Department
for Business
Innovation & Skills

THE CASE FOR PUBLIC SUPPORT OF INNOVATION

At the sector, technology and challenge area levels

JULY 2014

Produced by Technopolis Ltd for the Department for Business, Innovation and Skills. This study was co-funded by the Technology Strategy Board (TSB).

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Contents

List of Tables

List of Figures

Executive Summary

Introduction

This study sets out the barriers to innovation in 24 areas of economic interest, and in doing so outlines the rationale for public support for innovation at the sectoral level. The study was carried out by Technopolis and commissioned by the Department of Business, Innovation and Skills (BIS), and co-funded by the Technology Strategy Board (TSB).

Outline of the study

A typology of market and system failures

The first part of the study constitutes a review of the literature on different categories of issues that have been identified as inhibiting innovation in the absence of public support. Generally falling into two groups – market failures and system failures – the review found a considerable degree of variation in terms of the number and scope of categories identified by various authors. The range of categories outlined in the literature, stretching from those rooted in neoclassical economic theory (indivisibility, externalities, etc.) to much more socially and culturally grounded obstacles (capability failures, image problems, skills shortages, etc.), was ultimately condensed into a set of eight categories to be used for the remainder of the study:

- Character of science and technology: The size of scientific or technological problems is too great for individual private actors to tackle if markets are competitive, and may be accompanied by uncertainty, making it hard for the private sector to invest. It may be that innovation only yields return in the long run, hampering investment

- Market power: This can lead to, or be caused by, for example, the first supplier or user building insurmountable advantage, and may lead to consumer lock-in. More generally, high cost of market entry/exit

- Externalities: It is too hard to appropriate enough of the results of research or innovation to make private investment worthwhile. Innovation may depend upon the presence of external networks, which are beyond the means of innovators to create; innovation is easy for competitors to copy and there are limited opportunities to protect new ideas

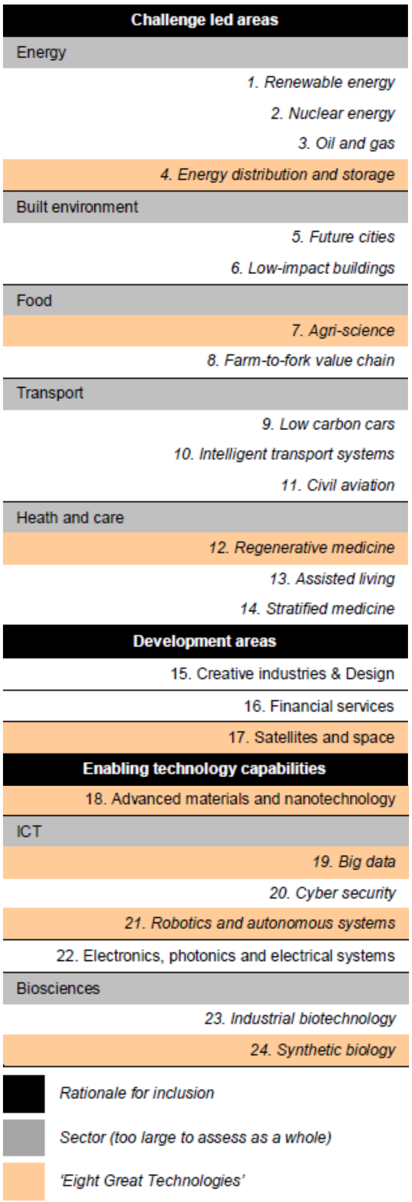
- Information asymmetry: High levels of specialised technical and/ or market knowledge mean that not all the economic actors involved have the basis for making informed decisions

- Capability Failure: These failures result from the difference between the capabilities of real firms and those assumed in the idealised economic model, so that firms lack needed skills, resources, ability to learn, absorptive and analytic capacity or otherwise to capture innovation opportunities

- Network Failure: Networks are fragmented and/or broad; communication and cooperation within networks are poor. Networks may be locked in to technological regimes, markets or products by their history and capabilities and find themselves unable to transition into new technologies or businesses

- Institutional Failure: Institutions (whether in the sense of ‘organisations’ or ‘rules and conventions’) operate in ways that impede innovation. Rules and regulation are not conducive to innovation and technological development. Government policy has the same effect

- Infrastructural Failure: Insufficient human and capital investment in infrastructures critical to innovation performance by the state



■	**Challenge led areas**
▨	Energy
	1. Renewable energy
	2. Nuclear energy
	3. Oil and gas
🟧	*4. Energy distribution and storage*
▨	Built environment
	5. Future cities
	6. Low-impact buildings
▨	Food
🟧	*7. Agri-science*
	8. Farm-to-fork value chain
▨	Transport
	9. Low carbon cars
	10. Intelligent transport systems
	11. Civil aviation
▨	Heath and care
🟧	*12. Regenerative medicine*
	13. Assisted living
	14. Stratified medicine
■	**Development areas**
	15. Creative industries & Design
	16. Financial services
🟧	17. Satellites and space
■	**Enabling technology capabilities**
🟧	18. Advanced materials and nanotechnology
▨	ICT
🟧	*19. Big data*
	20. Cyber security
🟧	*21. Robotics and autonomous systems*
	22. Electronics, photonics and electrical systems
▨	Biosciences
	23. Industrial biotechnology
🟧	*24. Synthetic biology*
■	*Rationale for inclusion*
▨	*Sector (too large to assess as a whole)*
🟧	*‘Eight Great Technologies’*

Barriers to innovation in 24 selected areas

These eight categories of issues were then used in the analysis of 24 substantive contexts, in order to categorise and classify the barriers to innovation highlighted in each of them. The 24 ‘innovation areas’ were chosen, as they reflect priorities of a number of key bodies, most notably BIS, the Technology Strategy Board (TSB) and the European Commission (EC). More specifically, the selected areas are of importance for one of three key reasons:

- Challenge-led areas: these are sectors that are relevant to several social, political and economic needs of a society. Successful innovation in these areas therefore has the capacity to generate a broad range of positive knock-on effects and contribute directly to a society’s overall wellbeing.

- Development areas: These are areas where the UK is already acknowledged to have exceptional strength. As particularly likely sources of future economic growth, removing barriers to innovation is of exceptional importance here.

- Enabling Technology capabilities: These are areas centred on general-purpose technologies, which have been identified as promising and may find application in any number of important sectors. As such, successful innovation in these areas has the potential to spawn further innovation and growth across all sectors where application might be possible.

It was additionally ensured that the ‘Eight Great Technologies’, highlighted on several occasions by David Willets and the Policy Exchange think tank, all feature among the selected innovation areas. In large part, the Eight Great Technologies fall under the heading of Enabling Technology Capabilities, though where possible, they have been used to illustrate problems encountered in Challenge-led and Development areas.

For each of the 24 areas, a review was then conducted, drawing on a range of sources including academic research, government reports (national and EU level), and reports from the sectors / industries themselves. Barriers to innovation identified in the literature on each area were then compiled into a template, placing descriptions of each barrier under one of the eight categories identified in the first part of this study.

In some of the innovation areas, sophisticated efforts had already been made to collect and describe all the main barriers to innovation existing within them. In the energy sector, the Technology Innovation Needs Assessment (TINA) reports are examples of such efforts. Where such prior work existed, use of further literature was used mainly to verify the existing compiled findings, and to check if any further barriers might have been identified elsewhere. In other areas, no such prior efforts existed, meaning that the range of barriers to innovation needed to be drawn from across the full range of literature found.

The literature used to identify and describe barriers to innovation draws on diverse types of evidence, ranging from quantitative surveys and numerical sector analysis to interviews, focus groups, workshops, case studies, collected expert opinions and historical analysis. This diverse range of evidence types reflects the differences that exist between the eight types of innovation failure identified through the literature review in the first part of this report: some types of failure can be quantified (e.g. size of market players, numbers of skilled graduates), others are better explained in qualitative terms, through historical narrative, expert opinion and, occasionally, through common sense.

Comparing barriers

In order to move beyond highlighting a range of barriers, each identified barrier was ranked on a 5-point scale, in order to go some way to distinguish the more significant barriers from the less significant ones. In order to avoid subjective judgement of barriers, the scale used in this report is based not on qualitative but on descriptive criteria, where factors considered are limited to prevalence of each barrier in the literature, as well as each barrier’s conceptual capacity to slow down the innovation process as opposed to stopping it entirely:

- ‘No evidence found’: Used if the literature/ reports on the sector contain nothing of relevance to a particular category of failure

- ‘Slowing down (a little)’: If there is a barrier that is explicitly noted as being of minor significance in contrast to others in a sector, or if a particular barrier is noted as being only applicable to very specific types of products within a sub-sector, this caveat is added

- ‘Slowing down’: Used if a barrier does not prevent successful innovation altogether, but nevertheless noticeably hinders it in some form

- ‘Slowing down (a lot)’: If there is a barrier, which, though not a showstopper, is explicitly acknowledged in the literature as being an especially severe barrier, or is mentioned by all or almost all reports on the sector, the ‘a lot’ caveat is added to indicate heightened significance

- ‘Showstopper’: Used if the nature of a barrier is such that it effectively makes successful innovation completely or almost completely impossible

There are several caveats associated with the approach of this study, and especially with implementation of such scales. Though the approach used here has yielded many important findings, the following limitations should be kept in mind:

- Not having identified a given type of failure (categorized as ‘No evidence found’) does not provide a guarantee that a failure does not exist in a given area or sector. This study, as well as the overall literature, may have failed to document certain failures. A lack of evidence of failures may also be an indication that some innovation areas are more dynamic and fast-growing than others and, as a result, we identify fewer failures.

- There are several failures in various areas that currently slow down innovation but, as a result of technological change, it is expected that some of these barriers to innovation will disappear within the coming years. Though impossible to predict with certainty, the potentially temporary nature of some barriers needs to be kept in mind

- Despite emphasizing a descriptive approach, ratings of the significance of different failures are to an extent subjective, and the scale by which we propose to measure the failures is imperfect. The effect of the failure (showstopper vs. slowing down) does not reflect the degree to which a failure is critical to the innovative development of the industry. Specifically, failures that block the value chain of innovative processes that are key to further advancement in the industry can be considered more *critical* failures.

- In many of the innovation areas we found multiple failures within a single failure category. Both the total score and frequency count only reflect whether a type of failure was identified and does not reflect the (number of) way(s) by which one type failure restrains innovation.

Despite these caveats associated with implementing a numeric scale we are still interested in learning whether this exercise will reveal any interesting patterns.

Observations

The big picture

Overall, the study succeeded in compiling evidence of a range of barriers to innovation in each of the 24 selected areas, categorising them according to the eight types of barriers identified through the literature review, and ranking them on the 5-point scale, in order to highlight those barriers that are identified within the evidence-base as being of particular importance.

Having done so, the initial general observation is that most of the eight types of barrier feature in most of the areas. However, far from signalling that all areas have broad and comparable sets of factors inhibiting innovation, the study instead highlighted with clarity that each sector, sub-sector or technological area has a unique mix and character of barriers, with little scope for grand theorising and catch-all explanations for lack of innovation.

As such, this study puts into question the use of grand theories to explain why innovation does not happen as much as is desired. It highlights that analysis at the level of specific areas is much more fruitful, both in terms of describing the exact character and cause of barriers, but also, due to the yielded detail and specificity, in terms of giving clearer indications of what kind of public support and policy intervention might help to lessen these barriers.

Key trends and tendencies

The 24 areas were divided into several different types of categories, in order to search for any broad types of areas that might have more significant barriers to innovation than other. The distinction between ‘Challenge-led areas’, ‘Development areas’ and Enabling technology capabilities’ were used as an initial distinction, though no clear trends of areas with greater or fewer barriers could be identified along these lines. Additional categories were assigned to each area:

- Whether or not it has been subject to significant and substantive state involvement
- Whether or not it has been heavily regulated
- Whether it has a strong high-street / consumer goods orientation
- Whether it is a new industry (i.e. non-existent before approx. 1980)

However, none of these features could be identified as a determinant of whether an area would have either especially high or especially low levels of barriers to innovation. This lack of clear, overarching patterns further highlights that barriers to innovation are strongly dependent on the particularities of each area or sector in question, and that grand overarching theories are for the most part too blunt to act as convincing and demonstrably applicable explanations. Some minor trends were observed, though they only ever contribute to understanding particular facets of the subject-matter in question, and never to better understanding the overall picture:

- Barriers were less significant in areas around the competency of digital services than elsewhere (e.g. Big Data, Financial services, Cyber security). All of these innovation areas score relatively low on the ranking and frequency count, indicating that barriers to innovation in the digital services are generally lower than elsewhere. Specifically, we found no evidence of failures of the character of science on digital services
- Infrastructural failures are most likely to be ‘Showstoppers’

- In sectors with heavy state involvement, we usually identify showstoppers or factors slowing-down innovation as a result of information asymmetry. We also find that infrastructural failures play a prominent role in sectors with heavy state involvement

- Infrastructural failures do not play a prominent role in the 8 great technologies

- Network failures are less frequently identified in sectors relying on newer technologies

- The ‘Eight Great Technologies’ have higher instances of failure than other areas relating to ‘Character of Science and Technology’, indicating that this ‘market failure’ from neoclassical economic literature – though overall to be of relatively low significance – still has purchase in sectors aligned more closely to basic research.

The importance of networks

Out of the eight categories of barriers to innovation, seven appeared with broadly similar frequency and overall severity. However, one type of barrier, ‘Character of Science and Technology’ was overall considerably less significant, appearing in far fewer of the 24 areas than other barriers and never constituting a ‘Showstopper’. The relatively low apparent significance of the character of the science and technology as a barrier to successful innovation is initially especially surprising, given that size, scope and risk attached to technology (‘indivisibility’) has been used as one of the fundamental arguments for public support of innovation throughout neoclassical literature and discourse.

This study found that whilst in all 24 areas there are elements of technological complexity, requiring extensive scientific expertise, some degree of unknown outcomes and large, sophisticated scientific efforts, this in itself is rarely acknowledged as a problem. Instead, the character of the technology often provided the rationale for requiring more skilled workers, better demonstration facilities, or, most often, better coordinated networks.

Across the case studies of large-scale, research-intensive manufacturing – satellites and space, energy, civil aviation, robotics, food production and agri-science – there is frequent reference to the importance of supply-chains and coordination between manufacturers of various constituent parts and sub-components. There is therefore a strong suggestion that sectors where indivisibility might once have been problematic, specialisation and fragmentation have had a mitigating role, lowering the minimum scale required for successful innovation. Put simply, there is a sense in the analysis that in many cases the indivisible has become divisible, but at the expense of splitting up technologies into networks of sub-components, which may easily become fragmented or un-coordinated. In the context of this argument, it is unsurprising that ‘Network Failure’ was the overall most common and significant type of barrier identified in the study.

Credit constraints and skills shortages

Credit constraints and skills shortages were two issues that received particular attention, given that they feature heavily in public and political debates on innovation, business growth and the future of the UK’s economy. The study found that both of these issues feature strongly in many of the 24 selected innovation areas. However, there is ample evidence to show that neither of these issues are a uniform problem with uniform causes and explanations. Credit constraints, the study found, can occur for a host of different reasons:

- They can result to the early stage of development of a technology, leading to risk in terms of whether successful products will in fact materialise

- They can likewise result from information asymmetry, where lenders do not have the expertise to understand a new technology and its application

- In some areas moreover, there is lack of awareness and expertise on the part of firms about the existing and available sources of credit

- The long-term perspective for development required in some areas was seen to clash with the short-termism characterising many investors and lenders

- In some cases, credit constraints are genuinely a temporary result of the overall financial crisis and not especially related to particularities of the innovation area

Skills shortages likewise were a considerable problem in most areas, but once again, the story is more complex:

- Skills shortages might simply be a direct result of the overall lack of STEM graduates and researchers in the UK

- However, in some areas there is also lack of knowledge in the part of the firms regarding what kind of skills are best suited to enhance commercial innovation

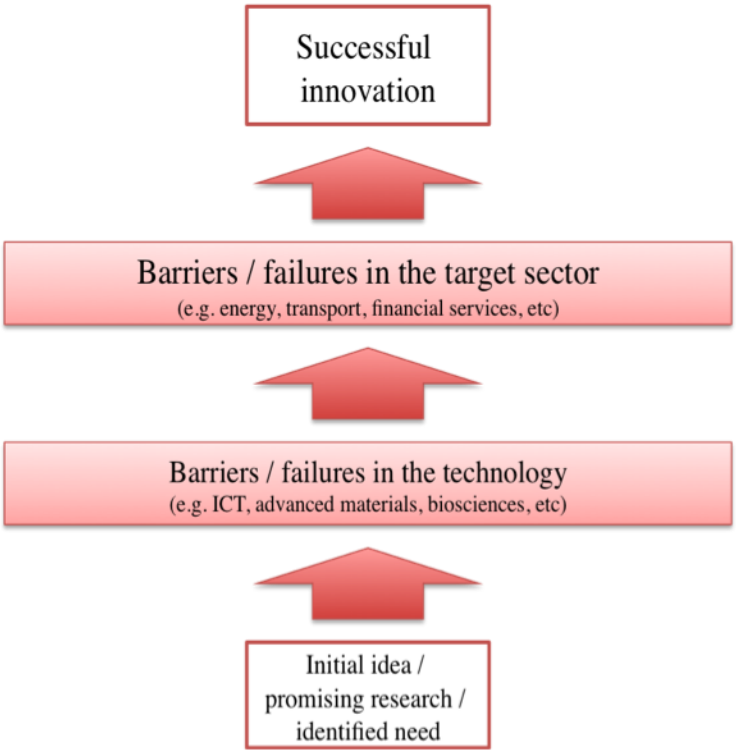
- Sectors with higher profit margins are in some cases able and willing to pay higher salaries to researchers and developers, leaving other sectors unable to attract the 'best in the business' without considerable expense

- The danger of 'poaching' sometimes acts as a disincentive, where researchers and developers are likely to change jobs upon receiving training from a business

- Some sectors, moreover, have an image-problem, leaving few graduates with relevant and useful skills showing any prior interest and being far more likely to work in other, more enticing sectors

Connections between the innovation areas

Though this study for the most part focuses on the level of the individual innovation areas, connection between the areas was a further important finding that emerged throughout the analysis. This research showed that each innovation area has a range of barriers inhibiting innovation to greater or lesser degrees. These barriers are consequences of the economic, political, social and cultural context in which each area exists, as well as of the particularities of the area itself. Innovation, put simply, does not occur in isolation from wider circumstances. And likewise, the 24 selected innovation areas do not occur in isolation from each other.



This was most noticeable when contrasting the ‘Enabling technology capabilities’ with the more substantive and sectoral ‘Challenge’ and ‘Development’ areas. Often, innovation in these more substantive areas constitutes the application of general-purpose technologies to specific sectoral contexts (e.g. photonics applied in the health sector, big data applied to create intelligent transport systems, etc.). At this level, a particular innovation, when viewed start-to-finish, is in fact subject to two sets of barriers before a successful, marketable product exists.

The role of the state

Maligned as the antithesis of creativity and private enterprise in some strands of thought, and viewed as a facilitator and entrepreneurial agent in others, this study found the role of the state to be varied and diverse across the 24 innovation areas considered here. The state’s capacity to create demand, especially in challenge-led areas (health & care, transport, etc.), often presented an important opportunity to bring innovations to market, whilst the stringent need for demonstrable utility and value for money required in many state-run arenas (e.g. the NHS) simultaneously presented challenges. In some areas, heavy regulation hampered successful research and innovation, yet at times this was a genuine result of outdated and poorly conceived rules, whilst in other cases regulation had to give consideration to important concerns beyond the topic of innovation itself (e.g. ethical/ moral issues in synthetic biology). Echoing the overall conclusions of this study, findings show that the state has many forms of involvement in innovation, as a customer, as a regulator, as a provider of skills and facilities, and that each of these roles at times enable, and at times stifle. A normative verdict on the state’s role in innovation is thus not contained here, but the extent of its multifaceted involvement and significance is documented here with ample examples.

Conclusion

The findings of this study in no way undermine existing and established rationales for public funding of basic research. Long established ‘market failures’ are still prevalent across the spectrum, and especially in new science and technology, where risks are substantial and knowledge and understanding of a technology’s potential are limited, the old rationales are as valid as ever. Likewise, this study supports much of the literature of innovation systems, where capability failures on the part of firms, as well as institutional, infrastructural and network weaknesses can decisively hamper the potential for innovation. Chiefly, this study has demonstrated that even within these categories, barriers to innovation take many different shapes, with different causes, consequences and degrees of severity. In-depth engagement with individual sectors, sub-sectors and types of technology yields a far more detailed and precise picture of why innovation does not happen as much as would be desirable. Additionally, understanding barriers to innovation at this substantive level also yields much clearer indications not just of whether or not public support is necessary, but also of what form that support needs to take.

Introduction

Objectives

The present project assesses the evidence of the rationales for public support for innovation with a particular focus at a more granular level than has traditionally been applied. The different aspects of the innovation environment assessed include challenge areas, enabling technologies and cross-sectoral competencies. In order to do that, this project has three differentiated objectives, divided in two parts.

The first section will provide a high level framework/taxonomy, to codify market and system failures relevant to innovation. Subsequently, we will provide evidence about the extent to which the market and system failures exist for a number of challenge areas, enabling technologies and cross sectoral competencies and for the UK context in particular.

This report

During the kick-off meeting, we reviewed the objectives and methodology of the project and confirmed the *innovation areas* (challenge areas, enabling technologies and cross-sectoral competencies) that are the focus of the analysis.

This report contains a compilation of all the material that we have worked on and will discuss the taxonomy and findings of the two key constituent sections.

The structure of the rest of this report is as follows:

- Summary of the literature review and key findings
- Presentation of a taxonomy of market/system failures
- Presentation of an analytical framework for analysing market/system failures and identifying rationales for public interventions in innovation (that can be re-used in future)
- Presentation of the evidence of market/system failures and corresponding rationales for a number of innovation areas as selected by the Technology Strategy Board
- Summary and discussion of the market/system failures identified across the group of innovation areas

Literature review

Introduction

In this Chapter, we review literature about the justifications for public intervention in research and innovation. Most of the literature deals in one or both of two categories of ‘failure’ – in markets or in the wider ‘system of innovation’. Here, we first trace how these ideas developed. Second, we classify the instances we have identified in the literature and propose a condensed set of definitions for use in describing failures that may justify government intervention in research and innovation related to sectors, technologies and challenge areas. These definitions provide the framework we use to analyse failures in the subsequent chapters of this report.

Where does the idea of ‘failure’ come from?

A central tenet of mainstream economics is that, other things being equal, the unfettered operation of markets will produce the greatest amount of social ‘welfare’ (in the sense of maximising the amount of goods and services available for consumption). While a great many requirements lurk among those ‘other things’, this implies that the main economic role of government is to ensure the operation of free markets and, broadly, that any intervention to counter the operation of markets will reduce welfare. The idea of ‘market failure’ is an acknowledgement that there are circumstances where markets produce sub-optimal outcomes. Environment and research are well-known cases. Markets fail in relation to the environment because they do not price in the costs of environmental damage. We return to research below.

The idea of ‘systems failure’ is an argument by analogy, where it is claimed that the imperfect operation of the wider system of innovation (the set of actors and institutions in society that are involved in research and innovation) can also lead to socially undesirable outcomes.

