 'supply side', 'demand side' and mixed 'demand/supply side'

The search of the literature has identified a number of policy interventions in the last 15 years that aim to tackle various stages of the innovation pipeline, from research and product development through to service improvement, via the diffusion and adoption of innovations in healthcare. Examples of interventions identified from the literature are presented in Table C.1 below. The majority of interventions identified in the literature are government-led initiatives, and are supply-side or measures that are mixed demand- and supply-side. These are often in partnerships with other actors to enable a

[248] Academy of Medical Sciences (2018).

[249] Guthrie et al. (2017).

[250] RAND Europe study – in preparation.

[251] Buxton & Hanney (1996).

[252] Guthrie et al. (2016).

[253] Glover et al. (2018).

[254] Sussex, Feng et al. (2016).

range of outcomes. There are also a large number of publically funded interventions from foundations and charities. Few interventions identified in the literature are from industry alone – some of these include crowdfunding platforms, pharmaceutical corporate venture capital arms and precompetitive collaborations between pharmaceutical firms. Interventions often begin as strategies, policies or plans that aim to change a particular aspect of the innovation system. The most common types of interventions involve a type of collaboration, often between public and private actors, with the aim of stimulating key innovation conditions, including data sharing, knowledge exchange and sharing of expertise, but also innovation uptake and culture change in the health system. Another common theme is early-stage translational funding initiatives, as well as a variety of tax incentives. Increasingly, a number of programmes aim to increase innovation uptake and streamline regulation.

Most interventions aim to promote public-private collaboration

A large number of interventions aim to foster links between industry, academia and the public sector, either to foster knowledge exchange for R&D, or to foster culture change to promote uptake of innovation in the NHS. On the research end of the innovation pipeline, there are a number of precompetitive collaborations between pharmaceutical firms and public partners that support drug discovery (e.g. the Structural Genomics Consortium)[255] or enable data sharing by providing researchers access to deprioritised compounds (e.g. the MRC-Industry Asset Sharing Initiative[256]). The Catapults are technology and innovation centres set up by Innovate UK to provide facilities and sector expertise to speed up the commercialisation of research.[257] Catapults have also attempted to improve regulatory procedures, such as the Cell & Gene Therapy Catapult, which works with legislators overseeing advanced therapies to shorten the time that new treatments take to reach the clinical trials stage.[258] Public-private partnerships targeting later stages of the innovation pathway include AHSNs that aim to promote cultural change,[259] NHS Test Beds[260] that were established to test 'combinatorial' innovation in real-world settings, and Vanguards, which aim to establish new care models.[261]

[255] Morgan Jones, Castle-Clarke et al. (2014).

[256] MRC (2015).

[257] Catapult (2018).

[258] Catapult Network (2017); EY (2017c).

[259] Leaver (2017).

[260] Galea et al. (2017).

[261] NHS England (2015).

Table C.1 Examples of interventions to support innovation in the UK pharmaceutical and life sciences sector

Supply side **Networks**	***Supply side*** **Capital**	***Supply side*** **Infrastructure**	***Demand & supply side*** **Structures**	***Demand side*** **Culture**	***Demand side*** **Driver**
MRC-Industry Asset Sharing Initiative	Industrial Strategy Challenge Fund	NIHR Biomedical Research Centres (BRCs)	Life Sciences Industrial Strategy	NHS Innovation Accelerator	Nesta Longitude Prize
NHS Test Beds programme	The Small Business Research Initiative Healthcare programme	Medicines Discovery Catapult	Patient Capital Review	Academic Health Science Networks (AHSNs)	
Centre for Therapeutic Target Validation (CTTV)	NIHR Invention for Innovation (i4i) programme	Cell and Gene Therapy Catapult	Accelerated Access Review		
MRC/Astra Zeneca Centre for Lead Discovery	UK Biomedical Catalyst	Genomics England	NHS Five Year Forward		
Vanguards	Wellcome Trust Pathfinder Awards		Personalised Health and Care		
Knowledge Transfer Partnerships	Crowdcube		Innovation, Health and Wealth		
Collaboration for Leadership in Applied Health Research and Care (CLAHRC) schemes	Patent box		Review on Antimicrobial Resistance		
MRC Translational Medicine Centres	BBSRC Follow on Fund				

Source: RAND Europe analysis.

Note: This is not an exhaustive list of all the interventions considered.

There are diverse funding initiatives to support health innovation

Biomedical innovation is characterised by a mix of both public and private sources of funding, including from national, regional and organisational resources. The evidence on interventions indicates that this funding landscape is relatively good and is increasingly able to support innovations across the whole translation pathway – from idea generation through to uptake and scale-up across the system. There are many early-stage translational funding initiatives, usually government or charity initiated. Examples

include: the NIHR Invention for Innovation (i4i) programme (see Box 7 below)[262]; the Small Business Research Initiative (SBRI) Healthcare programme (see Box 8 below)[263]; the Wellcome Trust Health Innovation Challenge Fund,[264] Pathfinder Awards[265] and Translational Fund[266]; and the Biotechnology and Biological Sciences Research Council's (BBSRC) Follow on Fund scheme.[267] These often focus on supporting small companies, or on specific categories of innovations such as medical technologies or therapeutics. Some initiatives, such as the Biomedical Catalyst jointly run by the Medical Research Council and Innovate UK, provide both early and late-stage funding (see Box 9 below).[268] There is an increasing amount of venture capital funding available in the UK, and several pharmaceutical companies have created corporate venture investment arms, with the intention of overcoming the translational gap.[269] However, venture capital funding still remains below countries such as the United States,[270] and overall venture capital has not been a successful source of funding for early-stage research in the UK.[271] Indeed, figures from the British Private Equity and Venture Capital Association indicate that total venture capital funding in the UK has been inconsistent over time.[272] Crowdfunding is emerging as a mechanism to support early stage research, particularly when venture capital is hard to come by.[273] The Nesta Longitude Prize was set up in 2014 and offers £10m to help solve the challenge of antimicrobial resistance.[274]

The government is exploring smart regulatory approaches

Initiatives to create supportive regulatory environments are being explored by government strategies such as the Accelerated Access Review.[82] For example, steps that are being considered include new clinical trial designs or streamlined clinical trial procedures, and rapid review processes or fast tracking of approvals of promising drugs.

Initiatives are starting to address cultural barriers to innovation uptake in the NHS

There are several recent initiatives that aim to address the cultural barriers to the adoption and diffusion of innovations in the healthcare system. This has traditionally been a significant bottleneck due to cultural resistance to new ways of doing things (e.g. digital innovations), but also the complexity of regulation and

[262] NIHR (n.d.).
[263] SBRI Healthcare (2018).
[264] Department of Health and Wellcome Trust (n.d.).
[265] Wellcome Trust (n.d.-a).
[266] Wellcome Trust (n.d.-b).
[267] BBSRC (n.d.).
[268] Ipsos MORI (2016).
[269] ABPI (2017); Academy of Medical Sciences & ABPI (2017); Academy of Medical Sciences (2018).
[270] Academy of Medical Sciences (2018).
[271] Jones & Wilsdon (2018).
[272] British Private Equity and Venture Capital Association (2017).
[273] Pigott, Barker et al. (2014).
[274] Nesta (2018b).

procurement channels into the NHS.[275] The Accelerated Access Review proposes an Accelerated Access Pathway for strategically important and innovative products to deliver patient benefit as soon as possible.[276] However, it is expected that only around five to ten innovations per year will receive the transformative designation and travel down the Accelerated Access Pathway. Similarly, other initiatives that focus on promoting cultural change and innovation uptake include the NHS Innovation Accelerator,[277] which supports delivery of the NHS Five Year Forward View[278] and the Next Steps on the NHS Five Year Forward View[279] by accelerating uptake of innovations in the NHS, and AHSNs,[280] alliances that connect NHS and industry partners.

Box 7 NIHR Invention for Innovation (i4i)

The National Institute for Health Research (NIHR) Invention for Innovation (i4i) programme supports the development of innovative medical technologies for patient benefit. NIHR i4i provides early-stage translational funding for the development of medical devices, diagnostics and medical technologies. The programme seeks to fill a gap in the innovation finance system by providing funding at an earlier stage than alternatives such as venture capital. The programme supports early-stage product development, generally at proof of concept and prototype stages. NIHR i4i funding seeks to de-risk projects and make them attractive to follow-on funders and investors. Projects involve collaboration between at least two partners from academia, the NHS and industry.

i4i has three funding streams:

- **Product development awards**: Funding stream that supports any stage of the translational research and development pathway, including the clinical development of laboratory-validated technologies or interventions.
- **Challenge awards**: Themed funding stream that focuses on innovation at later stages than product development, and on clinical development of laboratory-validated technologies or interventions in particular. It aims to fund the development of disruptive technologies.
- **i4i Connect**: The primary aim is to help small and medium-sized enterprises (SMEs) get to a point where they can apply for further funding, in particular for a full product development award, or to support projects at any stage of the translational research and development pathway to further de-risk them for follow on investment.

[275] Marjanovic, Sim et al. (2017).

[276] HM Government (2016a).

[277] NHS England (n.d.-b).

[278] NHS England (2014).

[279] NHS England (2017).

[280] NHS England (n.d.-a).

Box 8 SBRI Healthcare

The Small Business Research Initiative (SBRI) Healthcare programme is one of a number of UK SBRI programmes. The UK SBRI scheme has been providing funding for SMEs since 2009 and is overseen by Innovate UK. SBRI operates by increasing the demand for R&D that will deliver innovative solutions to defined market needs. It aims to promote innovation and the growth of innovative companies while simultaneously obtaining solutions for challenges faced by public sector organisations. Government departments, agencies and other public sector bodies then act as the lead customer for the products developed.

SBRI Healthcare has been funded by NHS England since 2013 and focuses on challenges that are relevant for the NHS and are specified by clinicians and experts within the Academic Health Science Networks. In each call, companies are invited to propose innovative solutions to address the specific challenges identified.

The scheme funds work in two phases:

Phase 1 awards are valued at up to £100,000 and last for six months. These are for companies to demonstrate the technical feasibility of their ideas.

Phase 2 development contracts are worth up to £1m over one or two years and can take a product to prototype development, pathway testing and validation within a clinical setting.

An evaluation[281] of SBRI Healthcare concludes that the programme provides effective support for small companies to develop innovations that address NHS needs. Some of the outcomes and impacts of the programme so far include:

- SBRI Healthcare funding enabled supported businesses to hire 181 full-time equivalent (FTE) staff and to retain another 275 FTE posts. In 2015, supported businesses, subsequent to receiving the SBRI Healthcare award, obtained a total of £36.7m of additional investment funding from other sources.
- Awards are valuable not only for the funding they bring but also for the associated kudos.
- Successful applicants report £4m of product sales so far (of which £3m was in the NHS).