Market failure

Mainstream ‘neoclassical’ microeconomics works with a small number of very simple ideas about economic production, consumption and the way markets mediate these activities. Key assumptions include the idea that producers and consumers are rational, that they know everything (not least that they know all the prices operating in a market), that producers can choose from a range of production technologies and that it costs nothing to move from using one technology to using another. Goods are homogenous and producers and consumers are small relative to the market so nobody can exert market power. (The archetype behind the model is the production and sale of corn in rural marketplaces under ‘perfect competition’.) While these assumptions are sufficiently unrealistic to make neoclassical economists easy to tease, in reality no one believes in them literally. Rather they provide a framework for analysing what happens when certain of these assumptions do **not** hold, as where there is monopoly, imperfect information or costly technologies. The most difficult assumption to relax is probably that of rationality. Without that, it is difficult to predict or mathematically to describe how markets behave.

In the context of a discipline founded on the analysis of physical goods, knowledge is a bit awkward. Yet, since innovation is based on knowledge, it needs to be understood. In economic terms, knowledge is a ‘non-rival’ good – meaning that many people can consume it at the same time. (Most goods, for example cake, are ‘rival’. If I eat the cake, then you cannot. Knowledge is one of the special cases where you **can** have your cake and eat it.) Knowledge is also ‘non-excludable’ – it is hard to stop people getting access to it. Non-excludable, non-rival goods are ‘public goods’. In economic theory, the results of basic research are such public goods (though there are also other categories of public goods). In theory the market cannot produce these, so since society needs or benefits from them the state must pay.

The idea of ‘market failure’ leading to under-investment in research has been the principal rationale for state funding of R&D[1] in the post-War period. Of course, governments had been funding research long before the economics profession produced a reason. Arrow is generally credited with describing the three major sources of market failure which – from a neo-classical perspective – make it useful for government to fund research

- **Indivisibility**, because of the existence of minimum efficient scale. This applies to knowledge as much as it does to investments more widely

- **Inappropriability** of the profit stream from research, leading to a divergence between public and private returns on investment. This results from two essential (and economically efficient) freedoms that researchers have: namely to publish and to change jobs

- **Uncertainty**, namely divergences in the riskiness of research respectively for private and public actors

Arrow’s argument is particularly relevant to more ‘basic’ (and, by implication, generally applicable) forms of knowledge because capitalists’ inability to monopolise the results of such research means they would be least likely to invest in it. His argument is, however, conceptually flawed. It simply **assumes** that there is under-investment in basic research compared to an imagined welfare-economic optimum. In fact, no one has observed or calculated what such an optimum would look like. It makes this assumption because it implicitly accepts the ‘linear model’ account of the role of science in economics and development, which is the idea that ‘basic’ research somehow causes applied research, which in turn drives innovation (the introduction of new products, processes and services). The linear model has largely been rejected as inaccurate[2] or as a special case that applies only in some industries.[3]

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[1] Ken Arrow, ‘Economic Welfare and the Allocation of Resources for Invention,’ in Richard Nelson (Ed.) *The Rate and Direction of Inventive Activity*, Princeton University Press, 1962; see also Richard Nelson, ‘The simple economics of basic scientific research,’ *Journal of Political Economy*, 1959, vol 67, pp 297-306

[2] Mowery, D.C. and Rosenberg, N., ‘The Influence of Market Demand upon Innovation: A Critical Review of Some Recent Empirical Studies’, *Research Policy*, April 1978

[3] Pavitt, K. (1984) *Sectoral patterns of technical change: towards a taxonomy and a theory*, Research Policy, Vol. 13, pp.343-373

The recognition that there are varying **degrees** of market failure in different types of research and innovation related activity underpins the fact that there is a 'slope' in the degree to which governments subsidise them. Thus, basic research in universities is fully funded while work intended to lead more directly to industrial application is typically funded privately or may be cost-shared between the state and industry where risks and potential spillovers are high.

The treatment of R&D costs by the state is also affected by the fact that these are mostly 'sunk costs', namely costs that do not necessarily produce re-usable values. While investment in equipment, for example, tends to deliver equipment that has alternative uses or that can be re-sold if it turns out to be irrelevant to its owner, an investment in producing knowledge may produce nothing or may produce knowledge that is not relevant to the investor's purposes. In that case, it is difficult to sell (except in the special case of patentable knowledge). For this reason, companies tend to fund R&D out of cash rather than through debt[4] and tax codes – including that in the UK – tend to treat R&D in a generous way. Even though R&D costs are in principle investments, companies are typically allowed to treat them as operating expenses precisely because they are sunk costs that may well be unrecoverable.

As Smith points out,[5] newer growth theory has incorporated more sophisticated thinking about knowledge into the neoclassical tradition. In particular, knowledge spillovers or externalities are seen not only as an inhibitor for investment in knowledge but also as a source of inputs into the firm's innovation processes. Thus the firm benefits not only from its own investments in knowledge (for example, through R&D) but also from externalities or 'leakage' of knowledge produced elsewhere. The presence of spillovers implies that social rates of return to R&D will exceed private rates.[6] Based on this thinking, models of the social returns to R&D have been developed which treat past R&D as a capital stock (with an assumed useful lifetime, after which it is aged off) and estimate the value of the spillovers.[7] However, despite such attempts to take better account of knowledge within mainstream economics, its production remains essentially exogenous to the economic system. By assumption

- It is generic. That is to say, an item of knowledge, or a particular advance in knowledge, can be applied widely among firms and perhaps among industries

- It is codified. The ability to transmit implies that knowledge is written or otherwise recorded in fairly complete useable form

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[4] Gerben Bakker, 'Money for nothing: How firms have financed R&D-projects since the industrial revolution', *Research Policy*, 42 (10), 2013, 1793-1814

[5] Keith Smith, 'Innovation as a systemic phenomenon: Rethinking the role of policy', *Enterprise and Innovation Management Studies*, Vol 1 No 1, 2000, 73-102

[6] The private rate of return is the annualised income (by implication, in perpetuity) deriving from R&D investment accruing to the investing organisation itself, as a proportion of that investment. The social rate of return comprises both benefits to the innovator and those to the wider community, potentially including, for example, benefits to the consumer and environmental benefits. The latter can be identified as the overall contribution to GDP from the R&D

[7] See for a good overview of the literature Ben Martin and Puay Tang, *The Benefits from Publicly Funded Research*, SPEU Electronic Working Paper Series No 161, Brighton: SPRU, 2007

- It is accessible without cost. On the one hand this can involve the idea that transmission costs are negligible, but it can also mean that firms do not face differential cost barriers in accessing knowledge or bringing it into production

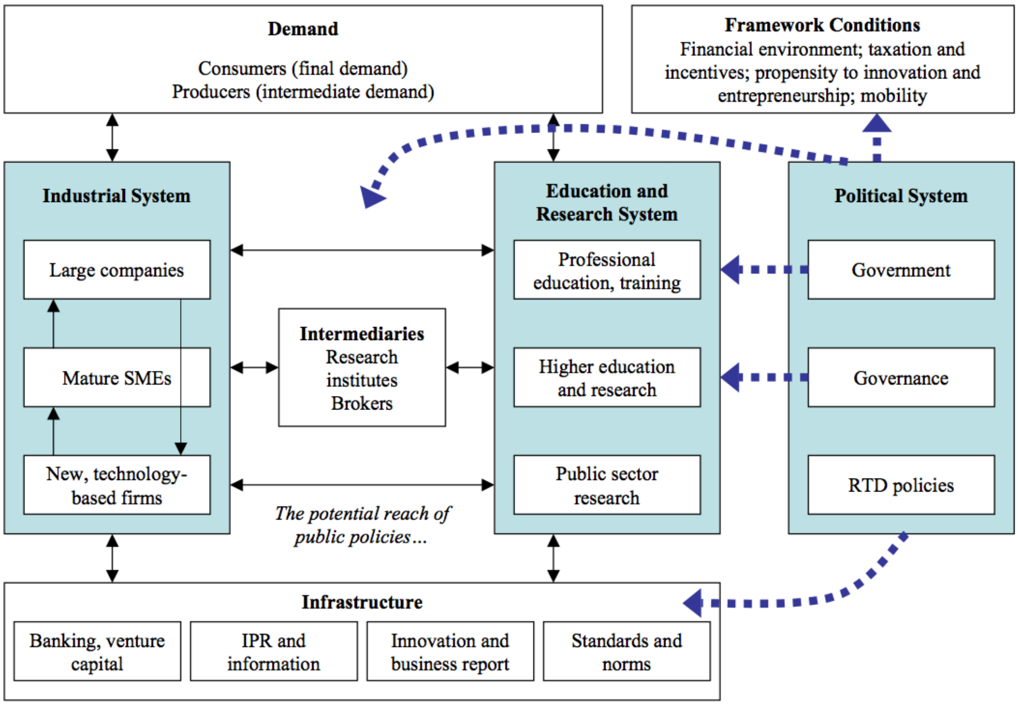
- It is context independent. That is firms have equal capabilities in transforming such knowledge into production capability[8]

Combined with the rationality assumption and the corresponding focus on individual decision-making, this means that many of the systemic characteristics of the innovation process are not treated in the mainstream economic view.

Systems failures

The seminal literature in the innovation systems tradition comprises a study by Chris Freeman of the Japanese organisations that organise the state's role in innovation, and studies of national innovation systems by Nelson and Lundvall.[9] Nelson followed Freeman's narrow focus on state institutions, while Lundvall broadened the idea of an innovation system to encompass all the actors in society involved in innovation, including important framework conditions such as regulation, the effectiveness of the banking system and so on. Figure 1 has been extensively used as shorthand, and summarises what this means in practice.

Figure 1 A National Innovation System Heuristic



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[8] Keith Smith, 'Innovation as a systemic phenomenon: Rethinking the role of policy', *Enterprise and Innovation Management Studies*, Vol 1 No 1, 2000, 73-102

[9] See Christopher Freeman, *Technology Policy and Economic Performance: Lessons from Japan*, London: Frances Pinter, 1987; Bengt-Åke Lundvall, *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning*, London: Pinter, 1992; RR Nelson, *National Innovation Systems*, New York: Oxford University Press, 1993

Source: Stefan Kuhlman and Erik Arnold, *RCN in the Norwegian Research and Innovation System*, Background Report No 12 in the Evaluation of the Research Council of Norway, Oslo: Royal Norwegian Ministry for Education, Research and Church Affairs, 2001. Also available at www.technopolis-group.com

The ‘innovation systems’ tradition can fairly be said to have grown up in deliberate opposition to the neoclassical view of knowledge, research and innovation and particularly to the linear model. However, its intellectual roots are in classical economics, especially in Marx’s view of technological change as endogenous to firms and as a driving force not only in competition but also in development and growth. Joseph Schumpeter tends to function as the iconic ‘touchstone’ for the innovation systems tradition – perhaps because in his later years he incorporated many of Marx’s economic views into his own but without adopting Marx’s inconvenient politics. While the neoclassical tradition sees economies as tending towards static equilibria, the Schumpeterian view is that capitalism brings a “gale of creative destruction” and therefore constant change, manifest in the form of innovation and the diffusion of innovations through the economy. This is what makes capitalism so robust and dynamic.

The innovation system tradition tends not only to see innovation as economically embedded but also as socially constructed – both in the sense that innovations tend to serve not only the economic but also the wider social purposes of innovators and in that innovation processes are seen as complex and non-linear. If innovation processes are endogenous to the economy then there is scope for research, science and innovation policy to affect them. Key figures in the innovations systems tradition such as Chris Freeman were also active in the OECD’s drive to establish science policy and R&D statistics during the 1960s.

The shorter-term origins of systems thinking about innovation are diverse. One important strand is the development of evolutionary economics,[10] which in effect puts people and behaviour into the economic idea of the firm. This throws out the neoclassical rationality assumption and implies that at the level of the individual firm, there is not perfect information; nor is available information always completely understood or interpreted; but the firm can learn. Such learning is based on experience and is cumulative. What a company or institution can do today depends upon what it could do yesterday[11] and what it has learnt in the meantime. Learning may be tacit and therefore difficult to access. Unlike in the neoclassical view, knowledge may be firm-specific, sector-specific or general.[12]

“Often, the elements of the system of innovation either reinforce each other in promoting processes of learning and innovation or, conversely, combine into blocking such processes. Cumulative causation, and virtuous and vicious circles, are characteristics of systems and sub-systems of innovation.”[13] This ‘bounded rationality’ not only implies that firms can take decisions that are sub-optimal for themselves and for others but also that their development is path-dependent. They can become ‘locked in’ or stuck in particular

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[10] Richard M Cyert and James G March, *A Behavioural Theory of the Firm*, New Jersey: Prentice-Hall, 1963; Richard R Nelson and Sydney G Winter, *An Evolutionary Theory of Economic Change*, Cambridge, Mass: Harvard University Press, 1982

[11] Nathan Rosenberg, *Perspectives on Technology*, Cambridge University Press, 1976

[12] WEG Salter, *Productivity and Technical Change*, Cambridge University Press, 1969

[13] Bengt Åke Lundvall (ed), *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning*, London: Pinter, 1992

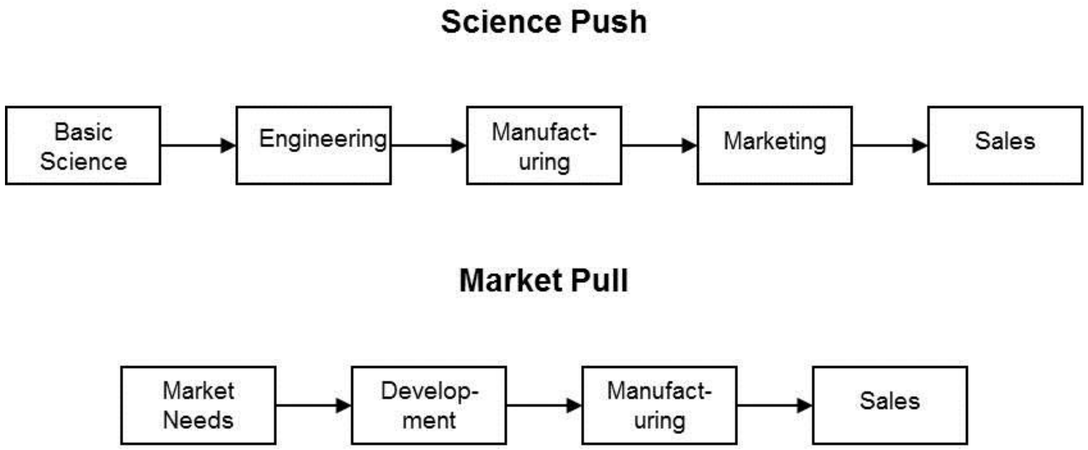
ruts, even when perhaps they should be changing direction. Their ‘search trajectory’ is likely to be limited.[14]

Lock-ins can exist only at the level of the individual firm but also at the level of technologies and the institutions that surround them. The idea of ‘technological trajectories’ in innovation[15] extends the product life cycle idea to consider the development trajectories of individual technologies and the firms and markets with which they become associated. The more recent idea of ‘technological regimes’ extends this notion to the surrounding institutions. As with product cycles, these technological concepts reduce uncertainty for producers and consumers, entail learning – and run the risk of being knocked brutally out of the way if and when a new paradigm emerges.

Another important strand is innovation research. During the 1950s, the linear, science-push model of innovation dominated.16 While there was some limited research support for this view in the 1950s, in its crude form it does not stand up to much scientific scrutiny. It is perhaps better thought of as part of the ideological superstructure of the post War expansion of science, rather than as a theory of innovation. In the 1960s, the empirical work of people such as Carter and Williams,[17] Schmookler[18] and Myers and Marquis[19] placed more emphasis on the role of the marketplace in innovation. This led to market-pull or need-pull models of the innovation process.

Figure 2 is a schematic of the two linear models.

Figure 2 Traditional (Linear) Models of Innovation



A key weakness of the linear models is a failure to conceptualise how the links between successive stages of innovation are supposed to work. Such links are, in fact, very difficult

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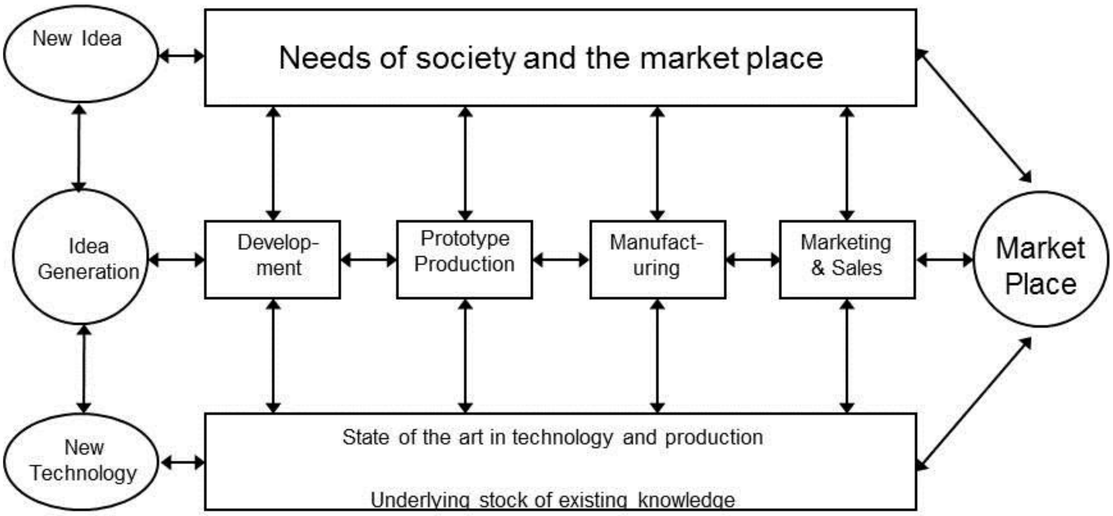
[14] Stepjen J Kline and Nathan Rosenberg, ‘An overview of innovation’ in Ralph Landau and Nathan Rosenberg (eds), *The Positive Sum Strategy*, Washington; National Academy Press, 1986
[15] Giovanni Dosi, ‘Technological paradigms and technological trajectories’, *Research Policy*, 11(3), 1982, 147-162
[16] This account of successive generations of innovation model is partly based on Roy Rothwell, ‘Successful Industrial Innovation: Critical Factors for the 1990s’, *R&D Management,:3 , p 221-239,* 1992
[17] Carter, C. and Williams, B., *Industry and Technical Progress*, Oxford University Press, 1957
[18] Schmookler, J., *Invention and economic growth,* Harvard University press, 1966
[19] Myers, S. and Marquis, D.G., *Successful Industrial Innovation*, National Science Foundation, 1969

to achieve in a managed way, even inside a single company. Typically, different people do the activities conducted at each stage in different places and often in different institutions. They tend to have different motivations and incentives and to operate in different interpersonal networks. *A priori*, one would expect it to be very hard to create the kind of chain-links between them, which are depicted in the linear models. Empirical studies such as SAPPHO[20] – which analysed matched pairs of successful and unsuccessful innovations – and the work of Daniel Shimshoni, Morris Teubal, Eric von Hippel and others[21] increasingly emphasised the role of producer-user relations in innovation. Often, innovation was not a heroic act undertaken by an isolated but inspired entrepreneur but was co-produced in relationships between suppliers and users. Correspondingly, new knowledge used was often generated in response to an identified knowledge gap, as opposed to the linear serendipity envisaged in the linear model.

By the late 1970s, Mowery and Rosenberg[22] largely laid the intellectual argument between push and pull to rest by stressing the importance of **coupling** between science, technology and the marketplace. Their coupling model constituted a more or less sequential process linking science with the marketplace (via engineering, technological development, manufacturing, marketing and sales), but with the addition of a number of feedback loops and variations over time in the primacy of 'push' and 'pull' mechanisms. This is shown schematically in Figure 3.

Figure 3 Modern 'Coupling' Model of Innovation



Source**: Modified from** Roy Rothwell (1994). Towards the Fifth-generation Innovation Process. *International Marketing Review*, 11(1), 7–31.

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[20] Roy Rothwell (1994). Towards the Fifth-generation Innovation Process. *International Marketing Review*, 11(1), 7–31

[21] Morris Teubal, *Innovation Performance, Learning and Government Policy. Selected Essays*, Madison: University of Wisconsin Press; Eric von Hippel, 'The Dominant Role of Users in the Scientific Instrument Innovation Process,' *Research Policy* (5)3 (1976) 212-39; Daniel Shimshoni, 'The mobile scientist in the American instrument industry', *Minerva*, 8, 1970, 59-89

[22] Mowery, D.C. and Rosenberg, N., 'The Influence of Market Demand upon Innovation: A Critical Review of Some Recent Empirical Studies', *Research Policy*, April 1978

The preoccupation of the earlier generations of innovation model is with the link between the **flow** of new knowledge and economic innovation. However, this ignores the huge importance of the **stock** of existing knowledge indicated at the bottom of Figure 3. The vast majority of the knowledge used in any innovation comes out of this stock, and is not created afresh in the project that gives rise to the innovation. Important parts of the knowledge stock could be very old, as had been shown in the HINDSIGHT and TRACES[23] projects, which tracked the movement of knowledge elements respectively from applied and basic research into industrial practice across very long periods of time.

A third systemic strand is the idea of 'clusters' of economic activity as being important in innovation. Marshall's idea of 'industrial districts'[24] points to the clustering of related economic activity, where competitors work side by side because of the benefits of a shared labour market, shared access to inputs, shared infrastructures and educational facilities and often the attractiveness of a cluster of alternative suppliers to customers. By implication, these benefits combined with the intensification of competition promote the competitiveness of firms located in such districts. Porter has famously developed the concept further, so that 'cluster policy' has become a feature in many countries. To the Marshallian benefits of co-location for the supply side he adds the importance of producer-user relations along supply chains (or, in the French tradition, 'filières'). The current focus in regional development policy on 'smart specialisation' extends this analysis better to consider the connections between cluster activities and the 'infrastructural' role of the state and other institutions – in effect aiming to generate a more complete innovation system.

A further, if not well recognised, input into the idea of innovation systems is the systems thinking that emerged in the 1940s and 1950s, stimulated by the potential of emerging computer technology that had been spectacularly demonstrated in theory and practice (such as code breaking) by Turing and others. Norbert Wiener[25] (*Cybernetics*) and von Bertalanffy[26] (the idea of a General Systems Theory) were leading figures in this movement. As Ingelstam[27] points out, they have important ideas in common. One is the principle of non-reductionism: the idea that the behaviour of systems cannot be explained only by reference to their components, but that it is also determined by phenomena at higher levels. Another is the idea of interdisciplinarity or 'borrowing tools' among disciplines. The third is that they envisage a core of systems theory emerging as a new and viable discipline or meta-discipline in its own right. 'Innovation systems' remains more of a heuristic than a theory. The need to abandon perfect actor rationality complicates any attempt to emulate the mathematical dimensions of mainstream economics. However, the collection of ideas associated with innovation systems remains a powerful way to understand events.

Figure 4 attempts to summarise the way the innovation systems tradition considers innovation itself. Innovation drives growth because there is constant competition to

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[23] Illinois Institute of Technology, 1969, *Technology in Retrospect and Critical Events in Science (TRACES: A report to the National Science Foundation)*, NSF Contract C535; Office of the Director of Defense Research and Engineering, *Project Hindsight - Final Report,* National Technical Information Service, 1967

[24] Alfred Marshall, *The Principles of Economics*, London: Macmillan, 1890

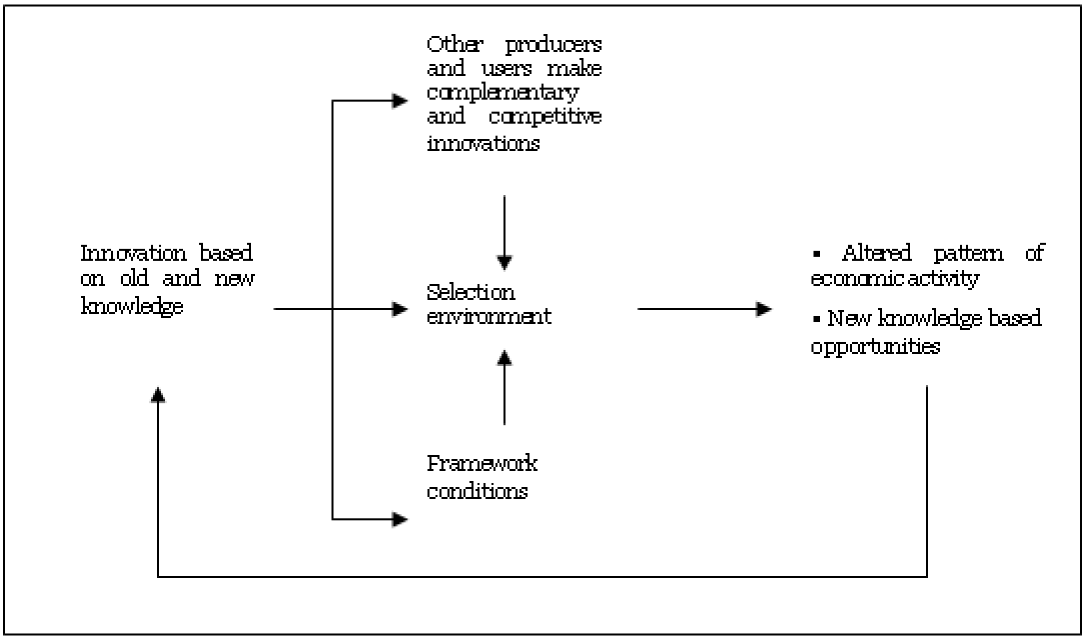
[25] Norbert Wiener, *Cybernetics – Control and Communications in the Animal and the Machine*. New York: John Wiley, 1948

[26] Ludwig von Bertalanffy, *General Systems Theory*, New York: George Braziller, 1968

[27] Lars Ingelstam, *System – att tänka över samhälle och teknik*, Eskilstuna: Statens Energimyndighet, 2002

improve. Unlike in the neo-classical economic models, where technological change is seen as external to the economic system so that *equilibria* tend to develop, the innovation systems approach sees the constant evolution of technology as **internal** to the system. Because there are no *optima*, each change in technology creates a new set of economic and technical opportunities, under which economic actors compete to create advantage, so that innovation constantly triggers new innovation (Figure 4).

Figure 4 Evolutionary View of Innovation in Innovation Systems



Source: While the diagram is our own, it was inspired by JS Metcalfe, 'Co-Evolution of Systems of Innovation,' paper presented at the Volkswagen Foundation Conference, *Prospects and Challenges for Research and Innovation*, Berlin, 8-9 June 2000, CRIC, Manchester University 2000

A key aspect of the innovation systems approach is therefore to understand that innovation is not only about technical change but its interplay with other factors. It is not only about new knowledge but also about the re-use of old knowledge. And it often involves other things than those we think of as 'technical'. The characteristics of knowledge and learning in firms are quite different from those assumed in the neoclassical tradition.

- They are differentiated, multi-layered, involving the systemic integration of many different types of knowledge

- They are highly specific, organised around a relatively limited set of functions, which firms understand well, and the system is thus characterized by boundedness, bounded rationality and `bounded vision'

- They involve significant tacit components embodied in the skills of engineers and R&D staff, workers and managers

- They are cumulative, developing through times as firms build up experience with particular technologies; this in turn implies that technological knowledge is path dependent

- They are developed through costly processes of search, through processes of learning and adaptation.

- They are internally systemic in the sense of being part of an overall production and marketing system which has many components

- They are externally systemic, relying on interactions between firms and other agents and relying also on infrastructural support[28]

Failures described in the literature

In order to explore the way market and systems failures are being described in the literature and to provide a basis for classifying failures in the areas identified by BIS for analysis, we reviewed 43 documents (see Appendix), spanning both BIS studies and the wider academic and 'grey' literatures, extracting relevant discussions and definitions to individual fiches. Not surprisingly, this literature contains massive overlaps, so in this section we try to cook it down to a comparatively short list of failures, which we subsequently use to analyse literature about the industries and technologies tackled in this report.

Market failure – Character of science and technology

Innovations, especially more radical ones, can depend upon the generation of knowledge that can be produced only over long periods of time or with major commitments of resources, which are often beyond the financial means or willingness to invest of individual firms. Because they depend on knowledge that has not yet been generated, such innovations can also involve not risk but **uncertainty**, i.e. risks that cannot be calculated.[29] A handy example is the seemingly endless search for viable fusion power. Not only research itself but also the equipment needed to do it may be very expensive or 'lumpy'. For example, it is not easy to build a 'small' particle accelerator.

The apparently increasing importance of complex technical systems presents a new kind of challenge to innovation, in the sense that radical innovation may require the reconfiguration or replacement of the results of substantial past investment.[30]

Market failure – Market power

A central tenet of modern economics is that where competition is constrained, resources are allocated inefficiently. Typically one part is able to extract 'rents' over and above the

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[28] Keith Smith, 'Innovation as a systemic phenomenon: Rethinking the role of policy', *Enterprise and Innovation Management Studies*, Vol 1 No 1, 2000, 73-102

[29] BIS, Innovation and Research Strategy for growth, BIS Economics Paper No 15, London: BIS, 2011

[30] Stephen Martin and John T Scott, 'The nature of innovation market failure and the design of public support for innovation', *Research Policy*, 29(2000): 437-447

level of income that would have been available under more competitive circumstances. Market power can be generated by (otherwise desirable) economies of scale and scope. A key policy issue is then whether the tendency towards monopoly can be made benign through regulation (notably of prices) or whether market power becomes a brake on technological change and innovation.

'Dynamic market failure' involves a particular kind of monopolisation, where first-over advantages and the ability to build economies of scale and scope ahead of the competition are so important as to become a block on innovation.[31]

The effect of market power on innovation is ambiguous. Market power can increase the likelihood that a firm can capture the benefits from investing in innovation (positive effect) and, at the same time, too much market power can stifle innovation (negative effect). The related theory, as explored by Aghion et al. (2005)[32] and Peneder (2012),[33] is that at low levels of competition, the relation between competition and innovation is positive but at higher levels of competition the relation between competition and innovation turns negative.

Market failure – Externalities

Externalities arise where technical characteristics of a good or service prevent property rights from being established or enforced, most commonly in relation to knowledge production. Where businesses cannot appropriate the full benefits of innovation, the incentive to innovate is reduced and this tends to reduce investment below the optimum level. Policy options include public funding and the creation of tradable property rights, as in the case of carbon pricing or the patent system.[34]

A common form of externality is **spillover**, which can involve both knowledge and market spillovers.[35] Knowledge spillovers are generated by publication, labour mobility, education and training, reverse engineering and are built into the patent system, which trades the deliberate generation of knowledge spillover for a temporary monopoly on the part of the inventor. Market spillovers occur where the sale of goods and services bring benefits to customers that are not fully reflected in the price paid. A traditional example is increases in quality over time. Ultimately these spillovers can be reflected at the level of final consumption in so-called **consumer surplus**. A related distinction is between **horizontal spillovers** among firms in the same industry (which are typically knowledge based) and **vertical spillovers**, which are more likely to be market spillovers and to operate along

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[31] Karl Aiginger, 'Industrial policy: A dying breed or a re-emerging phoenix?' *Journal of Industry, Competition and Trade*, (2007) 7:297–323

[32] Aghion, P., Bloom, N., Blundell, R., Griffith, R. and Howitt, P. (2005). Competition and Innovation: an Inverted-U-Relationship. The Quarterly Journl of Economics, 120(2): 701-728

[33] Peneder, M. (2012) Competition and innovation: Revisiting the Inverted-U-Relationship. *Journal of Industry, Competition and Trade,* 12(1): 1-5

[34] BIS, Innovation and Research Strategy for growth, BIS Economics Paper No 15, London: BIS, 2011

[35] Jaffe, Adam B. *Economic Analysis of Research Spillovers: Implications for the Advanced Technology Program*. Economic Assessment Office, The Advanced Technology Program, National Institutes of Standards and Technology, U.S. Department of Commerce. 1996

supply chains. Spillovers can be international, with open economies benefiting more from them than more closed ones.[36]

The processes of innovation adoption can also involve externalities. In some cases, (e.g. a communications network) the value of adoption increases as the number of other adopters goes up. (This is also known as 'dynamic increasing returns' or 'network externalities.) Both learning by using and learning by producing involve generating information, which then spills over to others users and producers, so that later innovators benefit from the experience of the earlier ones.[37] I parallel fashion, early investors acquire information that tends to leak to others – with later investors effectively free riding on the information the first generation of investors acquired at greater risk.[38]

Market failure – Information asymmetry

Here we can distinguish between situations where a lack of information on the part of some market actors causes inefficient allocation of resources and those where inequality of access to knowledge enables one party to make gains at the expense of another.

The fundamental idea here is that a 'buyer' and 'seller' will not necessarily have the same information on which to base their trading decisions, as a result of which markets can become severely distorted.

The issue of information asymmetry has received considerable attention in the economic literature in the last 30-40 years. This was initially prompted by Akerlof's (1970) 'lemons' paper on the second-hand car market, which led directly to an award of the Nobel Prize for Economics in 200118. The key assumption is that sellers will typically know much more about the quality of the vehicle in question than prospective buyers. As a result, sellers of good cars will be unwilling to enter the market, since buyers will demand low prices, expecting that the market will be dominated by 'lemons' – poor cars whose owners conceal their inferiority for personal gain. Mutually beneficial sales of good cars are therefore constrained, and the analysis suggests that the market could collapse entirely.

Information asymmetry may be particularly acute in financial markets, where sources of finance for innovative activity lack the capacity to verify ex-ante the claims of the entrepreneur-innovator, and 'excessively' discount expected revenue flows from the innovation. This may be particularly true for early-stage technological development.

Systems failure – Capability failure

Capability failures are, in effect, inadequacies in the resources and performance of real firms compared with textbook models as a result, for example, of managerial deficits, lack of technological understanding or learning ability. Inadequate 'absorptive capacity' – i.e. the ability to understand and make use of external knowledge, often through doing R&D[39]

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[36] Coe, D. T., & Helpman, E. (1995). International R&D spillovers. European Economic Review, 39(5), 859–887

[37] Jaffe, A. B., Newell, R. G., & Stavins, R. N. (2005). A tale of two market failures: Technology and environmental policy. Ecological Economics, 54(2-3), 164–174

[38] Howard Pack and Kamal Saggi, The case for industrial policy: a critical survey, World Bank Policy Research Working Paper 3839, February 2006

[39] Wesley M Cohen and Daniel A Levinthal, 'Absorptive capacity: a new perspective on learning and innovation,' *Administrative Science Quarterly*, Vol 35 (1), March 1990, pp128-152

– is a key capability failure. The neoclassical policy recommendation for tackling such failures would be non-intervention, on the grounds that underperformers will simply be driven from the marketplace. An evolutionary or innovation systems based approach would be to attempt to rectify at least some such failures, especially via information, training and access to support infrastructures such as technology transfer organisations.[40] Measures taken to address capability failure typically involve various types of learning and aim to generate .behavioural additionality'.

There is a difficult boundary between capability and infrastructural failure (below) in relation to skills. Capability failure may manifest as skill shortage, where the individual firm fails to understand the importance, and make use, of skills that are externally available. However, a skill shortage that arises at the level of the firm because a relevant category of skilled labour does not exist (or exists only in insufficient numbers) represents a failure in the provision of education and training by the state.

Systems failure – Network failure

Coordination failures occur where there is inadequate organisation for collecting, analysing and sharing information about innovation opportunities. The coordination mechanisms needed may range from loose ways of spreading information to close partnerships that overcome barriers between different parts of the system, such as along supply chains.

Another kind of network failure is **excessive** linkage among parts of the innovation system, resulting in **lock-ins**[41] or **transition failures**[42] where clusters or innovation systems fail to take on new technological opportunities or to shift from one generation of standards to a more appropriate one. Lock-ins or path dependency[43] have many origins, including embeddedness in a certain set of social, business and institutional arrangements but they can also result from the inflexibility of internal capabilities, or external infrastructures. According to Smith, “This means that technological alternatives must not only compete with components of an existing technology, but with the overall system in which it is embedded. Technological regimes or paradigms persist because they are a complex of scientific knowledge, engineering practices, process technologies, infrastructure, product characteristics, skills and procedures which make up the totality of a technology and which are exceptionally difficult to change in their entirety.”[44]

A further variety would be a ‘lack of weak ties’ in the sense of Granovetter,[45] who points out that it is often the weak links at the periphery of a social network that provide impulses and opportunities for innovation.

Systems failure – Institutional failure

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[40] Arnold, E., & Thuriaux, B. (1997). Developing firms’ technological capabilities. Technopolis Ltd

[41] BIS, Innovation and Research Strategy for growth, BIS Economics Paper No 15, London: BIS, 2011

[42] Keith Smith, ‘Innovation as a systemic phenomenon: Rethinking the role of policy’, *Enterprise and Innovation Managament Studies*, 1(1), 2000, 73-1022000

[43] Douglass C North, *Institutions, institutional change and economic performance*, Cambridge University Press, 1990

[44] Smith, Keith (1997): Economic Infrastructures and Innovation Systems, In: Edquist, Charles (Ed.): Systems of Innovation: Technologies, Institutions and Organizations, London: Pinter , 86-103

[45] Mark S Granovetter, ‘The strength of weak ties’, American Journal of Sociology*, 78(6), 1973, 1360-80*

Institutional failure may be ‘hard’ or ‘soft’. Hard institutional failure involves formal institutions such as legal systems or organisations that do their job inadequately. These may be a part of the framework of regulation, which consists of

- Technical standards, labour law, risk management rules, health and safety regulations, etc.

- The general legal system relating to contracts, employment, IPR within which the actors (not only firms, but also knowledge institutes and e.g. the government) operate[46]

Soft institutional failure involves deficiencies in ‘soft institutions’ such as culture and may be manifested in factors such as the level of trust in business relationships.[47] Soft or informal institutional failures include social norms and values, the willingness to share resources with other actors,[48] the entrepreneurial spirit within organisations, industries, regions or countries,[49] tendencies to trust, risk averseness etc.[50] and form the implicit rules of the game that can stimulate or hinder innovation.

Systems failure – Infrastructural

Infrastructural failure, as we use the idea here, is a kind of government failure, where there has not been an adequate policy response to another kind of failure. For example, under-investment in basic research would be an infrastructural failure that hampers innovation not only by producing too little new knowledge but also by failing to generate research-trained people able to absorb and use new knowledge generated by others.

Another kind of infrastructural failure is **framework failure**, where regulatory frameworks and other kinds of background conditions like the character of consumer demand or culture and not conducive to innovation.[51] The creation of standards is subject to market failure – there is an assumption that markets under-provide standards, owing to their character as public goods.[52]

At its broadest, the idea of infrastructural failure can be connected to failures in the performance of the state in its roles relating to the national innovation system. In this respect, Borrás identifies five generic functions: to reduce uncertainty; to manage conflict and cooperation; to provide incentives, to build competences and to define the boundaries of the system. She goes on to list ten specific functions in the system of innovation are listed: 1. production of knowledge 2. diffusion of knowledge 3. appropriation of knowledge 4. regulation of labour markets 5. financing innovation 6. alignment of actors 7. guidance of

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[46] Keith Smith, Innovation as a systemic phenomenon: rethinking the role of policy, in K. Bryant and A Wells (eds), A New Economic Paradigm? Innovation-based Evolutionary Systems (Commonwealth of Australia, Department of Industry, Science and Resources, Science and Technology Policy Branch) pp. 10-47, 1999

[47] Carlsson B. and Jacobsson, S., 1997, In search of useful public policies: Key lessons and issues for policy makers, in: Carlsson B. (Editor), 1997. Technological systems and industrial dynamics, Kluwer Academic Publishers

[48] Anna Lee Saxenian, *Regional Advantage: Culture and Competition in Silicon Valley and Route 128*, Cambridge, MA: Harvard University Press, 1994

[49] Carlsson and Jacobsson, 1997 , Ibid

[50] Francis Fukuyama, *Trust: the social virtues and the creation of prosperity*, New York: Free Press, 1995

[51] Keith Smith, ‘Economic infrastructures and innovation systems’, in Charles Edquist (ed), Systems of innovation: Technologies, institutions and organisations, London: Pinter, 1997

[52] Department of Trade and Industry, The Empirical Economics of Standards, DTI Economics Paper No 12, London: DTI, 2005

innovators 8. reduction of technological diversity 9. reduction of risk 10. control of knowledge use.[53]

Providing the needed infrastructure involves addressing large scale, indivisibilities and long-time scales for operation, all of which make investment appraisal difficult.[54] This is a problem because the effectiveness of the innovation system is crucially dependent upon the provision of such infrastructure.

Table 1 summarises this discussion and aggregates the different types of failure to a level that enables us to proceed with the empirical part of the study. The first three failures we propose are by and large a mix of market and systems failures, though with a heavy market component. The next three are essentially systemic: they relate to the ways institutions, rather than markets, work. The final category – Infrastructural failure – is strictly a sub-set of government or institutional failure, where there is a gap in policy or investment that causes innovation-critical infrastructures (whether hard or soft) to be missing. In the next chapter, we put this framework into practice in a few test cases, to see whether it is sufficiently robust for use in the full-scale analysis.

Table 1 Summary of failures identified in the literature

Barrier	Key features	Failure described in the literature
Character of Science and technology	The size of scientific or technological problems is too great for individual private actors to tackle if markets are competitive, and may be accompanied by uncertainty, making it hard for the private sector to invest. It may be that innovation only yields return in the long run, hampering investment.	Indivisibility Technological complexity Uncertainty
Market power	This can lead to, or be caused by, market power (for example, through the first supplier or user building insurmountable advantage) and may lead to consumer lock-in. High cost of market entry/exit.	Market power Economies of scale and scope Dynamic market failure Adoption externalities
Externalities	It is too hard to appropriate enough of the results of research or innovation to make private investment worthwhile. Innovation may depend upon the presence of external networks, which are beyond the means of innovators to create. Innovation is easy for competitors to copy and there are limited opportunities to protect new ideas	Externalities Spillovers (Horizontal, vertical, international) Inappropriability Network externalities Informational externalities
Information asymmetry	High levels of specialised technical and/ or market knowledge mean that not all the economic actors involve have the basis for	Information asymmetry Imperfect information

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[53] Borrás, S. (2004): "Systems of innovation theory and the European Union" in Science and Public Policy vol. 31, No. 6, Pp. 425 – 433

[54] Keith Smith, 'Economic infrastructures and innovation systems', in Charles Edquist (ed), Systems of innovation: Technologies, institutions and organisations, London: Pinter, 1997

Barrier	Key features	Failure described in the literature
	making informed decisions	Incomplete information
Capabilities	These failures result from the difference between the capabilities of real firms and those assumed in the idealised economic model, so that firms lack needed skills, resources, ability to learn, absorptive and analytic capacity or otherwise to capture innovation opportunities	Capability failures Learning failures
Network	Networks are fragmented and/or broad; communication and cooperation within networks are poor. Networks may be locked in to technological regimes, markets or products by their history and capabilities and find themselves unable to transition into new technologies or businesses	Network failures Interaction failures Transition failures Lock-in/path dependency failures Lack of weak ties
Institutional	Institutions (whether in the sense of ‘organisations’ or ‘rules and conventions’) operate in ways that impede innovation. Rules and regulation are not conducive to innovation and technological development. Government policy has the same effect	Institutional deficiencies/failures (hard and soft) Coordination failures Government failures Failure to standardise
Infra-structural	Insufficient human and capital investment in infrastructures critical to innovation performance by the state	Missing aspects of physical infrastructure or state provision (e.g. education)

Evidence of failures in each of the innovation areas

Barriers, scale, innovation areas and evidence

In this section we present the evidence of market/system failures and corresponding rationales for public investment in innovation for a number of innovation areas selected by BIS. We apply the analytical framework developed in the previous chapter to each of the areas, collecting study-evidence about the existence or applicability of the key features of each failure. This exercise has been conducted using a range of secondary sources, which are cited in the text and is based upon the categories of failure identified in Table 1, at the end of the previous chapter.

Scale

In order to move beyond highlighting a range of barriers in each innovation area, each identified barrier is ranked on a scale. This approach has been taken in other studies, in order to go some way to distinguish the more significant barriers from the less significant ones. Such scales are subjective, especially if already qualitative and subjective categories such as ‘critical’, ‘moderate’, ‘marginal’ etc. are used.[55] In order to circumvent this problem, the scale used in this report is based not on qualitative but on descriptive criteria, where factors considered are limited to prevalence of each barrier in the literature, as well as each barrier’s conceptual capacity to slow down the innovation process as opposed to stopping it entirely.

Table 2 Scale and descriptions for categorising barriers to innovation

Scale	Description
‘No evidence found’	Used if the literature/ reports on the sector contain nothing of relevance to a particular category of failure
‘Slowing down (a little)’	If there is a barrier that is explicitly noted as being of minor significance in contrast to others in a sector, or if a particular barrier is noted as being only applicable to very specific types of products within a sub-sector, this caveat is added
‘Slowing down’	Used if a barrier does not prevent successful innovation altogether, but nevertheless noticeably hinders it in some form
‘Slowing down (a lot)’	If there is a barrier, which, though not a showstopper, is explicitly acknowledged in the literature as being an especially severe barrier, or is mentioned by all or almost all reports on the sector, the ‘a lot’ caveat is added to indicate heightened significance
‘Showstopper’	Used if the nature of a barrier is such that it effectively makes successful innovation completely or almost completely impossible

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[55] see eg The Technology Innovation Needs Assessment (TINA) reports. Overview available: http://www.carbontrust.com/resources/reports/technology/tinas-marine-energy,-carbon-capture,-heat,-bioenergy,-electricity-networks-and-storage

Where evidence of a barrier is found and cannot be classed as a ‘showstopper, ‘slowing down’ will be the default. The additional caveats, ‘slowing down (a lot)’ or ‘slowing down (a little) will only be used if the literature and reports explicitly allow it in accordance with the criteria set out in the table above. Adding these additional caveats may not always be possible, but by using them in this sparing way it can be ensured that the influence of subjective judgement in the classification of barriers to innovation is kept to a minimum.

Innovation areas

The 22 innovation areas BIS defined to be dealt with in this study fall into four distinct categories. First, there are challenge led areas. These constitute substantive societal themes, where innovations from any number of different technological fields could yield substantial social and economic benefits. Second, there are competencies: namely high value manufacturing on one hand and digital services on the other. The third category, development areas, is made up of areas where there is especially significant existing and emerging strength and expertise in the UK. For the most part, areas in this category are conceptually close to the ‘challenge-led areas’ in the sense that they relate not so much to specific technologies as they do to specific areas of social and economic life (e.g. creative industries, financial services). However, this category also contains areas of technological expertise and promise that may find applications across a number of different sectors. Specifically, these are the much-publicised ‘8 Great Technologies’.[56] The final category, ‘Enabling technologies’ contains innovation areas that are explicitly non-sectoral, i.e. general purpose technologies that have an especially wide range of potential applications across a range of sectors: Advanced materials, ICT, Electronics, photonics and electrical systems, and biosciences. Many of the ‘8 Great Technologies’ simultaneously fit into this category, as well as constituting ‘development areas’.