C.4. Understanding of the effectiveness of interventions

A key finding is that many of the innovation initiatives found in the grey literature have been evaluated, except for those that are more recent. Therefore it is probably too early for an evaluation to have been conducted. Overall, the literature indicates that many interventions have broadly been effective at achieving their specific aims, be it funding early or late-stage innovation, fostering collaboration and knowledge exchange or providing access to expertise and facilities. The evidence suggests that interventions have been relatively successful at earlier stages of the innovation pipeline, that is, stimulating product development. There are also some examples of successful interventions at later stages of the health innovation pathway; however, cultural resistance to innovation uptake in the NHS still remains a barrier. There have been fewer interventions to promote innovation uptake in the NHS. Of those, evaluations

[281] Lichten, MacLure et al. (2017).

and evidence indicates that some interventions to promote innovation uptake in the NHS have been effective, such as the AHSNs[282] and the NHS Innovation Accelerator.[283] However, the Innovation, Health and Wealth Strategy was not very successful as it was not informed by an overall strategic sense of direction, was not effectively communicated and was not grounded in learning and emerging evidence a lack of clear communication and strategy.[284] This suggests that government strategies and initiatives need to take into consideration the implementation of the strategy at earlier stages. In the case of the NHS, this requires considering some of the structural pressures it faces and providing 'boots on the ground' to clearly communicate the value of innovations. Regarding funding initiatives, there is evidence that the duration limit of funding awards is often not sufficient to enable projects' objectives to be completed. It often takes a substantial period of time for bioscience research ideas to be translated into practical application. For example, this was the case with the BBSRC Follow on Fund.[285]

Public-private partnerships have revived aspects of life sciences innovation

Some evaluations indicate that PPPs have helped to reinvigorate and increase investment in pharmaceutical R&D, through sharing resources, skills and expertise and de-risking research.[286] For example, an evaluation of the SGC found that stakeholders value the collaborative research opportunities and access to expertise provided by the partnership.[287] Private sector funders have also highlighted the importance of the SGC in helping to 'de-risk' new areas of science. In addition, the SGC enables rapid and efficient research processes. An evaluation of the EU Innovative Medicines Initiative indicates that the initiative has enabled collaborations between competing firms, SMEs and academia, and has also provided access to critical research infrastructure.[288] The evidence also suggests that several precompetitive collaborations between pharmaceutical companies and public partners have helped to accelerate drug discovery processes.[289]

[282] Leaver (2017).

[283] Cox, Spiegelhalter et al. (2018).

[284] Bienkowska-Gibbs, Exley et al. (2016).

[285] BBSRC (2014).

[286] Bountra et al. (2017).

[287] Morgan Jones, Castle-Clarke et al. (2014).

[288] Syrota, D'Hondt et al. (2017).

[289] Bountra, Lezaun et al. (2017).

Box 9 Biomedical Catalyst

The Biomedical Catalyst programme was established in 2012 and is jointly run by Innovate UK and the MRC. The scheme provides early-stage funding to bioscience companies and universities for the translation of innovative scientific ideas into products and therapies for patients.[290] The programme provides a total of £240m of grant funding to SMEs and researchers looking to work either individually or in collaboration to develop solutions to healthcare challenges. The programme aims to bridge the 'valley of death' by de-risking innovative science and accelerating the translation of novel products to market, enabling them to attract onward investment.

The scheme offers funding to life sciences projects at varying stages of technical and commercial development:

- Confidence-In-Concept awards for portfolios of small projects at the earliest stages of technical development by academic institutions.
- Feasibility awards (comparable in focus to the Confidence-In-Concept awards, but awarded on a firm-by-firm basis by Innovate UK).
- Early and late-stage awards: more substantial funding for pre-clinical and clinical work (funding is available up to a Phase II clinical trial or equivalent).

A 2015 report by the UK BioIndustry Association highlights that the Biomedical Catalyst is a successful government intervention supporting translation at the middle stages of the technological readiness scale.[291] The programme is seen to fill a crucial structural gap at earlier stages of the investment pathway where private sector investors will not venture alone. It has helped to bridge the 'valley of death' by de-risking innovations to a stage that venture capital and other forms of financing will come in.

An evaluation of the Biomedical Catalyst published in 2016 indicates that it has successfully provided support to both academically and commercially led R&D.[292] The evaluation finds early evidence that:

- There is positive R&D additionality, with more R&D occurring as a result of the funding award.
- Projects awarded funding have accelerated their technological progress, above and beyond what would have occurred in the absence of funding.
- Biomedical Catalyst awardees have found it easier to raise additional follow-on funding.
- Turnover and employment rose more rapidly among successful applicants to the programme than for non-successful applicants.

Although the evaluation notes that at this stage it was too early to be confident about attributing all of these findings to the Catalyst.

Evaluations find that there is a barrier to the uptake of innovations

Analysis of evaluations suggests that there are challenges at later stages of the innovation pipeline due to challenges around uptake and use of the innovations. [293] This is due to a number of reasons, including cultural resistance in the NHS, complex procurement processes or difficulty obtaining regulatory approval. A Phase 1 evaluation of the UK government's Innovation, Health and Wealth strategy, which

[290] Ipsos MORI (2016).

[291] BioIndustry Association (2015).

[292] Ipsos MORI (2016).

[293] Lichten, MacLure et al. (2017); Marjanovic, Krapels et al. (2015); Marjanovic, Sim et al. (2017).

was a national strategy to embed innovation into the NHS, found that IHW has not been sufficiently informed by an overall strategic sense of direction, has not been effectively communicated and is not grounded in learning and emerging evidence.[294] It also found that progress towards IHW's objectives has been variable. A study in innovation as a driver of UK healthcare found that, so far, there is not much evidence for progress in culture change in the NHS.[295] However, a number of initiatives have been launched to promote cultural change and innovation uptake, and some are showing initial evidence of success. For example, a 2017 Impact Report indicated that AHSNs (see Box 10 below) have created effective regional networks able to deliver innovation and improvement within the NHS.[296] The NHS Innovation Accelerator has helped with the scale-up of innovations by providing real world insight, encouraging patient participation and providing a network of experienced contacts that can open doors to key influencers.[297] The Accelerated Access Review sets out strategies for culture change in the NHS through providing incentives for the adoption of innovation; however, this remains to be evaluated.[82]

Box 10 Academic Health Science Networks

Academic Health Science Networks (AHSNs) are regional networks that connect the NHS, academic organisations, local authorities, the third sector and industry.[298] There are 15 AHSNs across England, which were established by NHS England in 2013. AHSNs were created to speed up the delivery of innovation and improvement within the NHS. Specifically, they aim to identify and drive the adoption and diffusion of innovative ideas and technologies in the NHS.

AHSNs share knowledge and expertise to identify and drive the adoption and spread of innovation. They have developed programmes in partnership with NHS England to identify the innovations with the biggest potential impact if scaled nationally.

Lack of adequate metrics prevents communication of progress

Innovation metrics in the pharmaceutical and life sciences industry are broadly well developed to describe the product and technology development stages of the innovation pathway, often focusing on classic measures such as R&D expenditure, patents produced or venture capital investment, among many others.[299] However, the pharmaceutical industry is facing a widely acknowledged decline in productivity despite increases in R&D investment, which questions the robustness of R&D spending as a truly adequate indicator of innovative activity in this sector.[300] It has also been suggested that metrics are needed for the UK drug discovery landscape to evaluate different funding strategies, direct future areas of focus for funding, allow comparisons between the UK and the global ecosystem to attract investment, and

[294] Bienkowska-Gibbs, Exley et al. (2016).

[295] Marjanovic, Sim et al. (2017).

[296] Leaver (2017).

[297] Cox, Spiegelhalter et al. (2018).

[298] Leaver (2017).

[299] Guthrie et al. (2016).

[300] Mittra, Tait et al. (2011).

identify areas for improvement.[301] Moreover, it has been argued that the metrics for measuring the adoption and diffusion of medical innovation in the NHS are not adequate, which makes it hard to measure progress.[121] To facilitate evaluation along the innovation pathway, a process marker approach has been proposed in the literature, which identifies key translational research milestones along a generalised innovation pathway from research to practice.[302]

The timeline for the translation process

The development of life sciences products and services takes many years. According to one analysis of the biomedical sector, 'It takes an estimated average of 17 years for only 14 per cent of new scientific discoveries to enter day-to-day clinical practice.'[303] In order to be able to speed up the process and increase returns on investment, there is a need to measure time lags correctly and understand where along the innovation pathway they are most likely to occur. Yet, there is a lack of consistent measures reflecting the time lags between medical research and its translation.[304] Moreover, evaluations of policy interventions typically evidence time-limited impact to fit with short-term policy cycles, rather than looking at changes in impacts over a long period of time. For example, one evaluation of an early-stage funding initiative found interviewees were unsure how many innovations will reach the market and that it was too early to identify impacts on patients and the NHS.[305] Another evaluation concluded that 'despite aiming to target responses on completed projects, the survey responses included a mix of completed and ongoing contracts, the latter of which could require more time for impacts to accrue.'[306] Regarding the evaluation of the Biomedical Catalyst, it was acknowledged that many longer-term impacts are unlikely to have occurred yet given the long development process of many of the technologies being funded.[307]

Barriers that still need to be addressed

Regulation can sometimes constrain the development of disruptive biomedical technologies

Regulatory structures are important and necessary to determine the safety and efficacy of new technologies. However, some argue that regulation has not been flexible and adaptable, which means it can sometimes act as a barrier to the successful development and delivery of truly innovative technologies and therapies.[308] The lengthy, expensive and demanding nature of the drug regulatory system can represent a barrier to entry for smaller companies that are developing disruptive technologies or products without an established route to market. Medicines regulators abroad have already adapted their processes

[301] Nair et al. (2016).

[302] Trochim, Kane et al. (2011).

[303] Morris, Wooding et al. (2011); Westfall, Mold et al. (2007).

[304] Hanney et al. (2015).

[305] Lichten, MacLure et al. (2017).

[306] Marjanovic, Krapels et al. (2015).

[307] Ipsos MORI (2016).

[308] Mittra, Tait et al. (2011).

to increase the speed of approval, such as the United States' 'breakthrough designation',[309] or the European Medicine Agency's PRIME (priority medicines) scheme[310] in Europe. The UK's Accelerated Access Partnership (proposed as part of the Accelerated Access Review) will aim to address some of the present regulatory hurdles by providing accelerated access to transformative products through enhanced interaction and early dialogue with the Medicines and Healthcare products Regulatory Agency.[311]

Cultural resistance in the NHS often prevents innovation uptake

One of the main bottlenecks to the life sciences innovation pathway is the uptake of innovation in the NHS: 'despite the innovation happening here, our uptake in the NHS can be too slow'.[312] This is can be due to cultural resistance within the NHS, but also difficulty integrating novel technologies with existing clinical practice. The NHS as a customer is also characterised by complex and bureaucratic procurement systems, which pose difficulties, especially to small companies. However, the NHS faces a number of well-acknowledged structural pressures, meaning that innovation can be stifled because the funding, staff time or skills necessary to stimulate change are not always available.[313] Moreover, risk-aversion to guaranteed patient safety may also contribute to some of the resistance to innovation. Interventions such as the Accelerated Access Review and the NHS Innovation Accelerator, as well as structures such as AHSNs, are taking steps to transform the NHS into a system that welcomes innovation. The National Institute for Health and Care Excellence (NICE) also plays an important gatekeeping role for the NHS, with, for example, the NICE Medical Technologies Evaluation Programme promoting the adoption of innovative diagnostic and therapeutic technologies into the NHS.[314]

[309] US Food and Drug Administration (2018).

[310] European Medicines Agency (2018).

[311] HM Government (2016a).

[312] HM Government (2016a).

[313] Robertson, Wenzel et al. (2017).

[314] Groves et al. (2018).

Annex D. The defence sector

This Annex provides detailed evidence on the conditions needed to translate research and drive innovation in the defence sector.

The recently published Dunne review[315] highlights the defence sector's significant contribution to the UK economy. According to the report, around 500,000 people support defence across the UK. It also reveals that the UK's defence industry has an annual turnover of £22bn, supports 260,000 jobs and is one of the largest employers of apprentices with over 25,500 currently enrolled. The review also finds that defence's direct contribution to GDP features over an average of £7bn of exports generated each year. Therefore, understanding the conditions that enable innovation in an area of strength can help to inform the conditions that can deliver success to the system as a whole.

D.1. The depth of understanding of the innovation system

Much of the evidence to support this sectoral analysis was based on grey literature, the expert workshop and interviews. Due to the low availability of academic literature, this section of the report draws significantly on grey literature and expert insights.

The innovation ecosystem for the defence sector in the UK can reasonably be described as mature; it has been operating for many decades, there are extensive connections between established operators in industry (BAE Systems, QinetiQ and many others) and higher education (Cranfield, Southampton and many others), and there is significant government infrastructure supporting the whole enterprise (Defence Science & Technology Labs (Dstl)). But the networks and connections are less good between non-traditional actors, which makes it challenging to access novel solutions and talent, and much of the access to the market for smaller companies relies on working with large companies – this is in significant part because complying with defence standards is a significant burden that only large organisations can support. Furthermore, the discontinuity in funding that is often experienced can better be handled by large organisations, whereas SMEs can be readily impacted by shortfalls in funding. While it is not unique to defence, a phrase that was used in discussion with defence experts was, 'the need to have a golden thread of funding', that helps see an innovation through all stages of development which a large organisation can provide, whereas a small organisation has less certainty over funding and cash-flow.[316] In

[315] MOD & The Rt Hon Gavin Williamson CBE MP (2018).

[316] RAND workshop, 18 April 2018.

general, where there is a clear procurement programmes acting as a driver to stimulate innovation then the wider conditions needed to support innovation (e.g. talent, infrastructure) seem to be also available, whereas the absence of a clear driver can be linked to a shortage in the other conditions needed to support innovation. A further challenge is that as a monopoly/monopsony market, the entire innovation system is very vulnerable to changes in the funding – made available by the government as the only significant buyer.

Over the past 15 years there have been numerous interventions to support the defence innovation system, most of which can be considered to be supply side (e.g. the Defence Policy for SMEs) or mixed demand and supply side (e.g. the Ministry of Defence (MOD) Science & Technology Strategy).[317] It is notable that there are very few publicly available, independent evaluations of these interventions and so it is hard to know which interventions have been the most effective.

[317] MOD (2017c).

Box 11 MOD Science and Technology Strategy

The Defence Science and Technology Strategy was published in 2017.[318] The strategy recognises that science and technology are essential in supporting innovation in defence. It therefore aims to ensure that science and technology play a central role in the MOD's strategic policy and decisionmaking, but also in the implementation of those policies and decisions.

To ensure science and technology are embedded in strategic decisionmaking, the MOD's Chief Scientific Adviser will provide an independent technical challenge function to Defence. This will help to inform MOD decision makers of emerging technologies which present threats or opportunities to defence and security.

Science and technology can inform the implementation of policies and decisions through supporting defence to be an 'intelligent customer', supporting business-focused outcomes and supporting the pull-through of science and technology into systems and defence capabilities.

The strategy recognises that defence is relatively good at generating new ideas but is less good at implementing them in MOD's operations and business processes. Therefore, it stresses that every science and technology project should have a clear science and technology offer for defence and a clear customer focus.

The MOD's core research portfolio, and the funding associated with it, will be at the heart of implementing the science and technology strategy and sustaining the science and technology capabilities that are required for UK defence and security. The strategy also recognises the importance of collaboration with industry, academia and our international partners.

The key conditions for innovation in the defence sector

The evidence from the expert workshop discussion suggests that the conditions for innovation in defence in the UK are generally not as favourable as they could be.

There is relatively poor availability of capital for innovation in defence

Since the financial crash there has been a significant reduction in defence spending, which has reduced funds available including for procurement and innovation.[319] There was a discernible connection between having clear drivers (i.e. defence procurement programmes) and the availability of talent, albeit the availability of that talent is affected by the reward for working in defence compared to other sectors (e.g. cyber) and the 'image problem' that defence has with new entrants to the labour market.[320]

Talent in the defence sector is very closely connected with knowledge assets as so much of the knowledge is embedded in people

Many of these knowledgeable people are in their late fifties, meaning much of the talent is shortly to retire.[321] It was considered by defence experts at the RAND workshop that, while MOD infrastructure is not what it once was, industry generally has good infrastructure and the university infrastructure

[318] MOD (2017c).

[319] MOD (2017a).

[320] RAND workshop, 18 April 2018; RAND Europe interview with defence expert, 24 May 2018.

[321] RAND workshop, 18 April 2018.

supported by the Catapults is very good across the UK, which provides a great asset to innovation in defence.[322]

There is an interwoven set of challenges around cultures, structures and networks

The workshop organised by RAND revealed a wealth of information about the cultures, structures and networks for innovation in defence.[323] There is necessarily a culture of secrecy in defence, which can (but should not completely) limit the sharing of information and formation of new connections. Risk aversion is wide spread, and the behaviours of MOD, as the only customer, are mirrored by defence industry. The MOD has introduced many processes and structures that can be considered as outdated and the supply chain is required to follow these. If the MOD issues requirements that do not offer space for innovation, the industry will not proffer novel solutions. The amount of bureaucracy that can be involved in dealing with the MOD to see an innovation through its entire pathway can be a disincentive to new suppliers engaging with the MOD. All of these observations were revealed by defence experts at the workshop.

The translation pathway in defence is Technology Readiness Levels

The workshop identified key features of the translation pathway in defence.[324] The concept of technology readiness levels (TRLs – where TRL1 is basic principles and TRL9 is an actual technology system) is well-established in defence and is the main pathway for maturation of technological innovations (see Table D.1 for MOD definitions of TRLS).[325] Progression from one TRL is usually conducted by some form of 'gated' process of business case approval from relevant stakeholders There are variations on the theme of TRLs that permit a greater focus on different aspects of readiness, for example systems readiness levels (SRLs) which recognises that a technology rarely operates independently of a wider technology system and seeks to represent the readiness of the system of technologies (or even system of systems). There are also manufacturing readiness levels (MRLs) which assess whether the technology is ready to go into production, which is different to whether the technology has been shown to work within a system.[326] The position of a given technology or solution on the TRL or SRL scale is context dependent and depends on the requirement against which it is being developed; the same technology could have a higher maturity for one requirement but lower for a different requirement. The TRL pathway is generally speaking incremental unless there is an urgent requirement in times of operations (e.g. conflict or humanitarian crisis such as Ebola).

[322] RAND workshop, 18 April 2018.

[323] RAND workshop, 18 April 2018; James & Thomas (2014).

[324] RAND workshop, 18 April 2018.

[325] HM Government (2011); NASA (2017).

[326] RAND Europe interview with defence expert, 24 May 2018; Sauser, Ramirez-Marquez et al. (2006).

Table D.1 MOD technology readiness levels and their description

Technology readiness level	Description
1) Basic principles observed and reported	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development. Examples might include paper studies of a technology's basic properties.
2) Technology concept and/or application formulated	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative and there may be no proof or detailed analysis to support the assumptions. Examples are still limited to paper studies.
3) Analytical and experimental critical function and/or characteristic proof of concept	Analytical studies and laboratory studies to physically validate analytical predictions of separate elements of the technology are undertaken. Examples include components that are not yet integrated or representative.
4) Technology component and/or basic technology sub-system validation in laboratory environment.	Basic technology components are integrated to establish that they will work together. This is relatively 'low fidelity' compared to the eventual system. Examples include integration of 'ad hoc' hardware in the laboratory.
5) Technology component and/or basic sub-system validation in relevant environment.	Fidelity of sub-system representation increases significantly. The basic technological components are integrated with realistic supporting elements so that the technology can be tested in a simulated environment. Examples include 'high fidelity' laboratory integration of components.
6) Technology system/subsystem model or prototype demonstration in a relevant environment	Representative model or prototype system, which is well beyond that of TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in simulated operational environment.

Source: Adapted from Ministry of Defence.[327]

[327] MOD (n.d.-a).

Table D.1 (continued)

	Technology readiness level	Description
7)	Technology system prototype demonstration in an operational environment	Prototype near or at planned operational system. Represents a major step up from TRL 6, requiring the demonstration of an actual system prototype in an operational environment, such as in an aircraft or vehicle. Information to allow supportability assessments is obtained. Examples include testing the prototype in a test bed aircraft.
8)	Actual technology system completed and qualified through test and demonstration	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of demonstration. Examples include test and evaluation of the system in its intended weapon system to determine if it meets design specifications, including those relating to supportability.
9)	Actual technology system qualified through reliability and maintainability demonstration in service	Application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation and reliability trials. Examples include using the system under operational mission conditions.

Source: Adapted from Ministry of Defence.

Absorptive capacity

There are few recent studies giving detailed analysis of absorptive capacity in the defence sector, albeit a previous RAND Europe study looked at the question of innovation models for the defence sector.[328] Given the size of the defence sector in the UK, there is potential to increase capacity and to absorb ideas from a range of sources, and the analysis of the conditions to support innovation suggests that much of them are definitely available in the UK. However, the challenge lies in some of the processes being outdated and lack of clear procurement needs in some areas.[329]

D.2. Measuring impacts from research and innovation

As was identified in the commission by the National Academies to understand the impacts of research and innovation, there has been limited effort to undertake such measurements. Officials from the US Department of Defence (DoD) have argued evaluation of impact as 'difficult', and stakeholders and staff from DoD-funded Regional Centers cannot measure the extent to which the Centers meet their goals of

[328] Freeman, Hellgren et al. (2015); GES (2014); Mahroum et al. (2008).