Table 3 Innovation areas

Challenge led areas	Competencies	Development areas	Enabling technology capabilities
• Energy • Built Environment • Food • Transport • Healthcare	• High Value manufacturing • Digital Services	• Creative industries • Financial services • Design • Emerging technologies, such as the ‘eight great technologies’: Big Data Satellites and Space Robotics & Autonomous systems	• Advanced Materials • ICT • Electronics, Photonics and Electrical Systems • Biosciences

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[56] See eg Willets D (2013) Eight Great Technologies. Policy Exchange; available: http://www.policyexchange.org.uk/images/publications/eight%20great%20technologies.pdf; BIS (2013) Eight Great Technologies: infographics Homepage. Available: https://www.gov.uk/government/publications/eight-great-technologies-infographics

Challenge led areas	Competencies	Development areas	Enabling technology capabilities
		Life sciences, Genomics and Synthetic Biology Regenerative Medicine Agri-Science Advanced materials and Nanotechnology Energy and its storage	

Though it is initially helpful to divide various innovation areas into substantive/sectoral and technological/scientific categories, and to additionally distinguish between challenge led areas attached to pressing societal needs on one hand and areas of particular competence on the other, there are a number of problems with the scale, scope and structure of these 22 innovation areas in terms of conducting an analysis with sufficient focus and depth to yield meaningful results:

Firstly, each of the five challenge-led areas has considerable breadth, with multiple possible types of innovation in each area, ranging from advanced manufacturing to digital products, innovations relating to the transformation of entire infrastructures as well as small-scale development in no need of extensive coordination. A brief initial overview of some of these sectors highlighted that, if taken as a whole, each one of the innovation failures highlighted by the literature review and included in the template could be pointed out multiple times in each challenge-led area. This would not result in useful information, save for the relatively obvious conclusion that if a sector is defined widely enough, every imaginable barrier to innovation could most likely be pointed out within it. In order to produce more focused and nuanced results, each challenge-led area was therefore sub-divided into sub-sectors or sample-technologies that are prominent within it.

Table 4 Sub-division of challenge-led areas

Challenge-led area	Sub-sector / sample technology
Energy	Nuclear energy
	Renewable energy
	Oil and gas
	Energy distribution and storage
Built Environment	Future cities
	Low impact buildings
Food	Agri-science
	Farm-to-fork
Transport	Low carbon vehicles
	Intelligent transport systems
	Civil aviation
Health & Care	Regenerative medicine

Challenge-led area	Sub-sector / sample technology
	Assisted living
	Stratified medicine

This sub-division has enabled results that give an overview of barriers that are especially prominent in each sector along with explanations for their prominence, whilst also highlighting the *variation* of barriers to innovation within each sector. Second, as with the challenge-led areas previously, two of the sectors to be assessed in the category of ‘enabling technologies’ required division into sub-sectors or sample-technologies in order to avoid overly general statements about broadly defined sectors:

Table 5 Sub-division of broad technology sectors

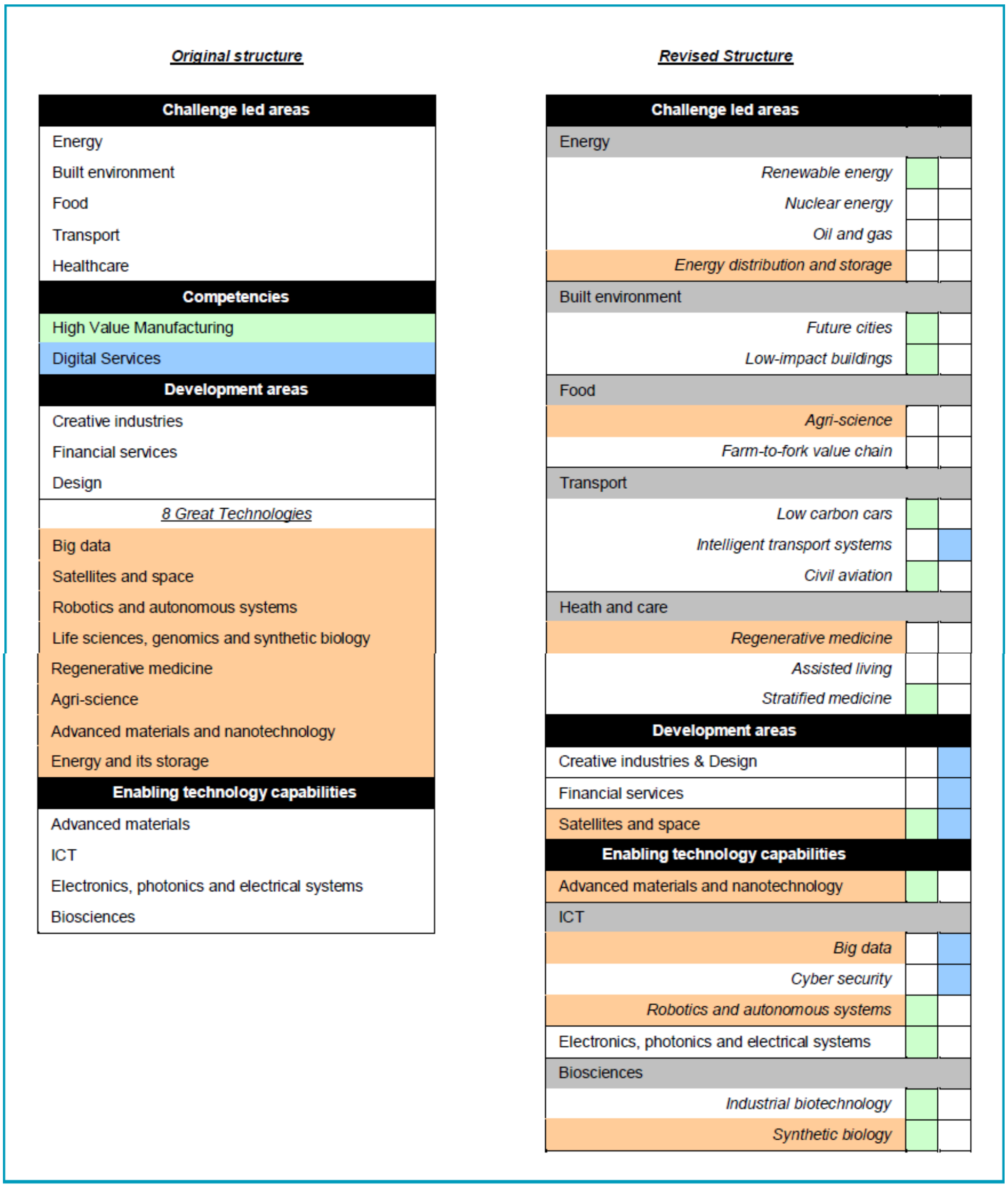
Sector	Sub-sector/ sample technology
ICT	Big Data
	Cyber Security
	Robotics and autonomous systems
Biosciences	Industrial biotechnology
	Synthetic biology

Third, whilst the challenge-led areas and specific enabling technologies could be assessed in suitable depth by subdivision into a few specific sub-sectors or sample-technologies, the ‘competencies’, high value manufacturing and digital services, are too broad even for this solution. Instead, these two terms will therefore be treated not as distinct innovation areas, but instead as descriptors that can be applied where appropriate to all other innovation areas to be assessed in this study. More than half of all the innovation areas to be considered here were found to fit squarely into either the ‘high value manufacturing’ or the ‘digital services’ competency. The value of these two areas is therefore not as a source of specific assessment of barriers to innovation, but rather as a tool to categorise and assess results across all the sectors. Drawing conclusions on the overall differences in the types of barriers to innovation in high value manufacturing and digital services, respectively evidenced by a range of more focused innovation areas, will be a key element of discussion and analysis in the latter stages of this report.

The fourth challenge with the existing structure concerns the ‘8 Great Technologies’. As already noted, these only partially fit into the category of ‘development areas’. In part, they also constitute enabling technologies, while some of them also make for particularly useful sample-technologies within the challenge-led areas (specifically regenerative medicine for ‘health and care’, agri-science for ‘food’ and energy storage for ‘energy’. The ‘8 Great Technologies’ have therefore not been treated as a comprehensive block, but are instead broken up and spread across the analysis as sub-sectors and sample-technologies where appropriate.

Based on these four considerations, the initial 22 innovation areas have been expanded to 24 and re-arranged into a suitable structure covering all areas in required depth, whilst simultaneously having thematic and conceptual divisions that will allow clearer and more sophisticated analysis at the conclusion of the study. For reference, each innovation area is marked at its heading, indicating whether it falls under one or more of the categories ‘challenge-led area’, ‘enabling technology’, ‘8 Great Technologies’, ‘high value manufacturing’ and ‘digital services’.

Table 6 Innovation areas: original and revised structure



Original structure
Challenge led areas
Energy
Built environment
Food
Transport
Healthcare
Competencies
High Value Manufacturing
Digital Services
Development areas
Creative industries
Financial services
Design
8 Great Technologies
Big data
Satellites and space
Robotics and autonomous systems
Life sciences, genomics and synthetic biology
Regenerative medicine
Agri-science
Advanced materials and nanotechnology
Energy and its storage
Enabling technology capabilities
Advanced materials
ICT
Electronics, photonics and electrical systems
Biosciences

Revised Structure		
Challenge led areas		
Energy		
Renewable energy	🟩	
Nuclear energy		
Oil and gas		
Energy distribution and storage		
Built environment		
Future cities	🟩	
Low-impact buildings	🟩	
Food		
Agri-science		
Farm-to-fork value chain		
Transport		
Low carbon cars	🟩	
Intelligent transport systems		🟦
Civil aviation	🟩	
Heath and care		
Regenerative medicine		
Assisted living		
Stratified medicine	🟩	
Development areas		
Creative industries & Design		🟦
Financial services		🟦
Satellites and space	🟩	🟦
Enabling technology capabilities		
Advanced materials and nanotechnology	🟩	
ICT		
Big data		🟦
Cyber security		🟦
Robotics and autonomous systems	🟩	
Electronics, photonics and electrical systems	🟩	
Biosciences		
Industrial biotechnology	🟩	
Synthetic biology	🟩	

Evidence

To generate evidence of barriers to innovation in each of the 24 areas, we conducted desk research to compile a selection of key reports on each area. For each area, several reports were ultimately drawn on directly for use as template evidence, with further reports used to backup additional points in the accompanying text. It was a key requirement that for each area, the nature of reports used stemmed from several different sources. In general terms this meant that where possible there were reports giving an international or EU, as well as a UK perspective, reports authored or commissioned by government as well as reports unconnected to government, reports commissioned or compiled within the relevant sector and independent academic research published in peer-reviewed journals. For each innovation area, several of these different groups of sources have been drawn on, in order to compile a broad and representative evidence-base. Overall, around 150 reports were drawn on to provide the evidence base across the 24 innovation areas.

The evidence base used to describe barriers to innovation draws on diverse types of evidence, ranging from quantitative surveys, numerical sector analysis to interviews, focus groups, workshops, case studies, collected expert opinions and historical analysis. This diverse range of evidence types reflects the differences that exist between the eight types of innovation failure identified through the literature review in the first part of this report: some types of failure can be quantified (e.g. size of market players, numbers of skilled graduates), others are better explained in qualitative terms, through historical narrative, expert opinion and, occasionally, through common sense.

In the template evidence as such, the existence of each barrier is therefore highlighted by cited quotes from the reports, with additional references where several reports make strongly similar statements. Quotes can therefore be read as summarising the various types of evidence on which the reports on each innovation area are based. Where possible, easily presentable numerical/ statistical evidence features in the accompanying text for each innovation area.

Sectors and subsectors

We begin by assessing barriers to innovation at the level of sectors. These sectors are a combination of challenge-led areas, i.e. areas with considerable social and economic externalities and implications, as well as key development areas, where the UK already has considerable strength. The challenge areas to be covered here are energy, the built environment, food, transport and healthcare, with creative industries, financial services and satellites/ space identified as additional development areas.

Energy

The energy market is widely recognized as a key challenge-led area of core concern for UK industrial development and welfare. Following the rationale of the development view, there is a need for public intervention in the energy sector because a lack of financial support, and a lack of investors' and consumers' trust in the self-organizing capacity of the market would result in sizable underinvestment in the energy sector.

Three features are of major importance to understand the (lack of) development in the energy market. First, private entities lack incentives to invest in renewable energy sources because (i) given current prices, investment in renewable energy is more costly than investment in more traditional forms of energy and (ii), given these prices, the demand for renewable energy is relatively lower than the demand for other types of energy. Second, private entities may not find it profitable to supply energy to more remote areas and as a result some consumers are vulnerable to energy access. Third, underinvestment in the energy market has a detrimental effect on overall industrial development and welfare because of the degree of dependency on energy supply. These reasons were sufficient for the UK government to keep the energy market state-led for much of the 20th century.

However, in the 1980's, there was an increased recognition of the problems associated with a lack of competition in state-led markets and of government failure. This resulted in increased debate on the type of government intervention that is most appropriate for the energy market. As an alternative to a heavily interventionist state, there is a possibility for government intervention by means of regulation and contracting. The basic premise is that if energy supply can be contracted to private suppliers on the basic of predefined conditions there is no real need for the energy market to be state-led.

In the 1980's, part of the UK energy market gradually became privatized, i.e. electricity and gas. Along with the privatization process, the energy market became heavily regulated addressing several of the abovementioned concerns. The 2003 energy white paper set out a national energy policy. In response to growing concerns regarding energy security and climate change, this energy white paper was followed by the 2006 energy review report, and subsequently also by the energy white paper of 2007 ("meeting the energy challenge"), the climate change act of 2008, the UK low carbon transition plan of 2009 and the 2012-2013 energy bill.

One additional change is that the UK energy market has become increasingly regulated at the EU level. UK policy and regulation has been reformed in line with the commitments to the EC. For example, following the Europe 2020 agenda, the UK aims to source 15% of energy from renewable sources by 2020 and aims to reduce greenhouse gas emissions by 80% by 2050.[57] These UK targets are in line with that of the EC's 2020 objectives.[58] One outcome is that the UK energy market is becoming more integrated with the EU energy market.

Today, broadly speaking, these UK energy strategy includes the following objectives: generate a large-scale renewable energy market, generate a competitive energy market,

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[57] The UK Department of Energy and Climate Change (2012) UK renewable energy roadmap update 2012

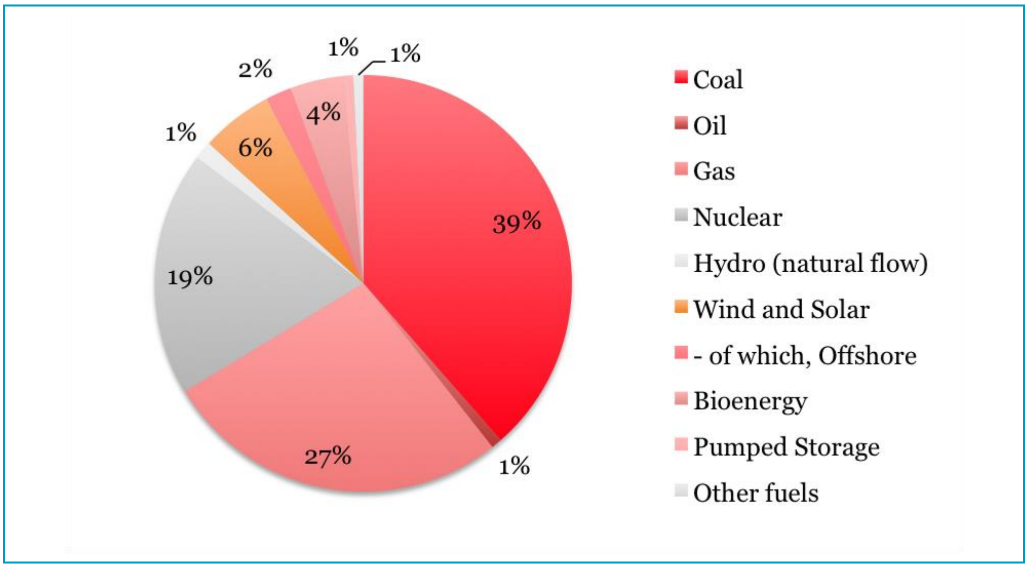
[58] COM (2010) Europe 2020: A Strategy for Smart, Sustainable and Inclusive Growth. 2020 final

ensure the overall competitiveness of the UK energy market, generate an integrated energy market, minimize health risks, expand knowledge and industry take-up, and reduce energy consumption in domestic buildings.

In this section we provide an overview of the current challenges and failures in the UK energy market. This analysis is divided into three sections. Section one covers failures in nuclear energy and section two covers failures in the renewable energy sector, such as wind and solar energy. In the third section, we analyse the failures that undermine the development of the electricity market and the challenges of energy storage.

It is important to note that the generation of electricity involves many sources. As illustrated in Figure 5, electricity is generated via nuclear energy (19%), renewable energy (roughly 14%), and fossil fuel energy i.e. oil gas, and coal which amounts to the largest component (67%).

Figure 5 Generation of electricity in the UK in 2012 by all generating companies



Source: UK Department of Energy and Climate Change

Nuclear Energy

Challenge led area

The first part of the analysis focuses on the nuclear energy sector. Since 2011, the Office for Nuclear Regulation (ONR) is responsible for regulating regulation on the nuclear sector. An overview of these regulations is set out in the ONR guide[59] accessible via the ONR website. Despite safety regulations and precautions, it is often argued that investing in nuclear energy involves high risk and can be extremely hazardous.

Table 7 summarizes some of the market failures associated with investing in nuclear energy. We evaluate the degree to which a given example of market failure is a showstopper to innovation or whether it slows down the innovative process. As indicated

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[59] ONR (2013) A Guide to Nuclear Regulation in the UK. Office of Nuclear regulation; available: http://www.hse.gov.uk/nuclear/documents/a-guide-to-nuclear-regulation-in-the-uk.pdf

by the sources, most of these failures are identified in the TINA report on nuclear fission.[60] According to this TINA report, the degree to which a given type of failure is critical is identified on the basis of consultation of nuclear experts.

At a first glance, it is possible to identify all types of market failures within the nuclear energy market. Some of the market failures–externalities and institutional failure–are identified as relatively more critical (see TINA).

Market power is identified as a significant failure because the sector lacks new entrants in the market. Albeit the UK energy market has become gradually more privatized, the bulk of nuclear energy supply remains controlled by a few large players. The main reasons are that entry in the energy market involves high sunk costs and, overall given market conditions, economies of scale are only achievable in the long run and on the basis of a large consumer base. Because the nuclear energy market is relatively protected against competitors, innovative development is dependent on the innovative capacity of the dominant players. As a result, there is a danger that the market will fail to invest in innovation. And, for this reason we indicate that this type of market failure is a showstopper to innovation.

Externalities can be identified as a critical failure. As a result of the hazards, the cost of investing in nuclear energy is high. In particular, following Sovacool,[61] the ‘true cost’ of investing in nuclear energy is substantially higher than the ‘true cost’ of investing in renewable energy. The concept of true cost refers to the cost of operations as well as the cost of industry on public health, environment and other factors that are not accounted for by the industry. The true cost of investment in the energy market, is difficult to estimate.[62] If investment decisions were to be made in the true cost of investment, it is possible that different investment decisions would be made. As a result, alternative energy markets made be underinvested which is slowing down the innovative capacity in these areas. For this reason, we classify this type of failure as slowing-down innovation.

One type of information asymmetry failure related to the nuclear energy sector is that of lack of monitoring. According to the TINA, this results on a coordination failure. However, lack of monitoring, for example in relation to nuclear safety, consists of an information asymmetry problem especially when some actors have more information about the degree of safety and hazard but lack incentive to fully disclose the risks. This type of information asymmetry is also referred to as moral hazard. A priori, it is not clear what the effect of moral hazard is on innovation but it is likely that it slows down innovative capacity.

According to the TINA on nuclear fission, capabilities are identified as a moderate failure for the nuclear energy sector. The identified obstacle is that of ensuring a skilled workforce

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[60] TINA (2013) Nuclear Fission. Summary Report

[61] B. K. Sovacool (2011) Contesting the Future of Nuclear Power. Chapter: The Self-Limiting Future of Nuclear Power. World Scientific Publishing Co. pte. Ltd. Singapore.

[62] If the so-called true cost of investing in nuclear energy is relatively higher what are the rationales for investing in nuclear energy? It was argued by the private company British Energy in 2001, one of the rationales for government financial support of the nuclear energy market is that nuclear energy can contribute to address climate change issues and that investing is this market helps ensure energy diversity and security. see OECD (2004) Government and Nuclear Energy. OECD Observer, available: http://www.oecdobserver.org/news/archivestory.php/aid/1310/Government_and_nuclear_energy_.html

over long-term horizons. Possibly, this type of failure is considered ‘moderate’ instead of more critical because labour market mobility can help solve bottlenecks in the UK energy market. In any case, this type of failure slows-down the innovative capacity.

Network failures are identified as significant: investors lack incentives to share information with (potential) competitions. Because different actors have to undertake similar types of investment instead of pooling knowledge, this type of failure slows down aggregate levels of innovation.

One of the major failures in the nuclear energy market is institutional failure. The regulations in this energy market have been reformed substantially over the past years and reform is still on-going. Because private sector investment decisions are dependent on these regulations, much investment is currently deterred. The market failure acts as a showstopper to innovation in nuclear energy.

Similarly, changes in the energy infrastructure are deterring investment. One specific example of a deterrent is that advanced manufacturing capabilities are restricted limiting efficient and effective advancements. According to the TINA report on nuclear fission, this type of failure is ‘significant’. The market failure likewise acts as a showstopper to innovation in nuclear energy.

It is clear that identifying the market failure as either a showstopper or as slowing-down innovation is not alike to identifying the degree of failure as e.g. critical, significant, moderate. For example, both the example of network failure and the example if market power failure given are identifies as ‘significant failures’. However, we identified the market power example as a showstopper and the network failure as slowing-down innovation.

Table 7 Failures in the Nuclear energy market

Failure	Source	Scale	Description
Character of Science and technology		No evidence found	
Market power	TINA, nuclear fission	Show-stopper	The high capital cost in the nuclear energy market act as a market entry barrier to new innovative players.
Externalities	TINA, Nuclear fission; Sovacool, 2011	Slowing down (a lot)	Costs related to health and environmental damage and catastrophic damage such as nuclear accidents are difficult to capture and therefore are not (fully) borne by nuclear energy suppliers. One reason such cost are not accounted for is that the event of e.g. catastrophic damages occurring is uncertain.
Information asymmetry	TINA, Nuclear fission	Slowing down (a little)	Lack of monitoring
Capabilities	TINA, Nuclear fission	Slowing down	“The necessary skilled workforce requires a long time to reach maturity and is vulnerable to high turnover rates and obsolescence, requiring constant investment even during lossmaking periods”
Network	TINA, Nuclear	Slowing down (a	“Insufficient sharing of array performance data due to perceived risks of losing competitive advantage”

Failure	Source	Scale	Description
	fission	lot)	
Institutional	TINA, Nuclear fission	Show-stopper	“Until government policy on waste management and reprocessing is clear the market does not have a strong incentive to innovate”
Infrastructural	TINA, Nuclear fission	Show-stopper	“Limited number of nuclear vendors with advanced manufacturing capabilities, low competition and high barriers to entry due to the need for costly testing facilities such as particle accelerators”

Renewable Energy

Challenge led area

High value manufacturing

Investment in renewable energy, i.e. offshore wind energy, biomass energy, solar thermal electricity, hydro, geothermal, ocean has become a priority for the UK. One criterion that distinguishes the renewable energy sector from the other energy sectors it the overwhelming lack of knowledge about the future value of investment in renewable energy, e.g. new technologies and energy storage, and this creates a barrier to the deployment of new possibilities in the field of energy and to innovation in the field. In particular, consumers lack knowledge on the current possibilities in the field.

UK targets for renewable energy are in line with those of the Directive 2009/28/EC of the European parliament and of the Council. Several advances have been made since the enforcement of this directive. For example, according to the UK Department of Energy and Climate Change (2012), during the period 2011-2012, the cost of photovoltaic installations decreased by 50%. At the same time, market failures undermine a rapid uptake of innovation in the field of renewable energy. In this section we discuss some of these challenges.