[329] RAND workshop, 18 April 2018.

empowering security practitioners and resolving security challenges.[330] The study team was also able to identify a paper from 2006 that showed a statistically significant link between the investment in R&D and the quality of military equipment a country has 10 to 25 years later.[331] In general, there is a deficit of understanding about how research and innovation impacts can be measured in the defence sector.

D.3. Understanding of interventions to support innovation

The overall picture revealed from the search of the grey literature is that the defence sector has, over the years, experienced many interventions, ranging from high-level government policy through to focused attempts to build skills in a particular area and the desire to build the strength of the innovation ecosystem in particular challenge areas. However, perhaps the most significant feature of the interventions are the many initiatives intended to support the supply chain in defence ranging from large defence contractors through to SMEs, and the attempts to foster partnerships that support knowledge exchange, understanding of how to access the defence market, and also diversification through dual-use technologies or exports.

The defence innovation ecosystem is mature, but, nonetheless, as technology develops and the nature of conflict evolves, there has been pressure to identify innovative ways and means of delivering military effect. Given this, there have been numerous interventions over the years designed to adjust some part of the innovation ecosystem. The study team has conducted an analysis of interventions over approximately the past fifteen years to understand what the nature and effect of these interventions has been. Examples of interventions identified from the search are documented in Table C.3 below.

The majority of the interventions can be considered 'supply side' or mixed 'demand/supply side'

Very few of the large-scale interventions identified were purely focused on demand side (e.g. procurement against a specific requirement) and it is assumed that this is because these tend not to be published as interventions to support innovation. However, in conversation, defence experts did consider that procurement programmes are in fact very important interventions that can stimulate innovation, as these provides a clear requirement against which technologies can be matured.[332] Instead, many of the interventions are strategies, policies or plans of some form ('structures' under the innovation framework for the purposes of this study), often published by a minister with the intent of marking a significant change or development in policy to secure a new aim. The policies very often state particular ambitions for some aspect of the innovation ecosystem, with common themes being skills, supply chain support and/or a technology/capability/challenge topic. The policies and strategies range from the relatively recent

[330] Hanauer et al. (2014).

[331] Middleton et al. (2006).

[332] RAND workshop, 18 April 2018; RAND Europe interview with defence expert, 24 May 2018.

Defence Innovation Initiative,[333] through the National Security Through Technology White Paper[334] and the Defence Technology Strategy.[335]

Supply chain support interventions are seemingly the most numerous

Supply chain support interventions include examples such as the Defence Industrial Strategy[336] or Defence Growth Partnership.[337] The various aims of these strategies can broadly be considered as supporting defence and security companies as the supply chain to MOD in what is an atypical market showing monopoly/monopsony relationships, providing confidence to the sector to try and stimulate innovation and to assure security of supply of sovereign capabilities. A common ambition also is to open the market up to a supplier base wider than just the defence prime contractors, with the aim of accessing innovation from SMEs and other non-traditional suppliers to defence, for example the MOD Policy for Small and Medium Enterprises[338] or the Supply Chain Advocates scheme.[339]

Box 12 Defence Industrial Strategy (2005) and Defence Industrial Policy (2017)

The Defence Industrial Strategy (DIS) was published in 2005. The strategy's aim was to provide greater transparency regarding the UK's future defence requirements. It set out the industrial capabilities the UK needs to maintain appropriate sovereignty and operate equipment independently. The strategy aimed to prepare industry to adapt to new requirements as the MOD's focus shifted to upgrading and maintaining platforms rather than designing and building new equipment. The DIS recognised and placed an emphasis on the following:

- The ability to support and upgrade technologically challenging and high-value systems through life.
- The need to retain skills together with the specialist systems engineering capabilities that defence required.
- The importance of sovereign capability and exportability.

The government developed a refreshed Defence Industrial Policy in 2017.[340] It proposes measures to help the UK's defence and security industries, in particular SMEs, to grow and compete successfully. The Policy focuses around three strands:

- Considering the wider economic, international and security implications of defence programmes at an earlier stage.
- Creating the conditions for the industry to be internationally competitive, innovative and secure.
- Continuing to make it easier to do business with defence, especially for SMEs.

[333] MOD (2017a).
[334] MOD (2012).
[335] MOD (2006).
[336] MOD (2005).
[337] DGP (n.d.).
[338] MOD (2016).
[339] MOD (n.d.-b).
[340] MOD (2017b).

Recent skills interventions have particularly focused on cyber

Skills interventions have tended to focus on supporting the development of science, technology, engineering and mathematics skills, as these are at the heart of much of traditional defence innovation. Lately, there has been a particular focus on the skills needed for cyber security.[341]

The defence sector also uses challenge, capability or technology-focused interventions

The defence sector quite regularly has interventions designed to stimulate innovation in a specific field related to a particular challenge that needs a solution (for example, the urban warfare grand challenge[342]), or the desire to build the knowledge and supplier base in a particular technology or military capability area (for example the synthetic environment Tower of Excellence[343]). These include specific challenges launched in tandem with a policy or strategy (the urban warfare grand challenge was part of delivering the Defence Technology Strategy 2006[344]), or regular calls for particular challenges, currently delivered through the Defence and Security Accelerator[345] (and previously the Centre for Defence Enterprise). The Defence and Security Accelerator also has an open call for innovation, which solicits ideas at any time on any topic that an innovator considers may be relevant for defence.

D.4. Understanding of the effectiveness of interventions

In general, the assessment of the effectiveness of these interventions is limited (or at least not publicly available)

A striking finding from the review of the grey literature for interventions in the defence sector is the lack of evaluations, reviews or impact assessments that are publicly available. It is possible that evaluations have been conducted but not published for security or commercial reasons. However, the lack of publicly available evaluations seems to be in contrast to the pharmaceutical/life sciences sector, which is also a well-established part of the UK innovation system. So, while significant interventions in the pharma sector, such as the Structural Genomics Consortium (a partnership between government, industry and the third sector), have been the subject of a formal evaluation that has been published, it was not possible to identify evaluations on significant policy interventions such as the Defence Technology Strategy 2006,[346] the Centre for Defence Enterprise[347] or the Defence Technology Centres.[348]

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[341] Pozniak (2017).

[342] MOD (2008).

[343] Dstl (2018b).

[344] MOD (2006).

[345] Dstl (2018a).

[346] MOD (2006).

[347] HM Government (2016b).

[348] Note – there is no longer an official website for the Defence Technology Centres, only a minimalist reference on Wikipedia. See: Wikipedia (2015).

Box 13 Defence and Security Accelerator

The Defence and Security Accelerator is an initiative run by the MOD, Dstl, Defence Equipment and Support and the Home Office.[349] It seeks to promote collaboration between industry, government defence and security departments, and academia, to speed up the development of innovative solutions to the most pressing security challenges.

The scheme focuses on:

- Funding proof-of-concept research that offers a high potential benefit to defence and security.
- Opening up defence and security challenges to the widest possible audience of providers, including those new to defence and SMEs.
- Helping to take Accelerator-funded projects towards market.

The Accelerator runs themed competitions to address specific defence challenges and also holds open call competitions for wider innovative ideas.

Themed competitions fund innovative ideas in the TRL2 to 6 range (see Table D.1 for MOD TRL definitions) in two phases. Phase 1 is open to technologies that have already reached TRL 2 to 3 and funds projects to develop these to TRL 4. The awards are typically in the range of £40,000 to £100,000 for work of 3 to 9 months duration for the first phase of work. Phase 2 projects aim to develop successful Phase 1 projects to TRL 6.

Open calls seek ideas in two categories: emerging innovations category is for less mature innovations, and the rapid impact innovations category is for innovations that are more developed.

[349] Defence and Security Accelerator (n.d.).

Table D.2 Examples of interventions to support innovation in the UK defence sector

Supply side	*Supply side*	*Demand & supply side*	*Demand & supply side*
Supply chain support	**Skills**	**Structures**	**Challenges, capability or technology focus**
MOD policy for small and medium enterprises	The STEM Awards 2018 Defence Technology Challenge	Industrial Strategy: building a Britain fit for the future	Defence Innovation Initiative
Supply Chain Advocates: connecting SMEs with the MOD	Cyber Security Skills Strategy	MOD Science and Technology Strategy	Defence & Security Accelerator
Defence & Security Accelerator	GCHQ's CyberFirst	Defence Industrial Policy	JHub
Dual-Use Technology Exploitation programme	Cyber Security Skills Immediate Impact Fund	National Security Through Technology	Tower of Excellence
Defence Growth Partnership	Apprenticeships	Strategic Defence and Security Review	UK Defence Solutions Centre Challenges
UK Defence Solutions Centre	The STEM Awards 2018 Defence Technology Challenge	Defence Technology Strategy	The Defence Technology Centres
		Defence Industrial Strategy	Defence Technology Innovation Centre

Source: RAND Europe analysis. Note: This is not an exhaustive list of all the interventions considered.

The most recent independent review was commissioned by the MOD Chief Scientific Adviser and delivered in 2015 by the then Government Chief Scientific Adviser, Sir Mark Walport, with the support of several expert advisory panels.[350] One of the key findings from that review was that 'despite the apparent high quality of the majority of the S&T (as assessed by the ten capability panels), there is not enough systematic independent peer review of Dstl's internal capability or that of the external supply base to provide assurance to the MOD and Armed Forces that the quality of S&T is held to account'.[351] It is possible that since this review the MOD has initiated a series of reviews/evaluations to address this finding, but this was not readily identifiable from the grey literature.

In 2017, a review of the SBRI as a whole was published, which included some assessment of how this was operated from the MOD as one of the larger funders of the SBRI.[352] One of the notable findings from this review that relates to the conditions for innovation for the defence sector is 'the lack of MOD funding between TRL4/6 and TRL 8 for UK defence and security innovations, and the weak demand pull through that results, represents a major missed opportunity to accelerate the rate of creation and growth of those STEM based UK SMEs for whom defence and security represent important international markets in their own right, as well as lead applications of technologies with wider applications'.[353] This

[350] Walport (2015b).

[351] Walport (2015b, 4).

[352] Connell (2016).

[353] Connell (2016).

highlights directly that while there are many interventions that aim to support the supply chain for defence innovation, the conditions are still not right with respect to the provision of capital and the linking of solutions to demand (drivers), which creates a structural incoherence for innovators. In 2004, the National Audit Office published its review of the management of defence research and technology by the MOD.[354] This looked at how the defence research and technology programme is managed, rather than the outcomes of the programme as such. A notable statement in the press release accompanying the NAO review was: 'Historically, the Department has lacked a coherent way of identifying and measuring the benefits of research programmes . . . [the report] recognises that measuring research outputs and outcomes is difficult because of the wide variety of outputs and the long-timescales involved. However, the Department should put in place performance measures suggested by the National Audit Office to track whether the aims of its new approach are being achieved and measure longer term outcomes.'[355]

The timeline for innovation in defence is typically 10 to 25 years

In defence, it is commonly accepted that it can take many years, decades even, for ideas to be translated into an innovation. However, in the event of an urgent operational requirement, the time can be shortened significantly down to a few months. There are not so many studies that give detailed formal analysis of time lags in defence, but an analysis of the impact of R&D funding on the quality of defence equipment showed that there was a time lag of 10 to 25 years.

Barriers that still need to be addressed

The main innovation pathway for defence is TRLs and the structures and processes that are arranged around this concept to enable ideas to be matured into new solutions for defence. While there are variations on the theme of TRL (e.g. SRL), the core pathway has been largely unchanged for decades – innovations mature as they are able to pass approval gates/business cases. This is in contrast to sectors such as pharmaceuticals, where there has been some experimentation with alternative approaches to clinical trials.

What evaluations are available in the public domain indicate that for many years there has been a need to undertake more detailed evaluations of the defence innovation ecosystem. This absence of independent evaluations of specific interventions (at least in the public domain) makes it challenging to identify what works for stimulating innovation in the defence sector, and whether the conditions needed for innovation are being developed to ensure an optimally favourable environment for innovation. To improve the effectiveness of future interventions in the defence sector, it will likely be beneficial to include formal, independent evaluations as part of the process.

[354] NAO (2004).

[355] NAO (2004).

Annex E. The fintech sector

This Annex provides detailed evidence on the conditions needed to translate research and drive innovation in the financial technologies (fintech) sector.

The fintech sector combines technology with the traditional processes of finance, two sectors that contribute significantly to the UK economy.[356] London represents the leading financial services centre in the world.[357] The financial services sector paid £65bn in tax in 2012/2013 and accounts for roughly 9.4 per cent of GDP.[358] The technology sector also contributes enormously to GDP, with the Internet industry alone accounting for roughly 8.4 per cent.[359] According to one report, in 2015 the UK fintech sector employed approximately 61,000 people, generated approximately £6.6bn in revenue and attracted approximately £524m in investment.[360] Fintech represents a fast-moving and innovative sector, but is still a young and developing sector and is therefore an interesting sector to investigate.

E.1. The depth of understanding of the innovation system

A search of the grey literature did not identify an established fintech-specific model of the process for translating research into innovation. Incumbent financial institutions generally have limited internal capacity to conduct research; for example, they may not have research and innovation units as such, and tend to have opportunistic strategies for adoption of innovations. However, it should be noted that financial institutions do have funding to conduct R&D, but they may choose to invest their resources elsewhere.[361] These characteristics, together with the lack of a defined framework in the literature, point to a more dynamic translation model than the sequential pathways seen in the literature on the defence and pharmaceutical sectors.

[356] Government Office for Science (2015).

[357] KPMG (2017).

[358] Government Office for Science (2015).

[359] Government Office for Science (2015).

[360] EY (2016).

[361] Personal communication

The key conditions for innovation

This section describes some of the key drivers and conditions identified as stimulating innovation in the fintech sector.

There are both demand-side and supply-side drivers of fintech innovation

A maturing consumer base has been identified as a key demand-side factor shaping innovation in fintech.[362] The rapid spread of smartphones and other mobile technologies has led to demand among consumers for mobile solutions in more and more areas of their daily lives, while the growth of e-commerce has driven the development of digital payments technologies. The result has been rising expectation among consumers of real-time payments.[363] Fintech innovations such as mobile payment technologies, online banking and online brokerage products have emerged to meet that demand.[364] Growing demand is also fuelled by demographics. First, younger people are more open to mobile banking and other fintech than older generations, as evidenced by a survey by the US Federal Reserve.[365] Second, there is increasing demand for financial services among populations traditionally underserved by incumbent institutions. For example, many emerging economies have seen particularly high demand for mobile banking among their expanding middle class populations, as technology enables them to access services without the requirement for physical banking infrastructure.[366]

On the supply side, incumbent financial institutions' desire to cut costs and streamline processes is viewed as an important driver of fintech innovation.[367] Since the global financial crisis, low interest rates have created pressure on banks to cut costs, making technological solutions attractive to incumbents. Fintech innovators have recognised this, for example, through the creation of blockchain technologies that help to speed up clearing and settlements, leading to lower costs for banks.[368]

Collaboration between incumbents and start-ups enables innovation

The development of connections between incumbent financial institutions and innovative fintech companies is helping to shape the development of new products and bring them to market.[369] Collaborating with fintech firms gives incumbents access to ideas and skills they do not possess internally, and enables a degree of crowdsourcing of solutions to fintech challenges.[370] This type of partnering also benefits fintech firms, who gain access to large datasets held by incumbents and which enable them to test new models, as well as incumbents' existing customer base. For example, through partnering with

[362] BNY Mellon (2014); BNY Mellon (2015); Deloitte (2016); Schindler (2017); Yeandle (2017).

[363] BNY Mellon (2015).

[364] Schindler (2017).

[365] Schindler (2017).

[366] BNY Mellon (2015).

[367] Schindler (2017); Yeandle (2017).

[368] Schindler (2017).

[369] PwC (2017c); Shaughnessy (2015); World Economic Forum (2017).

[370] Shaughnessy (2015).

incumbents, fintech companies seeking to add business-to-business activities to their existing business-to-consumer offerings have been able to tap into a ready-made client base in that market.[371]

Regulation can enable as well as constrain fintech innovation

While the heavy regulatory burden on incumbent financial institutions is generally viewed as a barrier to innovation, it also creates gaps for innovative fintech companies to fill. For example, post-crisis regulation made traditional banks more risk-averse and led them to cut back on lending to some groups. This helped to drive the growth of peer-to-peer lending technologies, which specifically targeted borrowers that incumbents had stopped serving, such as small businesses and high-risk consumers.[372]

Absorptive capacity in the fintech sector depends on a coherent innovation strategy

The absence of a coherent innovation strategy among incumbent financial institutions is seen as a key barrier to their uptake of new technologies.[373] One survey found that the majority of senior financial services executives viewed their banks' strategies for digital innovation as fragmented or opportunistic.[374] Moreover, a lack of thought leadership from senior levels within financial institutions has been identified as a root cause of this strategic deficit.[375] Incumbent institutions are increasingly seeking to address this problem by improving their monitoring of developments in fintech, with one study finding that around half of incumbents are carrying out such monitoring.[376]

E.2. Measuring impacts from research and innovation

The literature reviewed did not provide any examples of efforts to measure the impact of R&I in the fintech sector specifically. Moreover, the literature reviewed, as part of a previous study on measuring the impacts of research and innovation, suggests that it is particularly challenging to measure R&I impacts in areas of the digital economy that, like fintech, are driven primarily by private investment and endeavour with limited public involvement.[377]

[371] PwC (2017c).

[372] Schindler (2017).

[373] BNY Mellon (2015); Shaughnessy (2015).

[374] BNY Mellon (2015).

[375] Shaughnessy (2015).

[376] PwC (2017c).

[377] Guthrie et al. (2018).

E.3. Understanding of interventions to support innovation

What limited evidence that was available is summarised here.

There have been few formalised interventions to support fintech innovation

The literature contains very few examples of coordinated initiatives designed to foster innovation in the UK fintech sector. As this section will show, the majority of interventions within the sector are carried out by individual companies rather than collaborative networks or public bodies, and most take the form of one-off actions that do not fall under any overarching initiative. For example, efforts to increase collaboration between incumbent financial institutions and fintech start-ups tend to be one-off agreements between firms, which are not supported by any wider, formalised strategy or initiative. Table C.4 provides an overview of the limited number of formalised interventions contained in the literature.

Table E.1 Examples of interventions to support innovation in the UK fintech sector

Supply side Capital	Supply side Networks	Supply side Infrastructure
Santander InnoVentures fund	FinTech Innovation Lab	Financial Conduct Authority regulatory sandbox
HSBC Fintech Fund	Barclays Accelerator progamme	Open Banking Initiative

Source: RAND Europe analysis. Note: This is not an exhaustive list of the interventions considered.

Partnering between incumbent institutions and fintech companies has increased

Incumbent financial institutions have increasingly sought to collaborate with fintech companies that can provide access to innovation and technological expertise. A recent survey found that the number of incumbents partnering with fintech firms rose from 32 per cent in 2016 to 45 per cent in 2017, while 82 per cent of incumbents expected to enter into more partnerships with fintech firms in the coming years.[378] However, the literature reviewed did not identify any examples of such partnerships being driven by policies to support collaboration or innovation network policies of the type described in Section 2.5 of this report. This is in keeping with the finding from the literature that most interventions in fintech are initiatives taken by private firms rather than through public policy.

[378] PwC (2017c).

Fintech has attracted increasing investment in recent years

The literature reviewed did not provide any examples of direct public support for innovation in fintech of the type identified in Section 4.1 of this report. However, private start-up financing for fintech firms has increased over the past decade, with one study estimating that it grew from US$930m (£704m) in 2008 to US$2.97bn (£2.25bn)[379] in 2013.[380] In particular, venture capital funding for fintech has undergone rapid growth, rising three times faster than venture capital funding overall between 2008 and 2013.[381] Santander (InnoVentures) and HSBC (Fintech Fund) are among those that have set up venture capital funds dedicated to fintech,[382] while Japan's three largest banking groups in the country have established similar funds.[383]

Regulations and standards have been revised to promote fintech innovation

Various efforts have been made to create a supportive regulatory environment for fintech innovation. Among the limited number of UK examples in the literature is the Open Banking initiative, led by the Competition and Markets Authority. This initiative requires fintech companies to make it possible for financial transactional data to be shared online, allow third parties to make bank transfers directly from their bank account as an alternative to credit or debit cards, and to make product information and customer satisfaction scores available.[384] Other countries which have sought to create a supportive regulatory environment include Japan, which has revised legislation that prevented banks from owning more than 5 per cent of voting rights in non-financial companies. The previous rule had blocked collaboration between banks and fintech firms that fell into the non-financial category.[385]

As well as introducing or changing regulations to facilitate fintech innovation, the UK and other countries have created various initiatives to help fintech firms navigate existing rules. The UK's Financial Conduct Authority offers an advice unit to provide fintech firms with regulatory feedback and consolidates findings from previous fintech projects to disseminate lessons learned.[386] Similarly, Japan's Financial Services Agency has established a Fintech Support Desk to help fintech companies navigate legal and regulatory issues.[387] Regulatory sandboxes, such as the Regulatory Sandbox set up by the UK Financial Conduct Authority (see Box 14 below), allow fintech innovators to conduct testing in a regulated space and are aimed at: reducing the time needed to exploit and commercialise ideas; attracting investment due to the reduction of regulatory uncertainty for investors; and facilitating the integration of products into the

[379] Exchange rate as of 26 June 2018. Source: XE (2018).