Large and powerful players dominate the renewable energy sector. One example, as noted in the TINA report on offshore wind energy,[63] is the case in both the switchgear and cabling market. As noted in Table 8, big players dominate the turbine market but this situation is expected to change in the future. In the meantime, the lack of competition in the market is slowing-down innovation.

Externalities have a substantial influence on the renewable energy market. From an economic, social and environmental point of view it is desirable to have a large-scale renewable energy market. However, the renewable energy market remains underinvested because this type of energy is relatively more expensive and it is challenging to pass these higher costs on to the consumer. One assumption is that if an energy supplier chooses to invest relatively more expensive source of energy or if this supplier would restrict its supply to green/renewable energy it would become less profitable and hence the company would be driven out of the market. For example, the renewable obligation seeks to address this type of challenge within the market. Externalities also play a role in guiding the behaviour

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[63] TINA (2013) Offshore Wind Power. Summary Report

of consumers and or entrepreneurs, for example, in situation when they risk not being able to appropriate the returns from an investment such as that of the instalment of low-carbon electricity generation systems.

One type of information asymmetry failure identified in the market is the reluctance of manufacturers to share information. This results in some manufacturers with a competitive advantage and other manufacturers making similar investment in order to catch-up creating large inefficiencies in the market. According to the TINA report this type of failure is ‘important’. We identify it a slowing-down innovation rather than blocking innovation altogether. An additional type of information asymmetry that we identify is in the case where consumers lack information about the benefits of investing in renewable energy and for this reason refrain from doing so (see also Gillingham and Sweeney, 2010).[64] According to Soete,[65] consumers’ take-up of green technologies is lagging behind the industry capabilities. This gap between innovative capacity and commercialization can have a negative effect on industries’ incentives to innovate.

Regarding the failure of the type capability we have not elaborated a specific example. Still, it is likely that a lack of technical knowledge and skills available on the labour market will constrain the deployment of new energy possibilities. Moreover, the development of future possibilities in the energy market is dependent on the level of investment in research and innovation and investment in human capital. The cost of education, training, R&D and innovation is only partially captured by the private sector and public investment in education and training remain of high importance.

Network failures are pertinent to the development of renewable energy: the uptake and commercialization of future innovation and development in energy technology is dependent on the coordination with early stage research initiatives as well as the regulatory development. Also, as noted in the example in the Table, simultaneous developments are needed to ensure innovation uptake. As indicated in the TINA on bio-energy, the cost associated with supporting the process of innovation in bio-energy, e.g. runs in the 100 millions. Critical coordination failures are argued to undermine the development of a large-scale electric vehicles (EVs) market, e.g. to coordinate and integrate project investment. Network failures may block some innovation; however overall, we suggest that network failures slow down the overall process of development.

Some rules and regulations that steer the interactions between different agents may hinder the innovation and development in the energy sector. Institutional rules (social and formal) likewise contribute the dynamics in the energy sector and create a lock-in to relatively less efficient sources of energy. According to the EREC[66] report, administrative barriers inhibit renewable energy development. Examples of such administrative and regulatory barriers includes, but are not limited to, the implementation of one-step authorization procedures and the certification of engineers via accredited training programmes. The formation of

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[64] Gillingham, K. and Sweeney, J. (2010) Market Failure and the Structure of Externalities. in: A. J. Padilla and R. Schmalensee (eds.) Harnessing Renewable Energy. Available: http://www.yale.edu/gillingham/Market%20Failure%20and%20the%20Structure%20of%20Externalities.pdf

[65] Soete, L (2007) From Industrial to Innovation Policy. *Journal of Industry, Competition and Trade*, 7(3): 273-284

[66] EREC (2008) Renewable Energy Technology Roadmap 20% by 2020. European Renewable Energy Council

new institutional rules can contribute to the uptake of renewable energy. One example is that of the renewable obligation that requires energy producers located in the UK to offer a proportion of their energy supply that is generated using renewable energy sources. The state also plays an important role in regulating the energy market by ensuring the protection of (intellectual) property rights and respect for law and contracts. Additionally, as explained in the previous section, the regulatory structure of the electricity grid can also misalign incentives in the energy market. Because institutional failures create barriers that individual innovating firms cannot overcome, we argue that these types of failures have a significant showstopper effect in unleashing innovative potential.

According to the TINA report on offshore wind energy, infrastructural failures create critical failures in the market. In this case, the report particularly refers to the lacking ability of turbine manufacturers to develop their own test sites, and thus reliance on public support in this area. The House of Lords European Union Committee[67] has identified similar supply chain bottlenecks. Again, we denote these types of (critical) failures as showstoppers.

Table 8 Failures in the Renewable energy market

Failure	Source	Scale	Description
Character of Science and technology		No evidence found	
Market power	TINA, off-shore wind	Slowing down	“Lack of competition may hinder turbine innovation (i.e. imperfect competition and high barriers to entry). The OSW turbine market is currently dominated by a limited number of firms; however, entry by other players are expected soon”
Externalities	TINA reports	Show-stopper	Challenge to create a large-scale renewable energy market
Information asymmetry	TINA, Off-shore wind Gillingham and Sweeney (2010)	Slowing down	“There are barriers for companies to collaborate as turbine manufacturers do not want to share product warranty data” “If households have limited information about the effectiveness and benefits of distributed generation renewable energy, there may be an information market failure”
Capabilities		No evidence found	
Network	TINA, Bioenergy [68] (pp. 26)	Slowing down (a lot)	“Innovations from both crop production and crop development are necessary to unlock the potential of bioenergy. Achieving this requires the bioenergy markets for feedstock production, transport and conversion to develop symbiotically. New,

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[67] House of Lords (2008) European Union Committee. The EU’s target for Renewable Energy 20% by 2012

[68] TINA (2013) Bioenergy. Summary Report

Failure	Source	Scale	Description
			sustainable feedstocks and the conversion technologies that utilise them have to be developed hand in hand, to create an integrated, functioning, market. Due to high transaction costs across the diverse bioenergy supply chain, this does not happen sufficiently, restricting the extent and effectiveness of R&D activity”
	TINA; electricity, networks & storage	Show-stopper	“High level of coordination (and transaction costs) required for consolidated EV integration makes it hard for individual players in the market to drive demand”
Institutional	EREC (2008, pp. 3), Gillingham and Sweeney (2010)		Administrative barriers are still a major problem for renewable energy development. Regulation of electricity prices creates perverse incentives.
Infrastructural	EREC (2008) (pp. 3) TINA, offshore wind House of Lords pp.30	Show-stopper	“Infrastructure development and priority access for renewables to the grid are key for a large-scale penetration of renewables” “Turbine manufacturers lack the capability to develop their own test sites, and so rely on national centres or developers to provide sites.” “A further barrier to meeting the target was the industrial supply chain (…). We were told that suitable specialist vessels available for hire in Europe to build and maintain offshore wind farms are in short supply, that the market for turbine manufacture is limited and that the prices of copper and steel were making new offshore wind farms more expensive.”

Oil and gas

Challenge led area

Oil and Gas together fuel about 28 % of total UK electricity generation (UK department of energy and climate change data from 2012). However, most of this energy, 27% out of the 28%, is derived from gas. In terms of primary energy, the value of UK oil and gas is close to 50% of the total energy value,[69] The operating volume of the UK industry in 2009 was 2.48 million barrels of oil and gas per day, capital investments of £4.7 billion, and operating

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[69] HM Government (2012) UK Government Oil and Gas Sector Strategy

costs of £6.6 billion.[70] The industry employs roughly 440,000 people. Following HM Government (2013, pp. 17), "the development and implementation of new technology is of vital importance to maximising recovery from the challenging UKCS environment, yet overall R&D spend of the sector in the UK is reported to be 0.3% of sales; far lower than Norway's proportion of 4%".[71]

The UK oil and gas market is regulated by the 1934 petroleum production act, the 1998 petroleum act, the 1886 gas act, and several environmental and health and safety legislation. Operators require several permits and approvals prior to exploration. Following the 1934 petroleum production act, the UK government has the exclusive right to grant licences to operators to explore and extract oil and gas resources. Operators that have been granted licences pay an annual rent and remain liable for any costs arising from the exploration of oil and gas, even when such operators no longer have commercial interests.

Despite its relative size and economic value there are several barriers in the industry that impede the development of the industry and have shifted some of the energy focus to alternative energy sources. First, the industry outlook faces significant uncertainty due to high price volatility of both oil and gas; in 2009, for example, gas prices dropped significantly below oil prices. In addition to the uncertainty over prices and price trends some argue that the UK government has underestimated the importance of the gas industry to the economy. POYRY (2010)[72] are specifically sceptical of the degree to which the electricity market will yield the expected results because of high uncertainty of technological development in this industry. One argument is that the smart grid concept has not been tested. If the government has underestimated the costs associated with technological development, this may have resulted in underinvestment in the gas industry due to "'not sending the correct investment signals to the market, as evident in continuing delays in new investments".

One issue that is currently debated is that of pursuing shale gas drilling. As also noted by 'Practical Law' (2013), the UK shale gas industry is in early stages of development and has been limited to explorative drilling that had been temporarily suspended in 2011 for environmental and health concerns. According to IoD Big Picture[73] planning and issuing permits is still a major barrier to drilling and fracturing in the field. As additionally noted in the report, skills to shale gas extraction are a moderate barrier. In particular, reference is made to the aging workforce offshore which arguably hinders development. At a more generic level, the industry is also found to lack adequate skills and training such as project management experience, senior managerial and specialist engineers, subsea and drilling experience.

Oil and Gas UK[74] estimates that, over a period of roughly 40 years, the UK has invested more than £283 billion in offshore facilities, on transportation infrastructure and on onshore processing of oil and gas from the North Sea. However, the decommissioning of these

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[70] Oil and Gas UK (2010) Oil and Gas UK Activity Survey

[71] HM Government (2013) UK Oil and Gas Business and Government Action. Industrial Strategy: Government and Industry in Partnership, March 2013

[72] POYRY (2010) Gas: at the center of a low carbon future. Review for Oil and Gas UK

[73] IoD Big Picture (2013) Shale gas: overcoming the barriers

[74] Oil and Gas UK (2010) Decommissioning Insight

structures (installations, infrastructure, pipeline, wells) has been limited. The costs associated with decommissioning are estimated to be ten per cent of the total investment (Oil and Gas UK, 2010). Practical Law (2013) estimates that the cost of decommissioning oil and gas installations and pipelines is around £33 billion.

The UK state can require operators to submit a decommissioning programme, including a cost projection even when operators no longer have a commercial interest in the field. Upon approval, the operators are required to carry out the decommissioning programme and maintain liability (Practical Law, 2013). The cost of decommissioning are subject to tax relief at the time the costs are incurred. Following additional estimation of HM Revenue & Customs (HMRC), the £33 billion estimation implies a net cost of £13 billion after tax for the operators in charge. Because these costs are so high – and are difficult to predict – a major concern for operators is that of obtaining tax relief. Oil and Gas UK specifically mention the difficulty in determining scale, timing and value of the various technical activities related to decommissioning project and the effect of efficiency improvements and new technologies.

Decommissioning regulations put pressure on operators' financing structure, influencing investors' confidence in the industry. In response to the uncertainty around tax relief and the high decommissioning costs of oil and gas installations, the UK introduced a decommissioning relief deed regime in April, 2013.[75] "The basic principle behind the decommissioning relief deed is that it sets a reference amount as a benchmark amount of relief against which the deed holder can determine whether or not it has actually achieved the appropriate amount of relief through the tax system. Where it has not, then a shortfall claim can be made under the deed, with a payment due from the government. Such payments are not taxable".

The fiscal regime regulations in the field likewise influence the investment decisions, when these impact the returns on investment. Moreover, according to HM Government (2013, pp.15), "some supply chain companies are required to post sizeable performance bonds after being awarded large contract". When this negatively influences the financial status of the company, this regulation lowers the demand for such large contracts. Likewise, smaller companies working in the field find it difficult to implement new technology because if the high costs and long time frame involved with technological development. Additional barriers in the industry include that of acquiring financing. Especially since the financial crisis operators find it more difficult to acquire bank loans. HM Government also argues that some companies do not know how to access funding.

The types of network failures that are referred to are lack of cooperation between operators that work on different part so of the supply chain, e.g. drilling rigs, intervention vessels, and frac boats. This is argued to overheat the supply chain and generates additional pressure on prices. According to HM government, more cooperation could improve the fit between demand and supply.

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[75] Practical Law (2013) Decommissioning UK oil and gas installations: driving down the cost

Table 9 Failures in the oil and gas energy market

Failure	Source	Scale	Description
Character of Science and technology	Oil and Gas UK 2010, pp. 8 pp. 25	Slowing down (a lot)	"The industry currently lacks an insight into the scale, timing and value of the various technical activities which are needed to carry out a decommissioning project. Oil & Gas UK has made its own assessment based on total projected decommissioning expenditure throughout the UKCS. This assessment has been derived by combining actual data from a range of on-going projects with planned expenditure submitted in our most recent activity survey. Inevitably it is an approximation which will vary by area (southern, central and northern North Sea and West of Shetland) and by field. Nor can it capture the impact of efficiency improvements or new technologies which will inevitably emerge with time." "Technical innovations – which will further enhance oil and gas recovery, extend the life of many existing facilities and ultimately reduce the costs of decommissioning."
Market power		No evidence found	
Externalities	HM Government 2013, pp. 15 HM Government 2013, pp. 39	Slowing down	"The issue of accessing finance is one shared by many companies in the oil and gas industry – and not just smaller members of the supply chain. Multi-national operators choose where to best allocate their capital internationally by ranking their portfolio and selecting the projects that deliver the best returns. The fiscal regime is an important component in these company decisions". "Some supply chain companies are required to post sizeable performance bonds after being awarded large contracts. This makes them financially weaker in spite of winning a contract; a potential barrier to that company's growth". "It is suggested that there is a "race to be second" in terms of technology implementation in the UKCS, with end users wanting to implement technology with a proven benefit, but not wanting to be the first to trial a new technology in situ. Anecdotal evidence from discussions with the industry has suggested that some SMEs go out of business before their product is trialled."
Information asymmetry	HM Government 2013, pp. 39		"The 2008 financial downturn has made banks more risk averse to financing companies through debt. There are many financial instruments currently available to the oil and gas industry, but at present there is an incomplete understanding on the

Failure	Source	Scale	Description
	Oil and Gas UK 2010, pp. 24	Slowing down	industry’s side of how to access them". "Uncertainty around costs, and also decommissioning timings as will be shown in the next section, have made companies within the decommissioning supply chain hesitant to invest despite the scale of the forecast expenditure. Greater transparency and access to operators’ timelines would act as a potential catalyst for investment". "The 2008 financial downturn has made banks more risk averse to financing companies through debt. There are many financial instruments currently available to the oil and gas industry, but at present there is an incomplete understanding on the industry’s side of how to access them".
Capabilities	IoD Big Picture (2013)	Slowing down (a little)	Skills to shale gas extraction are a moderate barrier.
Network	HM Government 2013, pp. 39	Slowing down	"High activity levels can lead to an ‘overheating’ of the UK supply chain and increased demand for cost-competitive options overseas. Collaboration would work to smooth out demand and supply."
Institutional	Oil and Gas UK 2010, pp. 22 Oil and Gas UK 2010, pp. 25	Slowing down (a lot)	"Decommissioning of offshore oil and gas installations and pipelines is regulated by the Petroleum Act 1998. The current owners of the assets are jointly and severally liable for decommissioning and its costs. Whilst companies make full and proper provision for the costs in their accounts, currently there are no dedicated decommissioning funds, nor does the fiscal regime encourage such an approach. Liability for decommissioning costs is not however restricted to the current owners of an asset. Under the Petroleum Act, previous parties may also be held liable in the event that the current owners are unable to meet their obligations. This is achieved through Section 29 of the Act which places these decommissioning obligations on previous licensees, except where the Secretary of State has chosen to release them from their liabilities". "Certainty/uncertainty about the future fiscal and regulatory regimes – which will influence the investment environment (...)"
Infrastructural	HM Government 2012, pp. 4		“Skills continue to be a major issue for a number of sectors, including the oil and gas sector. Shortages are reported in project management, senior managerial and specialist engineering positions.”

Failure	Source	Scale	Description
	HM Government 2013, pp. 19	Slowing down	"High levels of activity and global competition have resulted in skills shortages; the availability of sufficient numbers of skilled workers is seen as one of the biggest challenges the industry faces. The supply/demand mismatch is impacting project schedules and driving up costs; a major threat to the overall competitiveness of the sector".
	HM Government 2013, pp. 20		"Current demand for experienced engineers and geoscientists in the UK (and globally) outstrips supply. The industry expects it will require an additional 15 thousand staff over the next 4-5 years across a range of disciplines, including design engineers (all disciplines), subsea and drilling".

Electricity distribution and storage

Challenge led area
'8 great' technology

The development of energy storage capacity is a key requirement in order to meet the current objectives for energy efficiency and emissions targets. Energy storage is important for the stability and flexibility of the grid and is critical to ensure that peaks of demand are satisfied. The transition towards more renewable energy generation, mainly from wind and solar sources, creates additional challenges in matching the supply and demand of energy. According to the IEA, global electricity storage capacities from 189 GW to 305 GW will be needed by the year 2050 to mitigate grid imbalances attributable to variable energy resources. The uptake of energy storage is very important in order to make possible the transition to smart grids and cities in the near future. The total available market for energy storage has been estimated at more than $600b in the period 2009 to 2020[76] even if just 1% of the total worldwide stationary energy generation market were to adopt some form of energy storage.

Energy storage can serve many different purposes in today's power system. Table 10 shows the different ways in which energy storage can provide value across different application scales and functionality domains. As it can be observed, the dynamic behaviour of storage is usually more important than its long-term capacity.

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[76] Piper Jaffray Investment Research (2009) Energy Storage: Game-Changing Component Of The Future Grid.

Table 10 Purposes of energy storage in today’s power system

	Transmission grid-central storage (national and European level)	Distribution grid storage (city level)	End-user Storage (household level)
Balancing demand and supply	• Seasonal / weekly fluctuations • Large geographical unbalances • Strong variability of wind and solar • (Electricity and gas storage need to be integrated)	• Daily / hourly variations • Peak shaving • (electricity and heat/cold storage need to be integrated)	• Daily variations • (electricity and heat/cold storage need to be integrated)
Grid management	• Voltage and frequency regulation • Complement to classic power plants for peak generation • Participate in balancing markets • Cross-border trading	• Voltage and frequency regulation • Substitute existing ancillary services (at lower CO2) • Participate in balancing markets	• Aggregation of small storage systems providing grid services
Energy Efficiency	• Better efficiency of the global mix, with time-shift of off-peak into peak energy	• Demand side management • Interactions grid-end user	• Local production and consumption • Behaviour change • Increase value of PV and local wind • Efficient buildings • Integration with district heating /cooling and CHP

Source: European Commission. DG ENER Working Paper. The future role and challenges of Energy Storage. 2013

Energy storage technologies are diverse and are at different stages in their commercial readiness. In Europe, Pumped Hydro Storage Systems (PHS) for large-scale electricity storage has been used for decades and represents almost 99 % of current worldwide storage capacity. However, by 2030 over half of this installed capacity in Europe will need to be refurbished because of ageing.[77] Nowadays, technologies are available across large-scale (GW), medium-sized (MW) or micro, local systems (kW) applications. The technological challenges of energy storage revolve around increasing the capacities and efficiencies of existing technologies, and developing new technologies for local (domestic), distributed or large centralised applications. A summary of the available technologies and their main characteristics can be seen in Figure 6.

Apart from pumped hydropower, most of the other technologies still need R&D efforts to reduce costs and improve performance. Specifically, pilot initiatives are needed in order to bring alternative storage technologies to a stage of commercial maturity and to accelerate the transition to mass commercialisation. In addition to technological challenges, the development and uptake of energy storage technologies will depend on the presence of appropriate market signals to incentivise the building of storage capacity and the provision of storage services.

One of the underpinning uncertainties in the field of energy storage is that it is unclear how much storage capacity is needed in the future and which types of energy storage systems will be most dominant. In addition to this type of uncertainty, Table 11 outlines three additional barriers to the mass deployment of energy storage: market regulation, current electricity and commodity prices, and performance of storage technologies. Uncertainty of the profitability of investing in energy storage is also related to the concept of ‘self-cannibalisation’.[78] The basic idea is that overinvesting in storage capacity could have a negative effect on its value.

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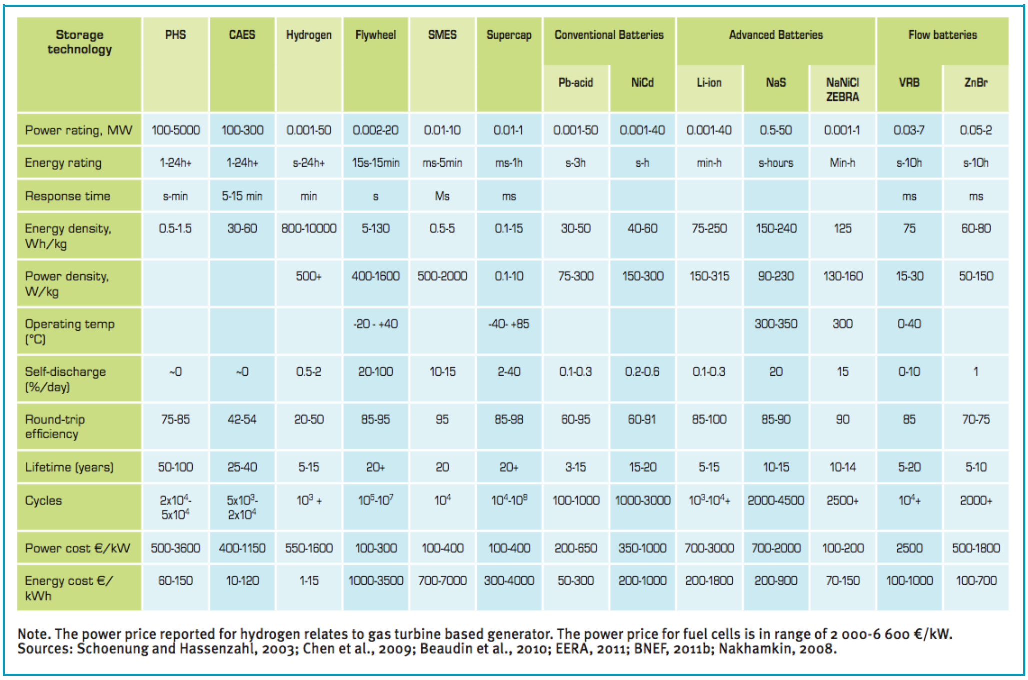
[77] EC Joint Research Centre (2013) Assessing Storage Value in Electricity Markets – A literature review. Institute for Energy and Transport, Joint Research Centre, European Commission

[78] Philipp Grünewald (2012) Electricity storage in future GB networks— a market failure? Centre for Energy Policy and Technology, Imperial College London

Figure 6 Technical and economic features of power storage technologies



Storage technology	PHS	CAES	Hydrogen	Flywheel	SMES	Supercap	Conventional Batteries		Advanced Batteries			Flow batteries	
							Pb-acid	NiCd	Li-ion	NaS	NaNiCl ZEBRA	VRB	ZnBr
Power rating, MW	100-5000	100-300	0.001-50	0.002-20	0.01-10	0.01-1	0.001-50	0.001-40	0.001-40	0.5-50	0.001-1	0.03-7	0.05-2
Energy rating	1-24h+	1-24h+	s-24h+	15s-15min	ms-5min	ms-1h	s-3h	s-h	min-h	s-hours	Min-h	s-10h	s-10h
Response time	s-min	5-15 min	min	s	Ms	ms						ms	ms
Energy density, Wh/kg	0.5-1.5	30-60	800-10000	5-130	0.5-5	0.1-15	30-50	40-60	75-250	150-240	125	75	60-80
Power density, W/kg			500+	400-1600	500-2000	0.1-10	75-300	150-300	150-315	90-230	130-160	15-30	50-150
Operating temp (°C)				-20 - +40		-40- +85				300-350	300	0-40	
Self-discharge (%/day)	~0	~0	0.5-2	20-100	10-15	2-40	0.1-0.3	0.2-0.6	0.1-0.3	20	15	0-10	1
Round-trip efficiency	75-85	42-54	20-50	85-95	95	85-98	60-95	60-91	85-100	85-90	90	85	70-75
Lifetime (years)	50-100	25-40	5-15	20+	20	20+	3-15	15-20	5-15	10-15	10-14	5-20	5-10
Cycles	$2x10^{4}$- $5x10^{4}$	$5x10^{3}$- $2x10^{4}$	10^{3} +	10^{5}-10^{7}	10^{4}	10^{4}-10^{8}	100-1000	1000-3000	10^{3}-10^{4}+	2000-4500	2500+	10^{4}+	2000+
Power cost €/kW	500-3600	400-1150	550-1600	100-300	100-400	100-400	200-650	350-1000	700-3000	700-2000	100-200	2500	500-1800
Energy cost €/ kWh	60-150	10-120	1-15	1000-3500	700-7000	300-4000	50-300	200-1000	200-1800	200-900	70-150	100-1000	100-700

Note. The power price reported for hydrogen relates to gas turbine based generator. The power price for fuel cells is in range of 2 000-6 600 €/kW.
Sources: Schoenung and Hassenzahl, 2003; Chen et al., 2009; Beaudin et al., 2010; EERA, 2011; BNEF, 2011b; Nakhamkin, 2008.

Source: 2011 Technology Map of the European Strategic Energy Technology Plan (SET-Plan). Technology Descriptions.

Network failures may also be regarded as significant.[79] One identified in the literature is that the lack of central coordination fails to stimulate distribution network operators (DNOs) to make the associated investments. The role of DNOs in the energy market is that of ensuring the operation of the network of towers and cables connecting the national transmission network and energy consumers. It is possible to regard network failures as showstoppers where improved coordination is needed to advance the development of energy storage technologies. As identified in several of the TINA, within the energy market, there is a high level of dependency on policy. In particular, policy dependent demand is identified as a critical constraint and failure because of the high uncertainty about the level of public support and development of future infrastructure planning. As a result of reliance of the private sector on public initiative and the uncertainty of public investment, private investment in the industry (e.g. electric vehicles, heat pumps) is lagging. Similarly, Pew (2011) argues that investor uncertainty -ahead of new policy announcements by a new government- may have contributed to the UK's low investment in green projects in 2010.

Regulation in the electricity market may also be inhibiting the optimal functioning of the market. It is possible that the regulations in place create sub-optimal conditions for private sector functioning and pricing mechanisms. As also explained by Gillingham and Sweeney (2010, pp. 11), the average cost pricing of electricity implies that consumers often face a price of electricity that does not reflect the marginal cost of providing electricity at any given time". Albeit, the relation between this type of market failure and innovation may not be evident, it is clear that the degree to which electricity supply is priced and distributed in

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[79] TINA (2013) Electricity, Networks & Storage. Summary Report. pp.15

the grid (peak time and off-peak) has a significant impact on the sustainability and profitability of the energy market.

The type of infrastructural failures identified in the text are those where substantial government investment is needed to advance and trigger the take-off of private sector investment in the fossil energy market. These failures are critical and apparent showstoppers.

From the cited list of relevant literature, Table 11 summarises the failures identified and barriers with a particular impact in the electricity distribution and storage market.

Table 11 Failures in the electricity distribution and storage market

Failure	Source	Scale	Description
Character of Science and technology	TINA, electricity, networks & storage	Slowing down	"All parties – including regulators, network operators, and technology providers – are unsure of the value and the extent of the role storage will play in the future energy system, creating a barrier to innovation and deployment"
Market power	TINA, electricity, networks & storage	Show-stopper	"The scale of investment required to integrate telecommunications in new equipment is a barrier to DNOs investment."
Externalities	TINA, electricity, networks & storage Grünewald[80] 2012	Show-stopper	"Network savings are not accounted for in the techno-economic model, since wholesale prices do not explicitly reflect local or regional network constraints." "The range of sources of value that storage potentially has to aggregate poses a challenge for its uptake in present markets. The discrepancy between market and system values within similar scenarios supports the suggestion that the private value of storage in electricity markets does not necessarily reflect the full system value." "Aggregation of a number of value streams accruing for different stakeholders across these regimes poses a commercial challenge for storage operators. Cross sectoral and strategic planning may be necessary if the long term aggregate value is to be captured in the common interest. Failure to do so

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[80] Philipp Grünewald (2012) Electricity storage in future GB networks— a market failure? Centre for Energy Policy and Technology, Imperial College London

Failure	Source	Scale	Description
			could inhibit the uptake of storage and may lead to a welfare loss." "Storage is often said to suffer from 'self-cannibalisation': the more storage is installed the less it is worth." First mover disadvantage: novel technologies entail learning costs borne by the first mover but shared, as a positive externality, with followers
Information asymmetry	ERP[81] 2011 EC 2013[82] TINA; electricity, networks & storage	Slowing down (a lot)	Asymmetric or incomplete information: energy efficiency opportunities are one example, whereby energy users do not realise the potential savings they could make and invest less as a result. "The value of some of the services that storage can provide, such as voltage support or T&D investment deferral, cannot be easily captured under existing market arrangements" Risk aversion resulting from a lack of information, the absence of a track record and the incapability of evaluating projects fully. High (perceived or real) transaction costs: While transaction and learning are real costs, they may be exaggerated for novel technologies without a track record "The lack of hard analysis of the role of energy storage in general means that reform proposals are likely not to recognise any potential system benefits from storage."
Capabilities		No evidence found	
Network	TINA; electricity, networks & storage	Show-stopper	"High coordination required for full —smart grid infrastructure makes it difficult for individual players (e.g. DNOs) to push forward in absence of central coordination" "Lack of clarity about infrastructure planning, particularly development of infrastructure that could substitute for storage technologies, does not give parties sufficient confidence to invest in R&D or deployment".

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[81] Energy Research Partnership (2011) The future role for energy storage in the UK. Technology Report, June 2011.

[82] European Commission (2013) The future role and challenges of Energy Storage. DG ENER Working Paper.

Failure	Source	Scale	Description
			"No current national coordination or roll out plan or developed roadmap for these technologies also creates demand uncertainty" (in reference to telecommunications).
Institutional	ERP 2011 EC, 2013 TINA; electricity, networks & storage BIS[83] 2011	Slowing down (a lot)	Policy uncertainty: green investments such as energy storage rely on government policies, which must be in place long-term; the lack of track record in long-term green policies is a risk to investors (but internal to policy makers). For example, investor uncertainty ahead of new policy announcements by a new government may have contributed to the UK's low investment in green projects in 2010 (Pew, 2011) "From a regulatory point of view, energy storage is not recognised as an asset class. By default it is viewed as generation and therefore cannot be controlled by a system operator under EU competition rules, despite there being a potential economic, environmental and security of supply case for such integration." "Regulation doesn't allow sufficiently dynamic tariffs to incentivise peak demand reductions, reducing a major underlying source of value for home hub – optimal regulation complicated by fairness issues, windfalls for inherently off-peak users, and potential switching to gas."
Infrastructural	TINA; electricity, networks & storage	Show-stopper	Novel technologies without a track record need successful pilot testing at scale and available large-scale research infrastructures in which to test new storage solutions. "Broader energy infrastructure plans are uncertain, including the extent of the role of renewables, energy efficiency improvements, electric vehicles, and deployment of heat pumps"

Built Environment

The built environment reflects an interdisciplinary area that refers to the man-made environment within which human activity – economic, social and cultural – occurs. The built environment presents both a challenge and an opportunity to address the challenges of climate change. The government has set ambitious targets to cut UK carbon emissions

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[83] BIS (2011) The economics of the Green Investment Bank: costs and benefits, rationale and value for money. Vivid Economics in association with McKinsey & Co. Report prepared for The Department for Business, Innovation & Skills, October 2011

by 80% by 2050. With estimates of 25-27% of the UK's CO2 coming from domestic homes,[84] with a further 18% coming from non-domestic building

Urban centres are more economically productive and the environmental footprint is lower than the national average. However, they face increasing pressures from a rapid growth in populations, changing demographics, network congestion and pressures on key resources.

Population estimates for the UK show that 80% of the total population live in urban areas. This is projected to rise by 0.7% per year to 2015. The 2011 census reveals some of the important demographic characteristics of the urban population, which will impact on delivery to meet carbon targets:

A prevalence of social housing and the transitory nature of net migration to urban areas present key barriers to innovation. The co-evolution of people, property and the inter-connecting networks present further challenges and barriers.

Future Cities

Challenge led area
High value manufacturing

Disconnected and parochial approaches to urban design will only heighten the challenges of increased urban living while denying a significant opportunity for integrated and innovative thinking in delivering sustainable solutions for a low carbon future.

A major barrier to effective introduction of low carbon innovations is the issue of externalities, arising from differences in incentives between individual actors and the wider group. This is the widely understood market failure problem where there is a divergence between marginal private and social costs and benefits.

In sustainable development the idea is more widely discussed in terms of Hardin's theory of 'tragedy of the commons'. In this theory individual agents who are acting independently and rationally according to their own self-interest, end up acting in contrary to the group's long-term best interests. This leads potentially to a rapid depletion of shared resources

In terms of efforts to mitigate against climate change the view 'think global, act local' reflects the idea that the measures and actions taken locally may not benefit individuals directly, but in aggregate go towards addressing the global or common challenge of climate change. The alignment of marginal private benefits with marginal social benefits, stimulate positive externalities.

The issue is compounded by the institutional failure arising from the non-alignment of decision making cycles. Politicians who legislate and can enforce regulations and long term strategic plans are often subject to shorter cycles due to electoral processes. They

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[84] Estimate from Federation of Master Builders 27% (Building a Greener Britain 2008), 25% from TINA Domestic Buildings Summary Report (November 2012)

may therefore delay or fail to develop actions that may only yield impacts after they have left office.[85]

While positive externalities can be identified within the incentives for actors to align private and social benefits, negative externalities, where the marginal social costs exceed the marginal private costs are also a major barrier. Price distortions cause the failure of the market to align incentives. Energy prices do not reflect the actual costs or are kept artificially low as a consequence of subsidies.

The suppression of prices also impacts on the incentives to invest in low carbon technologies. The combination of high upfront costs, longer payback periods and the higher risks from new innovative technologies or uncertainties around future policy regimes, make investments less attractive. Failures arising from split incentives also contribute to a slowdown in innovation and adoption. This occurs when there is a divergence in the incentives for investment and appropriation of returns and benefits from this investment. The issue of split incentives is considered in the review of buildings below; however, at the built environment level there is also a potential misalignment between micro generators of energy and the systems operators regarding the connection of micro generation sites to distribution networks

In addition a lack of supply of trained professionals and the reputational risks associated with poor quality implementation presents a barrier to innovation as there is insufficient capability to fully deliver effective installation and maintenance.

Within the built environment there is a tendency for organisations to centralise expertise around sustainability, which creates a major network failure. Network failures occur where there are significant costs in facilitating the flows of information between actors within the system. Sustainable development is a multi-disciplinary area, drawing on experts from many different fields such as planning, ecology, economics and other social and physical sciences. The tendency to create mutually exclusive departmental structures within organisations generates ‘silo thinking’, undermining the potential for effective flows of information between actors and increasing the costs of coordination.

Furthermore, most innovation occurs within specific city sub-systems with little effort or incentive to integrate. The diversity and individuality in the evolution of urban areas places constraints on the opportunities to transfer knowledge and experience between different projects. There is insufficient capacity within individual firms to build up enough collaboration so opportunities are lost. The absence of a central source for knowledge transfer or collaboration is thus a significant network bottleneck. The decentralisation and localisation of available information increases transactions costs reducing the incentives for collaboration.

Delivery of effective innovation within the built environment also needs to reflect the non-economic considerations for sustainable development.[86] This can lead to systems failure

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[85] THINK (2011) Smart Cities Initiative: How to Foster a Quick Transition towards Local Sustainable Energy Systems – final report. THINK, FP7 funded EU programme. Available: http://www.symple.tm.fr/uploaded/pdf/THINK_smart_cities.pdf

arising from capability. Current activities do not take account of the role of ‘people’: social and behavioural sciences are not sufficiently involved. The Royal Institute of Town Planning, in their submission to the Farrell Review notes that “the maximising of economic benefits suggests a distortion of priorities. Economic value should not be seen in isolation but has to go hand in hand with rich social capital, green infrastructure and healthy lifestyles.”

Table 12 Failures in the Future Cities market

Failure	Source	Scale	Description
Character of Science and technology		No evidence found	
Market power		No evidence found	
Externalities	Think 2011[87]	Slowing down	“Since there are various activities that require the coordination of different actors from different sectors or with different functions in the same sector, the divergence of interests is a frequent obstacle to the sustainability in a city…Examples of divergences….1) between owners and tenants…2) between micro-generators and systems operators”.
Information asymmetry		No evidence found	
Capabilities	Think 2011	Slowing down	“Mayors are not necessarily energy experts (at least not in general terms). Quite often, the people elected still have little introduction and appetency for the concepts of local sustainability and the related new culture of a new energy paradigm made of diversification, decentralization of sources and conversion facilities and of priority to the demand approach. Given the cross-cutting nature of climate change, and the corresponding wide variety of relevant issues (e.g., energy and all activities that are strongly dependent on energy, e.g., transport, buildings, industry, leisure, normal citizen life), it is everything but straightforward to have the required expertise at all these levels. Competence regarding sustainability might be limited, or it might be centralized (e.g., at the environ- mental department, which often has to deal with a whole range of environmental issues), not being able to spread its

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[86] TSB (2013) Technology Strategy Board 2013-14 Delivery Plan https://www.innovateuk.org/documents/1524978/2138994/Delivery+Plan+-+Financial+year+2013-14/c435471d-222c-4e63-8269-d0f4b2b61c2f

[87] THINK (2011) Smart Cities Initiative: How to Foster a Quick Transition towards Local Sustainable Energy Systems – final report. THINK, FP7 funded EU programme

Failure	Source	Scale	Description
			expertise or even its values and culture horizontally throughout all the levels/departments required”.
	TSB 2012		“No individual company has all the skills necessary to deliver the requirements of cities in the future. Even the largest ones find it difficult to build broad enough collaborations to meet the challenge. This is a particular problem for smaller innovative companies”
Network	TSB 2012[88]	Slowing down	“There is nowhere for city governments, business and the knowledge base to collaborate to develop new integrated solutions”
	TSB 2012		“Current activities do not take account of the role of people in cities. The social and behavioural sciences are not sufficiently involved”
	TSB Delivery		“Globally and in the UK, construction has a strong subcontracting culture. The market is dominated by a few large organisations, with a very large number of very small players who do most of the individual tasks on site. This means that information, and innovation, spreads slowly”
Institutional		No evidence found	
Infrastructural	TSB 2012	Slowing down	There is a lack of facilities for demonstration and validation at scale and in use

Low Impact buildings

Challenge led area
High value manufacturing

The construction sector is of strategic importance for the UK and EU as it delivers the buildings and infrastructure to enable economic and social activity. The UK construction industry contributes significantly to the national economy. In 2011 output was £107bn, accounting for 7.6% of total UK output. 90% of this came from buildings and around 2 million people are employed in the sector

Data for the EU suggest construction accounts for 10% of EU GDP and 50% of fixed capital investment. 20 million people are directly employed while estimates from the European Construction Industry Federation reveal a further 44 million workers who are directly or closely affected

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[88] TSB (2013) Technology Strategy Board 2013-14 Delivery Plan

While housing production and financing are dominated by a few major players, a fundamental barrier to innovation occurs with the fragmentation within the supply chain and the repair, maintenance and improvement (RMI) sector. Data from the National Housing Survey shows that 70% of new house building registrations in 2011 were recorded by businesses with 501 or more existing units. Of this, 10 very large companies with registration of more than 2,000 units accounted for 47% of the total. Those involved in the RMI sector tend to be smaller, with an annual market of over £23bn.

A further source of market entry is individuals choosing to build their own homes using innovative designs and building materials. This requires access to land and architectural services. However, there is no integrated source for information to support these initiatives. An OFT report into house building in the UK recommended government consider the need to assist small house builders and individuals building their own homes so they can access the necessary technologies, which currently are mainly only available from abroad

The traditional structure of the supply chain within construction tends to be locally sourced subcontracting. This creates search costs for householders who are attempting to introduce energy improvements to existing properties. This is reinforced by evidence of custom and practice in SME construction firms. Most of these work in geographically defined local areas, due to convenience of travel to and from site and partly due to the legacy of traditional approaches from family run businesses.

This is further compounded by a lack of information on performance of existing buildings as well as incomplete information regarding data on actual building performance

The benefits from implementing renewable energy technology measures may be outweighed by the transaction costs of gathering information and the perceived inconvenience of installing new equipment

A lack of standardisation can also result in the split incentive effect, especially for new builds, which inhibits a holistic approach. Decisions on renewable energy technologies for example, taken by different actors, including architects, developers etc. are often taken without any coordination. These technologies are often developed by small or medium sized local firms who cannot achieve sufficient economies of scale. A lack of standardisation at regional and global level makes it very difficult to penetrate international markets

A lack of necessary skills and experience required to implement new technologies is a fundamental barrier. A recent Chartered Institute of Building survey noted: “New initiatives and schemes such as BIM and the Green Deal, which have gained traction in recent years, may require a mixture of new and refined skills. 51% report that they feel construction workers won’t have these skills for BIM while 78% see real need for more training”.

The Green Deal provides an opportunity for job creation, innovation and decreased spending and energy demands. It however requires a joined up approach between business, education, professions and government to ensure the skills are available for small scale installations as well as the most complex within commercial properties.

Fragmentation of the supply of off-site production is also a failure, although is considered less of an impact.

A further systems failure arises from the lack of regulatory certainty about compliance. Despite this dual nature of the construction sector some argue that the concentration of output for new construction could enable the increased capability for innovation by agreeing processes and standards. However, house builders are unlikely to invest in innovative solutions to achieve carbon compliance until they know which metrics they will be measured against. They argue that, while existing energy efficiency programmes based on a list of cost effective measures are sufficient in the short term, a longer term approach for effectively reducing CO2 emissions from existing homes will require a transition from a measures based approach towards a standards based. This will impact significantly in terms of the stakeholders involved and the policy framework needed to stimulate innovation.

A significant failure arises from the split incentives effect. This refers to situations where the investor pays upfront costs for the technology but is not the same person who keeps the benefits from lower energy costs. Within the private rental sector this is also known as the landlord-tenant divide. Given that 16.5% of all households or nearly 3.8 million homes are in the private rented sector

The non-alignment of incentives occurs at other stages of the construction process. In terms of the implementation of renewable energy technology it can between the developer and building owner where the developer has no incentive to incorporate renewable energy technology. This is worsened by low rates of return and high risks for investments

Within the construction process itself these divergent incentives can be significant failures. Within the pre-construction and design stage, modelling and software are critical. However there are no incentives to share learning, made worse by inconsistency in data application and compliance. This is a critical failure for the construction process.

Table 13 Failures in the low impact buildings market

Failure	Source	Scale	Description
Character of Science and technology		No evidence found	
Market power	IEA 2012[89]; TINA 2012a;[90]	Slowing Down a lot	[High market concentration new construction, alongside a fragmented supply chain leading to failure to integrate markets effectively.]

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[89] IEA (2012) Renewable Energy Technology Deployment 2012 'Business Models for Renewable Energy in the built environment. Available: http://iea-retd.org/wp-content/uploads/2012/04/RE-BIZZ-final-report.pdf

[90] TINA (2012a) Non-domestic buildings summary report. Technology Innovation Needs Assessment. Available: http://www.carbontrust.com/media/218006/tina-non-domestic-buildings-energy-efficiency-summary-report.pdf

Failure	Source	Scale	Description
	2012b;[91] FMB 2008[92]		
Externalities	TINA 2012a	Show-stopper	“The landlord-tenant divide - where one party has no incentive to invest in carbon reducing measures as the other party receives the benefit of the investment. This also prevents data sharing from buildings‟ energy use”. “Energy costs are not seen as material – occupiers place greater premium on the look, comfort and productivity of a building rather than its energy use, so companies are not prepared to pay a premium in rent for a low carbon building” “The critical failure in modelling and software is due to a lack of incentives to share data - neither building owners nor operators provide (or even have access to) the necessary data on building performance. Similarly, developers do not conduct modelling incorporating unregulated demand (demand arising from appliances rather than integrated building services)”.
	IEA 2012		“The hassle factor is mostly relevant for existing residential buildings, where the owners occupy the building. In new buildings there is no inconvenience related to installing RET, because the installation takes place before building users move in. In commercial buildings or rented multi- family houses, RET are generally installed on the roof or in a separate room with technical equipment. In rented residential buildings, the decision to invest in RET is taken by the owner based on economic considerations. Here, inconvenience for the tenants is not such an important criterion as in owner-occupied buildings”.
Information asymmetry	TINA 2012a	Slowing down	“Companies do not have *tools* or *knowledge* to identify low carbon buildings, in part as there is no labelling for high performance buildings outside the public sector”. *(Also related to capability failure).*
	IEA 2012		“Lack of information about financing options, mortgage assessment and transaction costs are especially relevant for small scale projects which comprise of only one single-family house, which is either newly built or owner-occupied. Commercial building owners are expected to have more

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[91] TINA (2012b) Domestic Buildings, Summary report. Technology Innovation needs assessment; available: http://www.carbontrust.com/media/218010/tina-domestic-buildings-energy-efficiency-summary-report.pdf

[92] FMB (2008) Building a Greener Britain: Transforming the UK's existing Housing Stock. Federation of Master Builders. Available: http://www.fmb.org.uk/EasySiteWeb/GatewayLink.aspx?alId=2358

Failure	Source	Scale	Description
			knowledge about financing options, and in larger buildings or property develop- ments transaction costs relative to the size of the investment in equipment are lower”.
Capabilities	FMB 2008	Slowing down	Traditional business model of suppliers lacks capability for collaboration
Network		Slowing down	Localised activities result in lack of information and knowledge exchange
Institutional	TINA 2012a	Slowing down	“Existing building regulations are not tight enough, sufficiently enforced, or integrated well with planning tools”.
Infrastructural	FMB 2008	Slowing down	Lack of skilled professionals in low carbon and renewable technologies “51% report that they feel construction workers won’t have these skills for BIM while 78% see real need for more training”.

Food

The agri-science and food sectors comprise part of what is known as the ‘farm to fork’ chain, which traces the journey from primary agricultural production to food and beverage consumption. Overall, the EU-27 food value chain employed just over 48 million people in 2008, equivalent to more than 20% of the EU total workforce and around 6% of total GDP.[93] In addition to the economic weight of the sector, food is of key importance to society, as healthy people depend on healthy food systems.

We discuss the barriers and failures associated with innovation at the beginning of the ‘farm to fork’ chain in the ‘agri-science’ sector, while the ‘food’ section discusses those issues associated with food processing, wholesaling, transport and external trade, retailing and consumption.