[380] Shaughnessy (2015).

[381] Shaughnessy (2015).

[382] BNY Mellon (2015).

[383] Yeandle (2017).

[384] EY (2017a).

[385] Yeandle (2017).

[386] EY (2017a).

[387] Yeandle (2017).

market according to appropriate standards and regulations. In the UK, a report by the Financial Conduct Authority indicates that the sandbox model is providing the envisaged benefits it set out to achieve.[388]

Box 14 FCA Regulatory Sandbox

The regulatory sandbox was launched in 2015 by FCA (Financial Conduct Authority) Innovate. It aims to promote greater competition in the interests of consumers by allowing firms to test innovative products, services and business models in a live market environment, while ensuring that appropriate safeguards are in place.

The sandbox seeks to provide firms with:

- The ability to test products and services in a controlled environment.
- Reduced time and cost in getting innovative ideas to market.
- Support in identifying appropriate consumer protection safeguards to build into new products and services.
- Greater access to finance.

An initial 'lessons learned' report, published one year after the launch of the sandbox, provides an early indication that it has been successful in meeting the above objectives.[389]

Innovation incubators, accelerators and hubs aim to support fintech innovation

A number of incubator and accelerator initiatives have been established to provide early-stage innovation support in fintech. These fall under the category of interventions to support collaboration. Examples include: the global FinTech Innovation Lab, which seeks to build relationships between start-ups and big banks; and Barclays' Accelerator Progamme, which gives start-ups office space and access to data from Barclays.[390] FinTech Scotland is an organisation established in 2017 that provides funding and also facilitates collaboration between government, academia and industry stakeholders in fintech to foster knowledge exchange and develop skills.[391] In Japan, initiatives such as Mitsubishi UFJ Bank's acceleration programme provide fintech start-ups with support, including mentoring, workspace, training and networking events.[392]

[388] FCA (2017).

[389] FCA (2017).

[390] BNY Mellon (2015).

[391] FinTech Scotland (2018).

[392] Yeandle (2017).

Box 15 FinTech Scotland

FinTech Scotland[393] was established in 2017 by the Scottish government, industry (led by the Scottish Financial Enterprise) and the University of Edinburgh to represent Scotland's fintech community. FinTech Scotland's aim is to ensure that Scotland remains at the forefront of fintech innovation.

FinTech Scotland seeks to build connections between multiple stakeholders, including fintech companies, financial institutions, investors, public organisations, schools and universities, to enable the fintech innovation system to thrive. Through these networks, the organisation provides access to funding, infrastructure for the fintech community and access to fintech talent. It also seeks to develop talent in fintech.

E.4. Understanding of the effectiveness of interventions

A search of the grey literature on fintech did not find any attempt to evaluate the effectiveness of interventions to promote innovation in the sector. One report sought to compare the attractiveness of a number of cities as centres of the fintech sector. However, the report looked at the overall conditions that have enabled the growth of the sector, rather than evaluating specific interventions, and did not focus on innovation.[394]

There is a lack of evidence on innovation metrics for fintech

In the absence of any evaluations of interventions targeting innovation in fintech, a review of the literature on the sector found no evidence of any attempt to establish metrics to assess the effectiveness of such interventions. However, one report sought to define a set of characteristics to be used as metrics to quantify the attractiveness of a given location as a hub of fintech innovation. Drawing on established indices of business performance, the report produced a consolidated index for scoring a location based on factors including availability of talent, levels of investment, regulatory environment and government support for fintech innovation.[395] A second report proposed a similar set of indicators to quantify innovative capacity at the level of individual organisations. These include externalisation of processes (i.e. the ability to crowdsource knowledge and ideas) and thought leadership and strategy (including design thinking and the incorporation of feedback loops).[396]

Another report, which studied the overall attractiveness of a number of cities as fintech hubs, used a range of quantitative metrics to measure conditions that enable growth in the sector. Although the report did not focus specifically on innovation, several of the metrics used are relevant to innovation. For example, regarding the availability of fintech talent, the report compared the number of people employed in fintech in each location and the length of time taken for foreign fintech workers to obtain a visa. The report also

[393] FinTech Scotland (2018).

[394] EY (2016).

[395] Deloitte (2016).

[396] Shaughnessy (2015).

measured the availability of financing by comparing the respective levels of investment in fintech in each location.[397]

The timeline for the translation process

The literature reviewed did not provide any evidence on the timelines associated with the fintech translation process. Similarly, the lack of evaluations means there is no evidence around the time lags associated with policy interventions. However, innovation in the fintech sector revolves around data and therefore this suggests it is a relatively fast-moving industry.

Barriers that still need to be addressed

Regulation can constrain fintech innovation by both incumbent institutions and start-ups

Incumbents are generally viewed as being the hardest hit by regulatory barriers to innovation in fintech. A survey found that regulations relating to digital identity authentication and anti-money laundering measures are seen as blocking fintech innovation.[398] However, start-ups can also find their innovative activities stifled by regulation. For example, innovative lending services are subject to regulations that did not foresee their development.[399] Similarly, the US Federal Deposit Insurance Corporation's proposed controls on third-party lenders have the potential to discourage partnerships between incumbent banks and fintech lenders.[400]

Legacy infrastructure is often a barrier to fintech innovation

Legacy IT and payments infrastructure is viewed as a major constraint on innovation in incumbent financial institutions.[401] The financial services sector has a relatively high level of IT spending as a proportion of revenue, but it is estimated that over three quarters of that spending goes towards maintaining existing systems rather than developing new services.[402]

Cultural differences hamper collaboration between incumbents and fintech start-ups

Partnering is not traditionally seen as a strength of financial institutions,[403] with one survey finding that only 28 per cent believe they are good at collaborating with start-ups on innovative products.[404] One explanation for this is that innovation within incumbents is constrained by a bureaucratic culture that has developed over many years, whereas fintech companies are able to be more agile.[405] It has also been argued

[397] EY (2016).

[398] PwC (2017c).

[399] Knight (2018).

[400] Knight (2018).

[401] BNY Mellon (2015); PwC (2017c).

[402] BNY Mellon (2015).

[403] World Economic Forum (2017).

[404] Schindler (2017).

[405] PwC (2017c).

that partnering is made more difficult by differing levels of appetite for risk between incumbents and start-ups, with the former becoming more risk-averse since the financial crisis.[406]

A lack of skilled personnel can hold back fintech innovation

A survey found that 80 per cent of incumbent banks and fintech companies have difficulty recruiting and retaining people with innovation skills. The same study suggested that fintech firms face the challenge of attracting people who could join an established tech business with a higher profile and better salaries.[407]

[406] Deloitte (2016); PwC (2017c).

[407] PwC (2017c).

Annex F. The creative economy

This Annex provides detailed evidence on the conditions needed to translate research and drive innovation in the creative economy.

The creative sector is a vital part of the UK economy. According to the creative industries sector deal, in 2016 the creative industries contributed almost £92bn to the UK economy and employed over 3 million people.[408] The sector accounts for at least 9.7 per cent of the UK's Gross Value Added (GVA).[409] It represents one of the UK's fastest growing sectors, having increased its GVA by 7.6 per cent in 2016, more than twice as fast as the average 3.5 per cent growth rate in this measure across the UK economy.[410] Understanding the innovation process in this sector offers an insight into a significant and fast-growing sector that is less well understood than some of the more technological, R&D intensive sectors.

F.1. The depth of understanding of the innovation system

Due to the low availability of academic literature on innovation in the creative economy, the analysis of this sector draws significantly on grey literature, expert interviews and a workshop.

The term 'creative economy' emerged in the UK as the government sought to reframe discussions on the economic value of the creative industries and the range of activities that the creative sector encompasses (see Figure F.1 below) to acknowledge the spectrum of relevant actors to the creative economy – including actors with small-scale structures and unconventional working practices.[411] In the creative economy, products tend to be services or experiences, so innovation in this sector has been scarcely theorised.[412] Due to the low availability of academic literature, this section of the report draws significantly on grey literature and expert insights.

[408] HM Government (2018b).

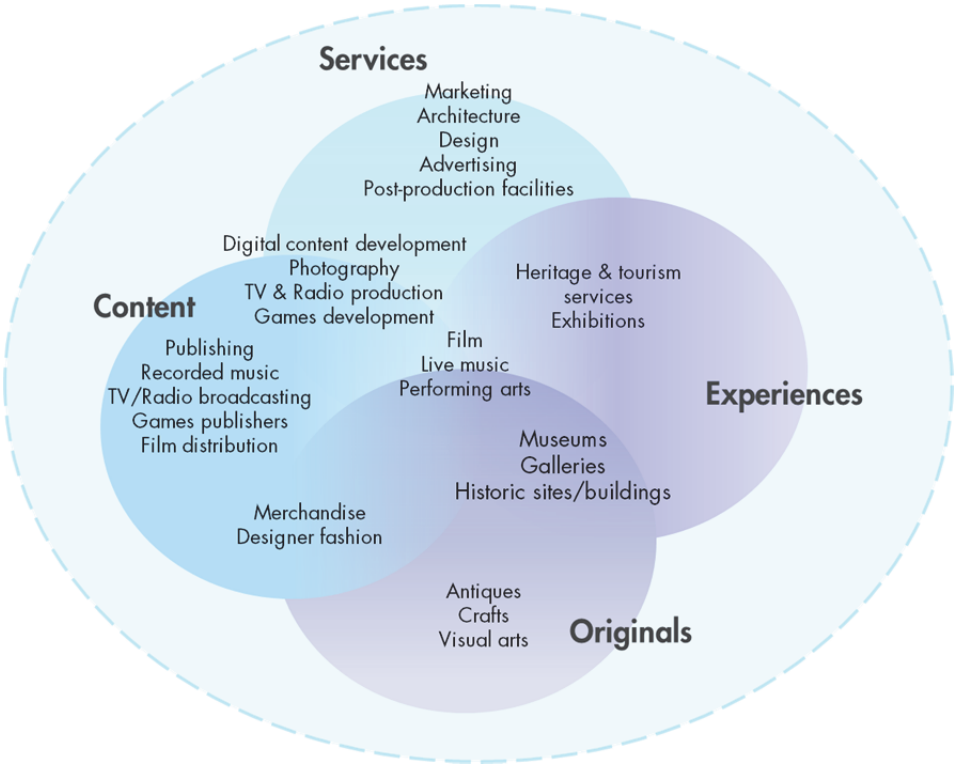
[409] DCMS (2017b).