Agri-science

Challenge led area
‘8 great’ technology

Agri-science is acknowledged as one of the eight great technologies, though with the caveat that it is not regarded so much a technology in itself, but rather the application of a range of scientific disciplines and technological competencies to the overall field of agriculture. Disciplines relevant to agri-science include biology, genetics, climate science and meteorology, physics, biochemistry and engineering, though this list is far from exhaustive. The technologies that come under this heading include genetic modification and optimisation of crops and livestock, satellite-assisted systems to improve planning and efficiency of agricultural cycles, improvements in lighting, food and other key conditions

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[93] Eurostat: From farm to fork - food chain statistics. Available at: http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/From_farm_to_fork_-_food_chain_statistics

based on deeper scientific understanding of crops and animals, as well as developments and advances in processes and machineries commonly used in the agricultural sector.

The significance of agri-science stems in large part from the fact that food production is the largest single manufacturing sector in the UK, with agriculture as its key cornerstone. Given the increasing world population, global food demand rises continuously. To prevent the most disastrous consequences, UN forecasts suggest that food production will need to increase by 70% between now and 2050.[94] Moreover, agriculture is not limited to food production: in addition to timber and several other crops traditionally grown for uses other than food, there is an increasing demand for biofuels, meaning that arable land for food production is becoming ever more of a scarce resource. Aside from the prospect of economic growth, successful innovation in agri-science thus also has considerable implications from a humanitarian point of view, given the potentially devastating consequences that loom if the demands for increased production and efficient use of time and space are not met.

The UK has considerable strengths in this sector, especially in terms of being a world leader in basic science related to agriculture. This is true in terms of overall research output, but also in terms of specific centres of excellence in this field: the UK-based Broadbalk winter wheat experiment is the world's longest running agricultural experiment, having been active since 1843. The John Innes Centre in Norwich and the Pirbright Institute in Surrey are just two of the most noteworthy world-leading facilities in the UK. However, there is nevertheless a host of barriers to successful innovation in the UK agri-science sector, and indeed, the literature frequently notes that there has been a noticeable decrease in successful innovation over the past decades.[95]

As noted, the agri-science sector covers a wide range of different types of product and process innovations. This means that while an especially wide range of different barriers to innovation exists in the agri-science sector, many of these only apply to some select types of innovation. The fragmented nature of the agricultural sector and relative lack of cooperation between businesses means that large-scale innovation that would require concerted efforts by several businesses are problematic. Likewise, innovations that do not require a network can still be hampered by technological lock-ins and long product cycles often inherent in large-scale activities like farming. Additionally, many new technologies generate benefits that lie outside the key aim of an agricultural business; where a new technology meets environmental needs without having immediate discernible economic benefit to the individual business, uptake is unlikely to be significant.

However, whilst these features are significant in individual cases of specific technologies or products, these kinds of barriers say more about those specific products and less about the agri-science sector as a whole: if an individual product carries no visible capacity for economic gain, or has not been suitably designed to be integrated into existing structures and processes, further research and development may have the capacity to solve these problems and lead to successful operationalisation. More significantly, agri-science

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[94] See eg HM Government Agri-science infographic; available: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/249259/agri-science_infographic.pdf

[95] see eg David Willets (2013) The Eight Great Technologies. Policy Exchange; available: http://www.policyexchange.org.uk/images/publications/eight%20great%20technologies.pdf

innovation overall is severely hampered by a wide range of institutional failures that cannot be remedied by agricultural businesses alone.

The first key institutional failure worth highlighting concerns just one subset of innovation in agri-science but, unlike the barriers listed above, this barrier is squarely beyond the realms of market solutions. EU legislation on genetically modified (GM) foods presents a complete showstopper in this area. Whilst other parts of the world are implementing the results of the extensive research in this area, the EU is effectively isolated from these developments. The stringent regulations on this aspect is of course partially reflective of public attitudes towards GM foods in many parts of Europe, meaning that in this particular regions there would still be obstacles and problems regarding consumer interest and marketability even in the absence of current regulation. However, the increasing global market for GM foods highlights that this is an important area, where as it stands, successful innovation is flat-out impossible. Nevertheless, as highlighted above, gene manipulation is just one aspect of agri-science and of course all other aspects are not significantly affected by this barrier.

More applicably to the entire industry, there is a perceived lack of available funds for innovation projects in agri-science. This is attributed to the fact that the most visible and publicised instruments to make funds available have generally been focused on those elements of the food industry that are closer to end-users (i.e. retailers, first tier suppliers). What is unclear from the literature is whether there genuinely is a lack of available funds, or whether there is merely a perception of this. Though this presents a barrier to innovation either way, this distinction will nevertheless be important when contemplating what kind of policy solution is advisable here.

Aside from the EU stance on GM foods, the most frequently cited barrier to successful innovation in agri-science is a decreasing level of scientific expertise, especially in the shape of a severe breakdown of the link between basic research and appropriate development. The lack of scientists in applied research is highlighted by several reports. This is often explicitly noted in contrast to the strong basic research in relevant fields. Reasons suggested for this disconnect often centre around the UK research evaluation exercises (RAE/ REF), which reward high quality research published in peer reviewed academic journals, but place considerably less emphasis on successes in applied research and development. This is of course a general point that could just as easily be said to apply to any other industrial sector in the UK. However, in the case of agri-science the translation from basic research to development is additionally problematic as the facilities respectively for basic research and product development differ so significantly: whilst basic research can generally be done in a laboratory, development often requires a demonstration farm, creating an especially large leap in terms of the facilities and context between research and development. The compounding problem is then that the past decades have seen a reduction in demonstration farms. This factor in conjunction with the lack of incentive for researchers to veer more into an applied context presents the most significant overall barrier to innovation in agri-science.

Table 14 Failures in the Agri-science market

Failure	Source	Scale	Description
Character of Science and		No evidence	

Failure	Source	Scale	Description
technology		found	
Market power	UKFCA 2011[96]	Slowing down	Commercial terms can create barriers to change if short term financial and other requirements push out medium and longer-term investments in processes and technologies.
Externalities	UKFCA 2011 HoL 2011[97]	Slowing down	Farming today is much more capital intensive than it was in the past. Farms can be locked into a particular way of working for a significant period of time because, like other businesses, they realise the return across the lifecycle of the investment in a technology or product. Once a 'big ticket' investment in equipment and systems is made, the incentive for a farmer to make further changes before those capital costs are recouped is low. Agricultural activity is multifunctional and many of the joint products are non-market goods and externalities, such as landscape features, biodiversity and animal welfare. Furthermore many of the joint products are negatively correlated with the main product. The consequences are first conflicts between competing goals (e.g. environmental protection and animal welfare as discussed by Milne et al., 2008) and second over/undersupply of non-market goods typically undesirable and desirable non-market goods respectively since, by implication, there is a lack of reward/penalty for provision of desirable/undesirable non-market goods.
Information asymmetry	UKFCA 2011	Slowing down	Farmers must currently seek out and finance the advice and technical expertise needed to guide them through the acquisition of new techniques and technologies. Many get the majority of their information from the farming press, especially segments sponsored and supported by interests that are promoting a specific, and often stand-alone, approach or solution. The UK farming press is generally of a very high standard and a valuable addition to information provision on new approaches and techniques. But it can be difficult for individual farmers to stay abreast of the latest thinking and advice, and weigh the competing claims made for alternative approaches.
Capabilities	UKFCA 2011; see also HoL 2011;	Slowing down	Farming is now highly technical, both in terms of business management functions and in the application of new techniques. Basic business administration expertise is required to assess cash flows and monitor input costs relative to potential returns. Farmers must also navigate an increasingly

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[96] UK Food Chain Alliance (UKFCA) (2011) Working Together to Safeguard and enhance UK farming. Discussion paper, Spring 2001; available: http://www.ghkint.com/LinkClick.aspx?fileticket=0rDwrLvM4YM%3D&tabid=126

[97] House of Lords (HoL) (2011) Innovation in EU Agriculture – Oral evidence with associated written evidence. Agriculture, Fisheries and Environment Sub-Committee; available: http://www.parliament.uk/documents/lords-committees/eu-sub-com-d/innovation/ieuawae.pdf

Failure	Source	Scale	Description
	see also HM Government 2013[98]		sophisticated series of commercial relationships relating to the production and supply of produce to market. They must understand myriad commercial terms, monitor and assess market signals, ensure compliance with increasing levels of regulation and navigate subsidy frameworks and the associated audit process. Together these create genuine manpower and financial resource pressures. Proper oversight and implementation of these arrangements demands a level of legal, compliance and financial competence that is far from universal among producers.
Network	HM Government 2013	Show-stopper (for large projects)	Across the farming sector, there is a significant disparity in relative productivity and performance. The top 10% of farms produce more than £180 output per £100 input while the bottom 10% fail to recover their costs. Differences in motivations and natural circumstances can partly explain this disparity. However, inconsistent levels of knowledge, slow uptake of technologies and perceived or actual barriers to knowledge transfer are often contributory factors. The diversity of the UK agri-tech sector makes it difficult for it to unite around cross-cutting sectoral issues, such as skills or R&D priorities.
Institutional	UKFCA 2011 HM Government 2013; see also UKFCA	Slowing down Show-stopper	Many primary producers face financial constraints – including inadequate margins and limited access to capital – which limit their ability to invest in their businesses. Accordingly, there is less chance of them being in a position to make the changes that can deliver environmental, social and economic improvements. So far, independent examinations of business practice and the terms of contract in the value chain have focused on commercial agreements in the middle, looking at the relationship between retailers and first tier suppliers. Proposed remedies in these areas, such as the establishment of an ombudsman or adjudicator with oversight of retailer-supplier relationships, are directed at improving outcomes for consumers, and are not aimed at ensuring that significant financial resources reach the primary production level. Good regulation sets the conditions for a well-functioning market that benefits industry and consumers and in general the EU has helped create these. However, […] the EU regulatory pipeline for genetically modified (GM) crops remains blocked. This is despite European Commission reports finding no scientific evidence associating GM

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[98] HM Government (2013) A UK Strategy for Agricultural technologies. Industrial strategy: Government and Industry Partnership, July 2013; available: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/227259/9643-BIS-UK_Agri_Tech_Strategy_Accessible.pdf

Failure	Source	Scale	Description
	2011; see also HoL 2011; see also CFG 2009		organisms with higher risks for the environment or food and feed safety. The EU approach is in contrast to other countries: GM crops are now grown by 17 million farmers on over 12% of the world's arable land.
	CFG No date[99]	Slowing down	The vacuum created by an overemphasis on support for basic science at the expense of applied science not only blocks the translation of science into practice, it also removes innovation at the applied level and breaks the contact with industry
	HoL 2011	Slowing down	The loss of applied demonstration farms, the lack of resources for farm extension and a concentration of research funding only on RAE published papers, has undermined the UK's capacity to commercialise its world class research base. A lack of effective communication between innovators and commercial businesses and poor communication and dissemination activity restricts the take up of new developments.
Infrastructural	CFG 2009[100]	Slowing down	There is a shortage of research scientists involved in applied research. One such assessment for arable crop scientists by the Rothamsted Research Association[101] indicated how few such scientists remain in this sector. In soils there is a dearth of expertise remaining which understands the interaction between tillage regimes and soil structure, soil nutrients, soil water and crop establishment.[102] In livestock there are few quantitative geneticists remaining in universities and colleges, and those involved in the nutrition of livestock and in the management of grazing and forage crops are in severe decline. Across crops and livestock there has been a significant loss of engineers engaged in research leading to practical solutions. Since the mid-1980's the science relating to agriculture has become narrower and deeper with

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[99] Commercial Farmers Group (CFG) (No date) The Need for a New Vision for UK Agricultual Research and Development. Available: http://www.commercialfarmers.co.uk/The%20need%20for%20a%20new%20vision%20for%20UK%20agricultural%20RD.pdf

[100] Commercial Farmers Group (CFG) (2009) Response of the Commercial Farmers Group (CFG) to the consultation by the Biotechnology and Biological Sciences Research Council on: Future directions in research relating to food security. Available: www.commercialfarmers.co.uk/BBSRCResponse.doc

[101] Mark Tatchell (2005) Scientific skills for knowledge transfer in arable agriculture in England: A Survey. Report to the Board of the Rothamsted Research Association

[102] Richard Godwin, Gordon Spoor, Brian Finney, Mike Hann, Bryan Davies (2008) *Viewpoint The current status of soil and water management in England*. Journal of the Royal Agricultural Society of England. Vol 169

Failure	Source	Scale	Description
			a focus on understanding how organisms work, not how this knowledge can be applied.

‘Farm to fork’ value chain

Challenge led area

Most of the food that is eaten in the UK passes from this chain of farms to manufacturers and further on to food and beverage retailers or consumer services, until reaching the final consumers. This section deals with the stages of the value chain that come downstream from the primary agricultural and farm production. It discusses issues associated with:

- The food and beverages manufacturing and processing stage
- The wholesaling, transporting and external trade of food and beverages
- The food and beverage retailing and consumption, from the point of view of consumers

The food and beverage manufacturing sector comprises all companies that process foods, starting from relatively simple operations such as cleaning, grading and then preserving, tinning or freezing foods, up to more elaborate transformations, such as the production of ready-to-eat meals. In 2008, the EU-27 food and beverage manufacturing sector comprised almost 288,000 companies, providing more than 5 million jobs and generating close to €1,000b of turnover.[103] In the UK, the food and beverages manufacturing sector is the single largest manufacturing activity, with a turnover of £92b and a GVA of £24bn.[104] In addition, the sector accounts for 18% of the total turnover of all manufacturing sectors and employs around 400,000 people, representing around 16% of the overall manufacturing workforce in the country. On average, workers in the sector of food and drinks production in the UK are 50% more productive than the EU average in terms of GVA per employee.[105] This comes as a result of a 12% increase in productivity of the labour force during the last decade.[106]

The UK’s food and beverage manufacturing sector is also a great trading partner internally and with the rest of the EU. It exports almost £19b of food and drink products a year, with over £12bn of food and non-alcoholic drink exports, 76% of which go to the EU. Internally, the sector buys two thirds of all the UK's agricultural produce of British farms. In terms of retail, the UK holds the largest food and beverage retail workforce (1.28 million, 17.3 % of the EU-27 total) and food services workforce in the EU (1.58 million, 21.6 %).

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[103] Eurostat: From farm to fork - food chain statistics. Available at: http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/From_farm_to_fork_-_food_chain_statistics

[104] Latest ONS Annual Business Survey

[105] Eurostat SBS statistics (GVA per employee)

[106] Defra (2013) Food Pocket Book 2013. Department for Environment, Food and rural Affairs.

This economic activity is carried out by around 7,700 food and drink enterprises, the majority of which are SMEs, employing less than 10 people on average.[107] However, the UK is also home to some food manufacturing and retailing heavyweights such as Unilever (with £791m of R&D investment in 2010) [108] and Tesco (with £111m). On the other hand, in terms of R&D investment relative to turnover and staff, SMEs tend to be around twice as R&D-intensive as large companies.[109] In aggregate the sector invested over £1b in R&D activities in 2011, which translated into more than 8,500 products.[110] Most technological innovation activities focus mainly on incremental development of new variants that usually involve innovations in packaging, reformulation and branding, hence the large figures of new products and product variants.

In terms of more fundamentally oriented research activity in Food Science, the UK is the fifth largest country in the world in terms of scientific output and the second in Europe (only behind Spain), with more than 19,000 scientific publications in the period 1996-2007. In terms of scientific quality the UK is in the top position in terms of citations per paper (19.51) for those countries with productions of larger than 10,000 papers, which evidences that research in the field is not only abundant, but also of international relevance.[111]

Figure 7 shows the main universities and research institutes that contribute to the UK's science base in this field. In addition to fundamental research, industry R&D is supported by initiatives such as the Biosciences KTN, the Food and Drink Innovation Network and the Food and Drink Federation, amongst others.

The main sources of public R&D funding in this field are run by the Technology Strategy Board (TSB) and the Biological Sciences Research Council (BBSRC) through measures such as the TSB's Sustainable Agriculture and Food Innovation Platform (SAFIP) and BBSRC's Diet and Health Research Industry Club (DRINC). In terms of overall strategy, Defra published the Food 2030 strategy in January 2010.[112] Food 2030 was the first national food strategy in the UK for over 50 years and it set out the previous Government's vision for a sustainable and secure food system for 2030:

- Enabling and encouraging people to eat a healthy, sustainable diet
- Ensuring a resilient, profitable and competitive food system
- Increasing food production sustainably
- Reducing the food system's greenhouse gas emissions
- Reducing, reusing and reprocessing waste

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[107] UK Food and Drink Federation (2013) Food and Drinks Export Performance. Available at: http://www.fdf.org.uk/publicgeneral/ UK-food-and-drink-export-first-half-2013.pdf

[108] BIS R&D Scoreboard. Available at: http://webarchive.nationalarchives.gov.uk/20101208170217/ http://www.innovation.gov.uk/rd_scoreboard/downloads/2010_RD_Scoreboard_data.pdf

[109] Arthur D. Little Limited (2013) Mapping current innovation and emerging R&D needs in the food and drink industry required for sustainable economic growth. Final Report to DEFRA, May 2013

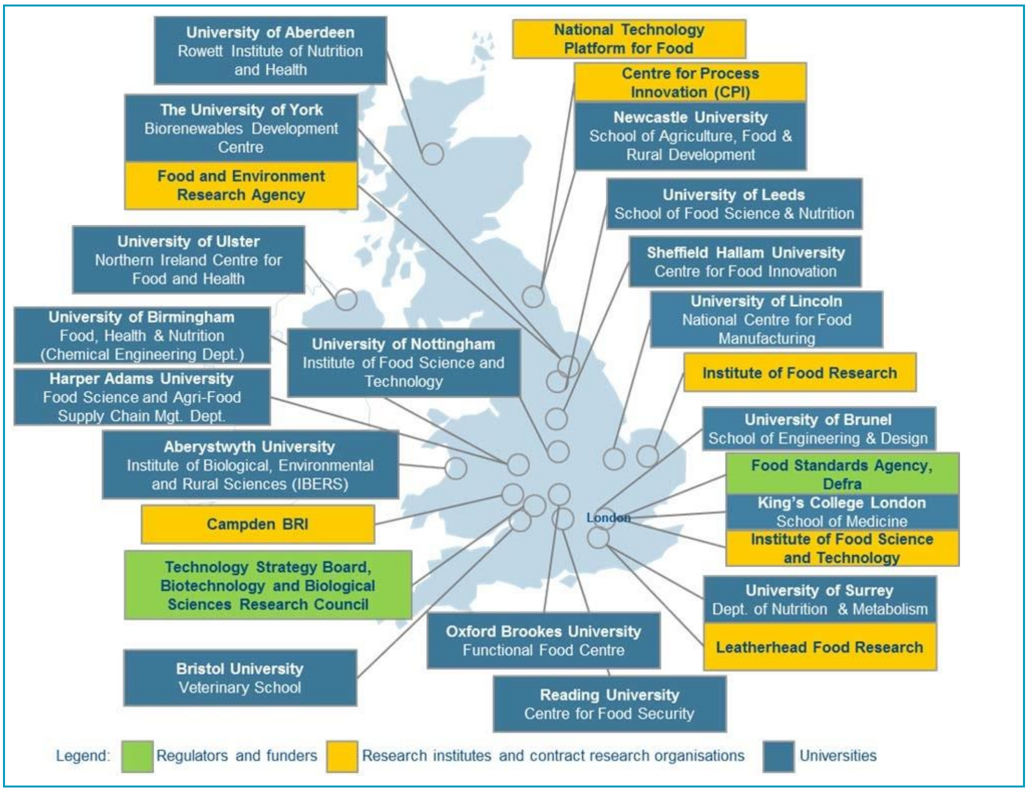
[110] Business Enterprise Research and Development (BERD) and Mintel GNPD

[111] SCImago Journal and Country Rank. Available at: http://www.scimagojr.com

[112] DEFRA (2010) Food 2030: the UK's national food strategy. Department for Environment, Food and rural Affairs. Available at: http://sd.defra.gov.uk/2010/01/food-2030/

- Increasing the impact of skills, knowledge, research and technology[113]

Figure 7 Main UK's food and beverage research organisations



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[113] Work on this aspects has been taken forward with more recent Defra publications, such as the Sustainable Consumption report, published in July 2013

Source: Mapping current innovation and emerging R&D needs in the food and drink industry required for sustainable economic growth. Report to Defra, May 2013.

Although the Food 2030 strategy does not necessarily reflect the views of the current Government, its overarching priorities are still relevant, as the market and system failures existing in the sector align nicely with issues that would stop or slow down the attainment of such objectives. Table 15 provides an overview of such market/system failures that have been identified in the literature for this sector, which comprise issues spanning from manufacturers of food and beverages to failures that manifest at the consumer's end of the chain.