[410] DCMS (2017b).

[411] British Council (2010).

[412] Granados, Bernardo et al. (2017).

Figure F.1 Examples of industries and economic activities in the creative economy



Source: Based on the British Council's Creative Business Models Framework.[413]

Translation pathways

The creative economy encompasses a broad range of industries and creative activities which, in turn, are just as diverse in terms of company structures, turnover, employment, markets, distribution channels and business models. The sector does not possess a one-size-fits-all translation pathway and innovations in this sector were described in the workshop as spontaneous, accidental and 'organic'.[414] In contrast to the defence and pharmaceutical sectors, innovation in the creative economy is rarely mission-oriented.

During the workshop discussion, participants identified a range of distinguishing features that make innovation in the creative sector unique and highly dynamic. Innovation in the creative sector was described to be driven by novelty, given swiftly changing consumer tastes.[415] The creative economy produces symbolic, experiential, aesthetic and expressive value and content, as well as tangible products. Value propositions in this sector include both economic and cultural value.[416]

Alternative concepts of innovation translation have been proposed in this sector. Granados et al. (2017)[417] posit that the innovation process in the creative economy is an integrated process that is not separated by

[413] British Council (2010).

[414] EKOS Limited (2017).

[415] RAND Europe workshop, 18 April 2018; EKOS Limited (2017).

[416] RAND Europe interview with creative economy expert, 23 May 2018; Crossick & Kaszynska (2016).

[417] Granados, Bernardo et al. (2017).

various stages, but instead has several micro-processes. There is an *ambiguous phase* that relates to idea exploration, and a *linear phase* when it comes to idea exploitation.[418] The ambiguous phase is depicted as a series of opportunistic and accidental activities.[419] In contrast, the linear phase is relatively more sequential and related to administrative and commercialisation processes.

Among the various industries within the creative economy, the video game industry is sometimes described as the industry whose innovation translation pathway most closely resembles traditional innovation pathways (see Box 16 below), but it is often seen as atypical for innovation in the creative industries.

Box 16 Innovation translation in the video games industry

The video games industry is growing rapidly, has a large talent and skills base in the UK and has high absorptive capacity. The industry's reputation for rapid innovation comes as a result of continuous consumer demand for novel products. The UK video games industry is set to grow at 6.1 per cent by 2022 and contributes £2bn to GDP. The industry employs over 21,000 developers in the UK and generates enormous high-paid employment. The video game industry's ability to adapt and change is considered to be very good; however, due to these rapid innovation patterns, this sector is known to be a 'rollercoaster industry', with no guaranteed success for SMEs.

The conditions that allow the video game industry to thrive include: high access to talent, networks, digital interconnectedness and low regulation. The UK has high access to talent due to the high number of games courses and the number of people gradating with video games degrees. There is a network of good conferences that the top talent in the industry conglomerate in to share ideas or explore potential collaborations. Increasing interconnectedness through digital technology is democratising access to tools for ordinary people to be involved in the innovation translation process. Regulations on the video game industry are light in the UK and the industry's main concern is to stay unencumbered.

Source: RAND Europe interview with gaming expert, 31 May 2018.

The key conditions for innovation

During the workshop, the major enablers that emerged for the creative economy were capital, talent, networks and a high degree of connectivity. Access to equipment and technology was perceived by workshop participants to be less important than access to digital infrastructure and online connectivity (see Box 17 below highlighting the growing importance of immersive technology).[420]

The high availability of talent is a major contributor to innovation in the creative economy

Talent and individual creativity feature strongly in the creative sector. The UK has a very strong creative workforce, employing over three million people in the creative economy.[421] However, there is increasing

[418] Granados, Bernardo et al. (2017).

[419] Granados, Bernardo et al. (2017).

[420] RAND Europe workshop, 18 April 2018; DCMS (2018); Oliver & Ohlbaum Associates Ltd and Analysys Mason (2017).

[421] HM Government (2018b).

recognition that the pace of skills needs is overtaking the availability of skills,[422] and that a larger and more diverse talent pool is required.[423] This partly stems from inadequate provision in schools, which often promote STEM subjects at the expense of creative subjects.[424] In addition to this, individuals with the right combination of skills are also needed. The creative sector is highly interdisciplinary, relying upon creative talent, but also digital, STEM and business/entrepreneurial skills. For example, a game project typically requires producers, game designers, sound engineers, composers and actors.[425] The sector has also changed rapidly with the advent of digital, leading to demand for a range of skills, such as computer programming skills.[426] The importance of maintaining a balance between different skills was demonstrated by the Arts and Humanities Research Council's Brighton Fuse project.[427] Creative companies often have difficulty recruiting due to a shortage of supply of individuals with the right combination of skills.[428] In response to these issues, there is recognition that the creative sector could benefit from an industry-led skills system.[429] The creative sector also relies on movement of skilled individuals from the EU, as well as the rest of the world, and there are strong concerns that the skills shortage will be compounded by the UK's exit from the EU.[430]

Creative industries often encounter challenges accessing capital

Generally, the creative sector is faced with limited access to funding. Creative businesses are typically small and face various resource constraints.[431] Given that there is limited data and market intelligence that would illustrate the growth potential of investments, venture capital's appetite for investment in this sector is low.[432] The insufficient availability of capital, in turn, inhibits the growth of enterprises. Crowdsourced funding platforms such as Patreon or GoFundMe present alternative funding mechanisms and are more commonly used in this sector than traditional manufacturing industries.[433]

The strong presence of collaborations is particularly supportive of innovation in the creative economy

The creative sector relies on networks and collaborations that that are typically cross-sectoral (for instance, between art and design, computer science and architecture, robotics and dance, banking and gaming, and

[422] RAND Europe interviews with creative experts, 23 May 2018; 29 May 2018; 31 May 2018.
[423] HM Government (2018b).
[424] Creative Industries Federation (2016).
[425] Miles & Green (2008).
[426] Nesta (2013).
[427] The Brighton Fuse (2016).
[428] Creative Industries Federation (2016).
[429] HM Government (2018b).
[430] Creative Industries Federation (2017).
[431] EKOS Limited (2017).
[432] RAND Europe workshop, 18 April 2018; BIS & DCMS (2011).
[433] RAND Europe workshop, 18 April 2018; Bone & Baeck (2017).

many others).[434] The UK's creative workforce is relatively large and some link this to the UK traditionally having been a culturally open country.[435]

Box 17 The immersive economy

The impact of digital technology on the creative sector can be seen in the growing importance of the immersive sector to the UK creative economy. Immersive technologies, which include virtual reality, augmented reality and mixed reality, are helping to create new experiences for users through enhanced environments.

An immersive economy report by Innovate UK[436] confirmed that the UK is at the forefront of this sector, which is rapidly growing. There are around 1,000 immersive specialist companies in the UK employing around 4,500 people and generating £660m in sales, which potentially represents as much as 9 per cent of the global market share.[437] PwC forecasts the UK virtual reality entertainment and media market will be worth £801m by 2021.[438]

The UK government has recognised the importance of immersive technologies to the creative sector and is investing £33m in immersive technology products, services and experiences as part of the Creative Industries Sector Deal.[439]

Absorptive capacity

There were mixed signals in the literature regarding the creative economy's capacity for innovation. Some sources said that there are low or variable levels of absorptive capacity in the creative economy.[440] Other sources stipulate that the creative economy is constantly innovating, linking creativity with technology and developing novel and exciting products and new ways to engage with new products and new ways to engage growing audiences.[441]

F.2. Measuring impacts from research and innovation

Intellectual property protection such as copyrights are used in the creative economy, but measuring their impacts, for example through patent analysis, can only provide limited value as many disciplines within the creative sector do not ever produce outcomes that generate intellectual property.[442] These areas may

[434] Weckerle et al. (2016).

[435] RAND Europe interview with creative expert, 23 May 2018.

[436] Innovate UK (2018).

[437] Innovate UK (2018).

[438] PwC (2017b).

[439] BEIS & DCMS (2018).

[440] EKOS Limited (2017).

[441] HM Government (2018a).

[442] Le Bas & Sierra (2002).

still generate commercial or societal value, but intellectual property analysis alone would not be able to provide accurate measures for the contribution of innovation in the creative economy.

In traditional measures of R&I, the cultural impact generated by the creative economy is perceived as a contributor to the economy, but typically is not ascribed as a value in its own right.[443] One study suggested the use of case studies, interviews, bibliometric surveys and workshops to gain an understanding of the cultural impact of research.[444]

F.3. Understanding of interventions to support innovation

Interventions in the creative economy comprise both supply-side and a combination of supply and demand-side interventions.

The majority of creative economy interventions involve increasing access and visibility of funding mechanisms

As access to funding at early stages is particularly challenging in this sector, there are a number of schemes that either seek to provide access to grant funding or that provide tax reliefs. The UK Department for Digital, Culture, Media & Sport and the Department for Business, Energy & Industrial Strategy launched a £150m fund to support cultural and creative businesses.[445] The UK Games Talent and Finance CIC was established to help develop the UK games development sector at early stages of development.[446] The Arts and Humanities Research Council has allocated £80m to support eight new creative research and development partnerships as part of the Government's Industrial Strategy Challenge Fund.[447]

Innovation vouchers are used to support creative SMEs

Many interventions are aimed specifically at SMEs. For example, innovation vouchers typically promote the use of services by creative industries (see Box 18 below for an overview of innovation vouchers). The City of Manchester piloted the Creative Credits scheme, during which 150 SMEs received £4,000 worth of credits to purchase a range of services.[448] In Baden-Württemberg in Germany, the government launched innovation vouchers for SMEs, with one category specifically allocated for the creative sector called innovation voucher C (Kreativgutschein). The scheme provided €5,000 for microbusinesses and self-employed individuals in the cultural and creative sector to access research and development services.[449]

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[443] RAND Europe workshop, 18th April 2018; Crossick & Kaszynska (2016).

[444] Krapels et al. (2015).

[445] HM Government (2018a).

[446] UK Game Fund (2018).

[447] AHRC Creative Economy Programme (2018).

[448] Coletti (2014).

[449] Coletti (2014).

Box 18 Innovation vouchers

Innovation vouchers[450] are small amounts of funding provided by the government to enable SMEs to access external expertise, typically from public research institutions. Vouchers allow SMEs to use the expertise of knowledge organisations (this can include universities, research institutes, Catapult centres, intellectual property advisers and design advisers) to introduce innovation to their products or processes. The vouchers provide incentives for SMEs to engage with external experts, which is important as small businesses often have limited resources for investment in innovation and knowledge transfer.

Innovation vouchers therefore have several advantages: they act to increase the R&D and innovation capabilities of SMEs by fostering collaboration with public research institutions and improving knowledge transfer; and they provide an incentive for public knowledge providers to work with SMEs. Innovation vouchers also enhance the awareness at knowledge institutions of the need for knowledge, and therefore signal the quality and societal relevance of public research.

In the UK there are a number of voucher schemes, including from government (Innovate UK) and by individual universities. These range in value from £1,000 to £40,000, although a typical voucher is worth around £5,000.

An analysis by Universities UK of previous innovation voucher schemes in the UK found indications that such schemes have been successful so far. The analysis found that it was highly unlikely that benefits to businesses and universities would have been realised without the voucher schemes. Furthermore, some two-thirds of businesses had obtained (or were likely to) further support from universities following their use of the vouchers.

Business coaching and educational interventions seek to drive up entrepreneurial thinking and business acumen in the creative economy

Some sources say that a lack of management and commercial vision is characteristic of the creative sector.[451] Some educational initiatives seek to instil entrepreneurial skills from the tertiary education stages. In Liège, Belgium, the ID Campus facilitates project collaborations between industry and creative students.[452] Les Réalisateurs in Nantes, France, is an art program that seeks to create opportunities for artists to produce artwork with the support of other artists and businesses.[453] The UK's Creative Enterprise Programme by Nesta[454] and the British Council Creative Economy[455] involves face-to-face workshops aimed at equipping creative entrepreneurs with the skills and confidence required to translate the commercial value of their ideas.

[450]Universities UK (2014).

[451] Granados, Bernardo et al. (2017).

[452] ID Campus (2018).

[453] ID Campus (2018).

[454] Nesta (2018a).

[455] British Council (2014).

Some interventions have targeted particular geographic areas with strong innovation potential

Designating a special status to particular areas is aimed to facilitate place-sensitive innovation support to creative cities.[456] In Romania, Iaşi was designated the status of a potential 'creative city' by a multinational project that was funded by the British Council in South-Eastern Europe.[457] The UK identified England's West Midlands region as an area where the Screen, Image and Sound industries were exhibiting strong growth in business formation and high levels of innovation, particularly in the video game industry.[458]

Collaborations in the creative economy are supported by innovation incubators and conferences

Some interventions are geared at supporting the forging of networks between potential collaborators through partnerships, innovation incubators or conferences. In Linz, Austria, ARS Electronica/Living Lab was established to support interactions between the museum, its content and events to the wider innovation community – involving collaborations for knowledge transfer of societal relevance in art and science.[459] The New Factory in Finland connects entrepreneurs, local universities, academics and investors, and creates multidisciplinary teams that seek to support companies find innovative solutions and students to develop entrepreneurial thinking.[460] The EU's Creative Europe programme involves events and conferences that seek to establish the cross-sectoral relationships needed to support innovation.

Specialised incentives for the creative sector are required

As the sector sits outside the traditional industries, it is argued that there is a need for targeted incentives that the range of industries within the creative sector can access.[461] The UK provides tax relief for a range of sectors, including: the Film Tax Relief, Animation Tax Relief, High-End Television Tax Relief, Children's Television Tax Relief, Video Games Tax Relief, Theatre Tax Relief, Orchestra Tax Relief and the Museums and Galleries Exhibition Tax Relief (see Table C.5 below).[462]

F.4. Understanding of the effectiveness of interventions

Few interventions in the creative economy have been evaluated, which has led to a lack of robust, evidence-based information on the impacts of policies in this area. Indeed, one of the recommendations the UK Creative Industries Council set out in its Creative Industries Strategy is to develop and promote a

[456] DCMS (2006).

[457] British Council (2010).

[458] British Council (2010).

[459] ARS Electronica (2018).

[460] New Factory (2017).

[461] RAND Europe workshop, 18 April 2018.

[462] HM Revenue & Customs (2018).

toolkit and framework that could lead to more effective evaluations of creative businesses.[463] Nevertheless, a few interventions were identified in the literature review to have had positive impact on creative businesses. For example, as a result of the Creative Industry Finance Pilot Programme in London and Yorkshire and the Humber, creative business growth was £1m.[464] Evaluation surveys showed an increase of annual revenue turnover by 47 per cent, with 19 per cent of companies reporting an increase of more than 10 per cent.[465] In addition, 55 per cent of companies reported an increase in clients.[466] Creative businesses that were previously refused debt finance by banks were able to access additional finance of £486,000 through the Creative Industry Finance Pilot Programme.[467] The evaluation of Manchester's Creative Credits scheme found that the award of a Creative Credit increased the likelihood of SMEs and creative businesses working together by about 84 per cent.[468] The UK's Video Games Tax Relief scheme enabled video game developers to transition away from work-for-hire and into developing their own original games and was felt to improve the likelihood of a culturally British or European game reaching the marketplace.[469] Since the UK's TV tax relief scheme, there has been an increase in production of around £1.5m since the scheme was introduced. [470]

Currently available metrics do not sufficiently capture innovation in the creative economy

Capturing information on innovation in the creative economy is challenging due to the various informal, small-scale transactions that contribute to innovation, but are not captured in a systematic manner.[471] Moreover, relative to the pharmaceutical/life sciences and defence sectors, knowledge inputs for creative sector innovation tend to rely less on formal R&D. Although translation in this sector draws on research, it rarely involves maturing an idea against a set of standards.[472]

[463] Create UK (2014).
[464] Tom Fleming Creative Consultancy (2014).
[465] Tom Fleming Creative Consultancy (2014).
[466] Tom Fleming Creative Consultancy (2014).
[467] Tom Fleming Creative Consultancy (2014).
[468] Bakhshi, Edwards et al. (2013).
[469] Pettigrew et al. (2017).
[470] British Film Commission (2013).
[471] EKOS Limited (2017).
[472] EKOS Limited (2017).

Table F.1 Examples of interventions to support innovation in the UK creative sector

Supply side	***Supply side***	***Supply side***	***Supply side***	***Demand & supply side***
Capital	**Networks**	**Talent**	**Infrastructure**	**Structures**
UK's High-end Television Tax Relief	Creative and cultural skills sector skills council	Creative Skill Set scheme	Creative Sheffield	Skills Development Scotland's Creative Industries Skills Investment Plan
UK's Video Games Tax Relief	Skillfast-UK sector skills council	Creative Enterprise Programme		Creative Europe programme
UK Theatre Tax Relief	Creative Economy Knowledge Exchange partnership			British Board Film Classification
Creative Industry Finance Pilot Programme	AHRC Knowledge Catalyst scheme			
UK Games Talent and Finance CIC	REACT in Bristol			
UK Film Tax Relief				
Children's Television Tax Relief				
Orchestra Tax Relief				
Museums and Galleries Exhibition Tax Relief				
Animation Tax Relief (n.d.)				
Manchester's Creative Credits				

Source: RAND Europe analysis

Note: This is not an exhaustive list of the interventions considered.

Innovation surveys could capture innovation in the creative sector through the introduction of better sampling techniques that are geared for the creative economy.[473] Furthermore, innovation surveys currently do not measure the value creation that takes place in the creative sector because questions focus on the activities of large organisations and downplay non-technological innovation.[474] There may be a case for more specialised surveys that specifically target the creative sector, given the unique set of circumstances that comprise innovation in this sector.[475] Surveys such as the Community Innovation Survey, conducted by EU Member States, are based upon industry sectoral classifications, so do not provide good indication of *creative activities* as opposed to *creative industries*.[476]

Some existing databases that could be drawn upon to provide partial data on innovation in the creative economy include the Department for Digital, Culture, Media and Sport Economic Estimates,[477] Office for National Statistics Business Demography and UK Business: Activity, Size and Location. Growth in the percentage of the workforce in creative occupations, increased creative industries' share of UK employment and increased number of enterprises could be used as indicators for innovation in this sector.[478]

Timelines for the translation process

Innovation in the creative sector often operates on relatively fast timelines. This is particularly true in the video games industry, often due to continuous consumer demand for novel products.[479] This can result in mismatched timescales between industry and the academic sectors.

Barriers that still need to be addressed

The economic value of the creative economy is underappreciated

During the workshop, a recurring theme that emerged was how the commercial value of the creative economy remains undervalued by actors across the creative economy innovation ecosystem as an area for commercial exploitation. For example, the design industry mixes technological and aesthetic knowledge, but design is often seen as a secondary activity to product development and innovation.[480] Investors often underestimate the creative economy's market potential and, simultaneously, people working in the creative economy tend to underestimate the commercial value of their products and services and therefore do not seek out to monetise them.[481] In some cases, creatives may fundamentally seek to limit growth, as

[473] Miles & Green (2008).

[474] Miles & Green (2008).

[475] Miles & Green (2008).

[476] Miles & Green (2008).

[477] DCMS (2017a).

[478] Create UK (2014).

[479] RAND Europe interview with gaming expert, 31 May 2018; Accenture (2014).

[480] Miles & Green (2008).

[481] RAND Europe workshop, 18 April 2018; The Council of the European Union (2015).

growth of the organisation is not seen as a desirable outcome,[482] which could therefore disincentivise innovation.

The tension between the creative process and management tasks can create friction between artistic and commercial satisfaction in the innovation translation process

The counteracting pressures of the creative and management can be one of the biggest challenges to translation when both forces limit growth or creativity. There are also entrenched cultural and language barriers across the diverse range of industries in this sector, which create practical barriers to collaborations of mixed teams and disciplines.[483]

Formal innovation management systems in the creative economy are rare

A study by Miles and Green (2008)[484] found that many creative businesses struggle to formalise systematic innovation processes as the great majority of ideas are generated spontaneously and on an ad hoc basis. This could potentially enable innovation by freeing agents in the creative economy from burdensome structures that can slow or impede innovation, but equally, it can also result in a lack of data gathering mechanisms that could help to identify good practice and areas of weakness. For example, in the video games industry, the implication of the spontaneous generation of ideas is that there are difficulties anticipating demand.[485] There is little evidence of much use of formal R&D, even in industries that are more commonly associated with technology development. There is also little availability of formalised metrics, as no systematic monitoring of innovation in these industries takes place. Due to the fragmentation of actors, and the recognition of the commercial value of creations taking place after innovation translation is already underway, support in this sector tends to be reactive.[486]

As a result of the lack of formalised management systems, there is a lack of data and metrics for innovation in this sector and investors find it difficult to assess risk, which disincentivises much needed investment.[487] Moreover, there is a risk that the lack of evidence on effective interventions to support innovation in this sector could lead to more short-term, knee-jerk and non-evidenced interventions.[488]

[482] RAND Europe interview with creative expert, 13 June 2018.

[483] ECIA (2018).

[484] Miles & Green (2008).

[485] Miles & Green (2008).

[486] EKOS Limited (2017).

[487] Create UK (2014).

[488] Create UK (2014).