Table 15 Failures in the farm-to-fork value chain market

Failure	Source	Scale	Description
Character of science and technology		No evidence found	
Market power	Grant Thornton report[114]	Slowing down (a little)	Access to raw materials: "Even for commodities where the UK is relatively self-sufficient, we are price takers rather than price makers in the global market. This means that FDM businesses are particularly exposed to volatility in raw material prices and availability. One way of mitigating this risk is to seek to develop more resilient supply chains as well as seeking greater trade liberalisation"
	Grant Thornton report	Show-stopper	Access to finance: "Even if funding is overall available to fund current operations, SMEs acknowledge they have difficulties in accessing bank loans for investment". "There seem to be two contradictory versions regarding access to finance. On the one hand, banks point out that there has been a lack of demand, whilst businesses believe that there was not necessarily a significant drop in demand, but they are discouraged from applying. This is mainly due to the fact that banks have tightened lending criteria or are more risk averse and, therefore, charge high rates"
	Defra, 2013[115]	Show-stopper	Obtaining funding for technological innovation: "One area where a gap was identified concerned the ability to fund capex outlay for commercially available new technologies, including scaling up and turn-key plant. This concerned difficulties in justifying and committing funding within businesses as well as a lack of externally available funding sources. Availability of funding for technological innovation was less of an issue than access to it, suggesting that consultees and survey respondents

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[114] Grant Thornton (2011) Sustainable Growth in the Food and Drink Manufacturing Industry. Grant Thornton report commissioned by the Food and Drink Federation. Available: https://www.fdf.org.uk/corporate_pubs/Grant_Thornton_full_report_2011.pdf

[115] DEFRA (2013) Mapping current innovation and emerging R&D needs in the food and drink industry required for sustainable economic growth. Report to Defra, May 2013

Failure	Source	Scale	Description
	Grant Thornton report	Slowing down (a lot)	felt that funding was available, but had difficulties in understanding how it fitted together and in being signposted to that which was likely to be most relevant to them.” Balance of power shift in the supply chain over the past five years: “Both corporates and SMEs surveyed agree that the balance of power has shifted gradually towards retailers over the past decades. Therefore, in the supply chain the power now lies with the retailers because of the sheer scale they achieved through consolidation. As a result, smaller companies may be obliged to operate under reduced profitability, limiting their ability to invest in improved product quality and innovation.”
Externalities	Rocha, 2007[116]	Slowing down (a lot)	Externalities associated with some manufacturing practices: e.g. “Factory farms create many and very significant negative market externalities through their operations. Pollution of ground water (increasing the cost of purifying water for communities nearby), and the foul smell (reducing the value of neighbouring properties) are just a few of the examples of the negative externalities factory farms can create. Thus, while consumers pay a lower price for the meat produced by factory farms, society at large is incurring a much higher cost for food produced in this way – a cost that is not captured by the market price.”
	Eurostat, 2011[117]	Slowing down (a lot)	Waste: “There are a range of externalities that may result from food and beverage processing, among which one of the most important is waste. The EU’s food, beverages and tobacco processing sector generated over 35 million tonnes of animal and vegetal waste in 2008, of which some 7.5 million tonnes was animal waste from food preparation.” “Household waste associated with food essentially concerns food packaging and animal and vegetal wastes. Animal and vegetal wastes from households amounted to 23.8 million tonnes in 2008 in the EU-27, around 10.8 % of all household waste, and equivalent to 48 kg per capita; these levels and this share are believed to be underestimates.”
	Eurostat, 2011	Slowing down (a lot)	Environmental impact due to over-reliance on transported foods: “The transportation of foodstuffs can have a considerable environmental impact through fuel use for transportation itself (so-called food miles) and energy use for refrigeration. Bulk foodstuffs have traditionally been transported over

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[116] Cecilia Rocha (2007) Food Insecurity as Market Failure: A Contribution from Economics. Journal of Hunger & Environmental Nutrition, 1(4), 2007

[117] Eurostat (2011) Food: From farm to fork statistics 2011 edition. Eurostat pocketbooks. ISBN 978-92-79-20239-1

Failure	Source	Scale	Description
			long distances by ship, although increasing use is being made of aviation for transporting perishable goods. Road freight transportation of agricultural products and foodstuffs is largely a national operation, although certain foods are moved considerable distances around the EU by road – for example, fruit and vegetables being transported from Spain or the Netherlands."
	McCormick, 2007[118]	Slowing down (a lot)	Health issues concerning the consumers: Obesity: "Individuals may well rationally choose to exercise less or eat more than is medically optimal in the sense of maximizing life expectancy. If the individual bears the full costs of these decisions (and is fully informed of the risks), many would find it difficult to support government intervention. However, if the individual does not bear the full cost, 'consumption' will be higher than optimal and society bears the cost of this 'externality'." "The House of Commons Health Select Committee (HSC) recently estimated a subset of these costs, updating previous estimates made by the National Audit Office. The HSC estimates that the total cost of obesity [i.e. for those with a body mass index (BMI) greater than 30] and its consequences in England in 2002 was around £3340–3724 million."
	Eurostat, 2011	Slowing down (a lot)	Issues derived from alcohol abuse: "Alcoholic beverages represent an important cultural element in several EU regions or countries. Nevertheless, harmful and hazardous alcohol consumption can be linked to a variety of health problems as well as traffic accidents, and can have a broad social impact through anti-social behaviour, crime, family and work problems. As well as the human consequences, alcohol abuse has economic costs, for example in terms of absenteeism and increased healthcare expenditure."
Information asymmetry	Grant Thornton report	Slowing down (a little)	"There is a public perception that the industry must remain 'traditional', make use of conventional agricultural resources and that the use of new technologies such as genetically modified foods or nanotechnology might be harmful"
	Defra, 2013	Slowing down (a little)	Industry 'reputation': "This barrier did not focus on the availability of appropriately qualified graduates in science and engineering. Instead, it concerned the ability of industry to attract scientists and engineers from non-food industry related backgrounds into the food and drink sector and in particular how to energise young scientists and technologists." "When

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[118] McCormick, B., Stone, I. and Corporate Analytical Team (2007), Economic costs of obesity and the case for government intervention. Obesity Reviews, 8: 161–164

Failure	Source	Scale	Description
			questioned further as to why this barrier is apparent, some consultees indicated that this was because that the industry was considered to be of insufficient scientific challenge and interest to those with such skills, and to lack clearly defined scientific challenges which would enable scientists and technologists to publish in the best journals and develop a strong scientific reputation. Other consultees observed that it could involve an unattractive working environment compared to other sectors, and that salaries were often higher in other, adjacent sectors (e.g. the pharmaceutical industry).”
	Defra, 2013	Slowing down (a little)	Resistance to change due to information issues: “Reluctance amongst consumers to accept new technologies and change existing consumption behaviours and purchasing habits was cited as a barrier, particularly in terms of how consumers perceive the risks associated with novel food products and how open they are to embracing the use of new, unfamiliar technologies.”
	McCormick 2007	Slowing down (a little)	Imperfect information regarding optimal choices for consumers: “If individuals do not fully understand or accurately perceive the risks and consequences of their choices regarding diet, exercise and weight, they may make decisions that do not maximize their welfare. Imperfect information may take several forms in this context – information on the calorie content of different forms of food and activity, information on the links between calories and weight, information on the relationship between weight and health risks and costs, etc.”
Capabilities			
Network	Defra, 2013	Show-stopper	“The linkages between food manufacturers and retailers were highlighted as being particularly strained at times. Some manufacturers felt that they were not in control of their own destiny, with a strong emphasis by retailers on the promotion of own-brand products. Others observed that uncertainty was an issue in deciding where to invest in technological innovation, and worried that the needs of retailers might change at short notice, such that a significant investment in a new piece of equipment might become redundant if the retailers requirements changed (e.g. for a particular type of packaging).” “Other issues concerned finding the right organisations to partner with for specific technological innovation activities, and in transferring technologies from the public research base (i.e. research institutes and academia) to manufacturers.” “Others observed that headway is being made in this area – particularly in the relationships between retailers and primary producers.”

Failure	Source	Scale	Description
Institutional	Defra, 2013	Slowing down (a little)	The ability to make and register health claims: “The way in which companies can advertise health benefits has recently been tightened up to better protect consumers from dubious or misleading claims. It is now very costly and difficult to demonstrate proven health benefits, such that only a small number of products (for example cholesterol-reducing spreads, yogurts and drinks) now do so. Consultees and survey respondents observed that this had implications for stifling innovation, in terms of the volume of expensive data required by the European Food Safety Authority, and the risk of claims being rejected in spite of significant effort. This is part of broader concerns around the way in which research and innovation proposals at the European level can influence businesses. Providers of raw materials and food manufacturers also expressed intense difficulties in making health claims for food ingredients (e.g. milk as a source of calcium and its impact on skeletal health).”
Infrastructural	Grant Thornton report	Show-stopper	Skill shortages: “Companies have access to sufficient candidates with adequate skills for creative positions (sales, marketing), but struggle to find suitable candidates for engineering and science positions. In particular, companies face issues in recruiting food scientists, food nutritionists as well as technologists and engineers with the ability to adapt complex bespoke automated systems.” “The industry’s outdated image leads to a small number of students pursuing food and drink related degrees or apprenticeships and an inability for manufacturers to attract high calibre talent. Over the past decade, the number of students enrolled in higher education (HE) food and beverage courses has been experiencing ups and downs, with the latest years seeing an increase of c. 27% between 2006/7-2009/10. However, students studying towards a degree in food and beverages still represent only 0.1% of the total student population.”

Transport

Transport is an especially broad economic sector, which the TSB has described as a ‘system of systems’ that can be divided into sub-sectors in a number of ways. Transport in the respective areas of road, sea, air and rail has several distinctive characteristics for instance. Furthermore, the transport sector comprises both the vehicles themselves, as well as the infrastructures in which they operate. Additionally, and across these various sub-sections and subdivisions, there are private and public components, as well as a wide variety of different links connecting and coordinating the various components of ‘transport’.

For the purposes of the analysis here, there are two distinctive features of the transport sector worth highlighting. Firstly, this sector has considerable implications for the UK economy not just in and of itself, but in terms of its relationship with most other sectors. For instance, the Eddington Transport study estimates that current levels of congestion across all modes of transport costs the UK economy £7-8bn GDP per year. Additionally, the excess pollution caused by congestion impacts on the health, safety, and overall desirability of urban environments. Both in terms of vehicles themselves and in terms of the infrastructure and systems in which they operate, there is a strong case for fostering innovation in the transport sector, not least in order to ensure avoidance of adverse effects on other sectors.

Secondly, the transport sector has in recent years become subject to regulation on emissions and pollution, resulting from considerations that go far beyond the immediate adverse effects noted above, specifically from issues such as climate change and both environmental and geopolitical issues resulting from the exploitation of fossil fuels. Regulations and agreements to cut greenhouse gas emissions have placed a heightened necessity for effective and widespread innovation on the transport sector, leading to a heightened need to understanding the barriers to innovation in this area.

Low carbon car manufacturing

Challenge led area
High value manufacturing

Producing an overview of barriers to innovation across the entire transport sector is unlikely to yield especially useful results: given its breadth and multiple different sub-sectors, it is more than likely every single possible failure will be observable in some form, with many almost certainly appearing in several different guises across the sub-sectors. Identifying a specific area of innovation within the sector is likely to produce are more nuanced result. Low carbon technologies provide a useful example with considerably more specificity than the sector as a whole. This has been selected as an initial example due to the particular urgency for innovation in this area. It is a theme that appears consistently in the literature from both UK government departments and from the EU equivalents, and the additional significance of the need for innovation resulting from several wider societal challenges is self-explanatory. However, even the rather more specific theme of low carbon technology has considerable breadth, given that it can feature across all modes of transport and all types of vehicles. To narrow down further, JRC provides a useful analysis, which is more-or-less fully reproduced by the International Transport Forum: it places different modes of transport on a scale ranging from state monopoly to most intense competition. Specific types of public transport are at the former extreme end of this scale, where monopoly conditions act as a significant disincentive to innovation with especially small research activities being typical. At the latter end of the scale is the trucking and hgv industry, where competition levels are exceptionally high, and low entry and exit barriers result in many small firms operating at small margins, leading to limited capacity to cover fixed costs and finance innovation (see also ITF, 2010). Moreover, service providers in this area sell a relatively homogenous good that differs mainly through price, implying that innovative products contribute only marginally to the total turnover of the sector. Car manufacturing is placed in the moderate region of this scale, and is thus defined as ‘monopolistically’ competitive. The JRC report notes:

> *Unlike other transport sectors that offer a mainly homogenous service, the automotive industry aims to differentiate their products between competitors. Innovative products serve as one criterion for this branding and may ultimately be one of the 'selling factors' of vehicles, as users*

> *are not only price sensitive but also performance sensitive. In consequence, innovative products contribute significantly to the turnover of the industry…*[119]

Out of the various types or ‘modes’ of transportation, the car manufacturing industry thus presents what might be termed a ‘best shot’ at identifying an area with comparatively few barriers to innovation. Further narrowing down to the specific issue of low carbon technology, we have a suitably focused sample case. However, even on this focused scale, the literature identifies almost all key market and system failures, sometimes in multiple different ways. Though the data in the template contains some failures that apply not only to low carbon technology, all are cited specifically in relation to this particular area of innovation.

The barriers to innovation in this area are relatively diverse and are for the most part only interrelated to a limited extent. Though not as fiercely competitive as the trucking/ HGV sector, competition in car manufacturing is nevertheless highly competitive and capital intensive, leading to problems with market entry and high levels of risk when attempting to bring new products to the market. Given that issues around climate change and carbon emissions are socially contentious and subject to considerable change and fluctuation, there is additionally an inherent uncertainty about consumer demand, further augmenting the risks involved in innovation. In the case of successful innovation, the competitiveness of the industry combined with the visibility of new products leads to especially rapid and significant spillovers, resulting in situations where innovators are unlikely to benefit from new products for significant periods of time.

Additionally, there are skill and network related barriers. Though there have been many significant changes in the way cars are manufactured, and several hugely significant technological developments, the fundamental aspect of internal combustion through use of fossil fuels has remained relatively constant. Thus, the need for innovation in this particular aspect now requires knowledge and skills not traditionally found in the automotive sector, with skills shortages and a lack of networks and expertise to adequately locate and foster the newly required skills.

Finally, there are some especially significant infrastructure failures, although these only apply to certain types of products and technologies within this field, specifically those that might be termed ‘radical’ rather than ‘incremental’ innovations. In such cases, there can be problems of path dependency in the wider national transport infrastructure that can be sufficiently severe to stop successful innovation in its tracks. This is particularly the case with electrical vehicles, where a nationwide infrastructure of re-charging points would be necessary, or any other technology where the existing and long-standing network of refilling stations would need to be comprehensively replaced or modified. The extent of coordination necessitated by this cannot be delivered by individual businesses alone.

Table 16 Failures in the low carbon vehicle market

Failure	Source	Scale	Description

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[119] T. Wiesenthal, G. Leduc, P. Cazzola, W. Schade, J. Koehler (2011) Mapping Innovation in the European transport Sector - An assessment of R&D efforts and priorities, institutional capacities, drivers and barriers to innovation. JRC European Commission 2011; available: http://publications.jrc.ec.europa.eu/repository/bitstream/111111111/26129/1/lfna24771enn.pdf

Failure	Source	Scale	Description
Character of Science and technology	Dept for transport[120] 2007, Wiesenthal et al 2011	Slowing down	Transport technology is highly capital intensive and therefore exhibits slow replacement rates. The average replacement rate for passenger cars and light vehicles is around 10 years. […] Capital intensity and slow replacement rates in the transport sector inhibit low carbon innovation in a number of ways. They make purchasers more risk averse and inclined to opt for proven alternatives over new technologies. They significantly increase the costs of demonstration projects, which are generally an essential phase in the innovation process, prior to commercialisation.
Market power	E4tech 2007[121]; Dept for Transport 2007[122] Dept for Transport 2007, Wiesenthal et al 2011	Slowing down	Many areas of the automotive sector have relatively low profitability, making short-term gains more important and feasible than long-term developments. Additionally, there is still uncertainty about consumer demand for low-carbon vehicles, given the debates and lack of decisive public awareness on climate change and other factors behind the need for innovation in this area. It is therefore not possible yet to confirm inherent consumer demand. Capital intensity and slow replacement rates in the transport sector […]limit the size of the market open to new technologies at any moment in time, and thus the speed at which new lower carbon transport technologies can achieve market penetration, even if other barriers can be overcome. They also increase the challenges associated with raising capital or new finance to support the development and demonstration of new lower carbon options.
Externalities	Wiesenthal et al 2011	Slowing down	As the automotive industry is especially competitive, spillovers are an especially significant problem. However, in the transport sector, it is important to consider spillover effects between and within subsectors. For example, the rail industry benefits from truck engine research. This amplifies the benefits that could result overall from spillovers in the transport sectors, especially in the case of more generally applicable areas such as low-carbon technology.
Information asymmetry		No evidence	

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[120] Low Carbon transport innovation strategy, Department for Transport, May 2007; available: http://webarchive.nationalarchives.gov.uk/20081022212629/http:/www.dft.gov.uk/pgr/scienceresearch/technology/lctis/lctisdocpdf

[121] E4tech (2007) A review of the UK innovation system for low carbon road transport technologies; a report for the Department of Transport, E4tech, March 2007; available: http://www.inference.phy.cam.ac.uk/sustainable/refs/transport/e4tech.pdf

[122] Dept for Transport (2007) Low Carbon transport innovation strategy. Department for Transport, May 2007; available: http://webarchive.nationalarchives.gov.uk/20081022212629/http:/www.dft.gov.uk/pgr/scienceresearch/technology/lctis/lctisdocpdf

Failure	Source	Scale	Description
		found	
Capabilities	Wiesenthal et al 2011	Slowing down	Lack of skills and knowledge is mentioned as one important barrier to transport innovation from both industry and public bodies (see e.g. ITF, 2010a,c). High-skilled employees will become increasingly important in a sector that needs a high pace of innovation in order to keep its global competitiveness and to comply with stricter environmental and safety regulations. Within transport, in particular the automobile sector and road freight sectors that are strongly affected by the decarbonisation would need to have a lead on clean high-value technologies in order to keep their employment levels stable (Dupressoir, 2009). [...] Already today, there is some indication of shortage of highly skilled workforce in the European transport sector
Network	JRC 2011	Slowing down	Radical innovations on electric battery and fuel cell vehicles necessitate knowledge that goes beyond the automotive sector (see e.g. Sofka et al., 2008) and may involve a wide variety of changes in the way mobility is conceived. Hence, the sector needs to overcome the institutional lock-in effect and create novel cooperation with sectors that lie outside of the scope of traditional networks.
Institutional	E4tech 2007, jrc 2011, transport forum[123] 2010	Slowing down	Uncertainty regarding the likely strength of government policy for CO2 reduction, and the consequent priority to attach to this issue in terms of developing carbon-reduction efficiency. The Stern Review emphasises that cuts will need to be made in transport emissions in the long term, while acknowledging this these may be difficult to meet, leading to uncertainty on the necessity or urgency for innovation in this area.
Infrastructural	E4tech 2007	Show-stopper	The nature of the UK's existing transport infrastructure can act as a constraint on the technological options that are viable or cost-effective to introduce, creating infrastructure lock-in. This is most evident in the road sector where an extensive network of filling stations and refineries has been created over many years to support road transport based on gasoline and diesel fuels. Replacing this network with one based, for example, on the supply of hydrogen fuels, or numerous re-charging points for electric or part electric vehicles, could be a significant undertaking.

Even in the promising and relatively focused area of low-carbon car manufacturing there is a broad range of barriers to successful innovation, highlighting the need for public support.

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[123] Transport and Innovation: Towards a View on the Role of Public Policy. International Transport Forum. Forum Paper 2010 (No.9); available: http://www.internationaltransportforum.org/pub/pdf/10FP09.pdf

However, as noted, the transport sector has several distinct sub-sectors, and it is worth assessing barriers in some of them, to produce a clearer idea of the range and diversity of barriers to innovation. Low-carbon car manufacturing is located in the subsector of vehicles production. However, transport includes not just innovation in the manufacture of vehicles themselves, but also in the wider systems and infrastructures in which they operate. It is worth taking an example from this area, as it is so fundamentally distinct from vehicle manufacture, that a significantly different set of barriers is likely to be present. The TSB highlights intelligent transport systems (ITS) as a key area of strength in the UK,[124] making this a useful case for further investigation of barriers to innovation.

Intelligent Transport Systems

Challenge led area
Digital services

Intelligent Transport Systems (ITS) comprise various forms of digital systems, services and infrastructures that enhance the safety, ease and efficiency of use of the transport system. This includes systems aimed at demand management, such as road toll and congestion charge systems, where both the operationalising of the system itself, as well as products facilitating easier interaction with these systems are relevant. ITS also includes information systems for travellers, enabling for instance notification of disruptions, route planning, and availability of parking spaces. Systems of this type can also be adapted to freight and logistics, as well as to emergency services with systems enabling automatic notification of accidents, delays and congestion. Live timetables and integration of different modes of transport are further aspects that fall into this category.[125]

The importance of innovation in this area is considerable. The economic consequences of traffic congestion and inefficient networks are well documented,[126] as are the environmental consequences.[127] It has furthermore been noted that systems to improve reliability and planning in the transport system could mitigate other adverse effects on individuals, such as personal cost, stress and frustration.[128] It is furthermore most likely that pressure on transport systems will increase rather than decrease in the future, which, combined with financial strains on councils and governments negating many possibilities for large scale investments in ‘hard’ infrastructure, will lead to a heightened necessity to implement intelligent transport systems wherever possible. The Transport systems catapult initiative notes that if the UK does not emerge as a leader in this field, these systems will eventually have to be purchased from other countries.[129]

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[124] Technology strategy board, Transport priority area: https://www.innovateuk.org/transport#action

[125] IBM (2007) Delivering Intelligent Transport Systems – Driving integration and innovation. Transport systems white paper, available: http://www-935.ibm.com/services/us/igs/pdf/transport-systems-white-paper.pdf

[126] The Eddington Transport Study (2006) www.dft.gov.uk/about/strategy/transportstrategy

[127] Stern Review on the Economics of Climate Change (2006) www.hm-treasury.gov.uk/sternreview_index.htm

[128] Technology strategy board, Intelligent Transport Systems and Services Innovation Platform. Available: https://www.innovateuk.org/documents/1524978/1814018/Intelligent+transport+systems+and+services+-+innovation+platform+%2528Archive%2529/c60fe25f-4504-4286-8c9f-32595606273d

[129] Transport Systems Catapult (2013) Five Year Delivery Plan to March 2018 - Driving the UK’s global leadership in Intelligent Mobility, promoting sustained UK economic growth

In this area, there is a broad range of barriers to successful innovation. Some of these are relatively generic: start-up costs can be high, depending on the type of product. Furthermore, there is a distinct lack of knowledge on the part of potential customers about what exactly intelligent transport systems can do and what their advantages and benefits are. Additionally, there is need for clarification on some matters of liability: in many cases, it is so far unclear to what extent manufacturers of an ITS might be liable, if use of their product leads to undesirable outcomes (delay, accidents, etc.). However, whilst these various issues need to be addressed, especially that of low awareness and understanding on the part of potential customers, these are generally not identified as the main barriers to innovation in the fields of ITS. The most significant barriers stem from the scale and integration required by most ITS products.

Most ITS products need to draw on data that allows them to cover broad geographical areas. The smallest common scale here are city-wide systems, such as the London congestion charge and related services, but often they need to stretch further, either nationwide or even internationally. A clear example is the data necessary for GPS systems in cars, where additional functions such as notification of congestion and accidents require data to be available at least nationally, ideally internationally and in a standardised format, for products to be suitable for wide distribution. Likewise, systems often require integration of live travel information of several different modes of public transport and transport systems. The availability of standardised data to be coordinated and adequately processed within an ITS product is so far lacking or decisively deficient. Given that this is a structural issue requiring coordination and standardisation beyond the capability of the companies involved in making the ITS products, there is a critical need for public support and a concerted effort to produce a more coherent data infrastructure allowing these products to be deployed more easily and widely.

Table 17 Failures in the intelligent transport systems market

Failure	Source	Scale	Description
Character of Science and technology		No evidence found	
Market power	Niches 2010[130]	Slowing down	[Scale is generally quite large for most types of products/ systems. The resulting start-up and implementation costs create additional difficulties in bringing innovations to the market]
Externalities		No evidence found	
Information asymmetry	EU 2011[131]	Slowing down	The lack of easy and efficient access to knowledge about the benefits and costs of ITS applications and

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and wellbeing. Available: https://ts.catapult.org.uk/documents/2157668/0/Five+Year+Delivery+Plan/17da4867-9309-455a-afa6-f92abfac357e?version=1.0

[130] Niches (2010) Guidelines for implementors of innovative bus systems. Niches, Coordination action funded by EC FP7. Available at: http://www.niches-transport.org/fileadmin/NICHESplus/G4Is/21582_policynotesWG2_3_low.pdf

[131] EU (2011) intelligent transport systems in action – Action Plan and legal Framework for the Deployment of Intelligent Transport Systems (ITS) in Europe. Directorate General for Mobility and Transport, European Commission

Failure	Source	Scale	Description
			services, and about experiences and evaluations of ITS implementation is recognised as a key reason for slow investment. Decision making for ITS deployment on the urban, regional and national level has been slow and uncoordinated. […] Investment decisions are typically based on awareness and understanding of possible options, steered by perceptions of benefits versus costs. For decision-makers to be able to give full consideration to ITS, they must understand the pros and cons of ITS and be aware that ITS make it possible to do more than simply add more 'hard' infrastructure to the transport network. Developing this awareness and understanding will help to cement ITS as a valid option for mobility-relate problem-solving, which should in turn help to boost ITS funding, investment and deployment.
Capabilities		No evidence found	
Network	EU 2011; See also ITF 2010[132]; See also Giannoutakes and Li 2012[133]; See also IBM 2007[134] Catapult[135] 2013	Slowing down (show-stopper for some specific products) Slowing	Given advances in data-collection technology and with growing demand for more precise and real-time information, the need for more — and better — data is increasing all the time. Yet differences between national policies on traveller information and information markets across Europe persist. […] Accurate road data is needed for in-car navigation devices as well as for travel planners and all kinds of traffic-management applications. However, data shortcomings are restricting the ability of in-car systems to consider traffic-management plans or routes established by the road authorities. Rules in EU countries on the collection of road and traffic-regulation data have been uneven and often completely lacking. There has also been a lack of standards regarding the attributes to be used for recording traffic regulations and traffic circulation plans or recommended routes for heavy goods vehicles. […] …the potential of ITS to make an impact on issues like congestion, safety and carbon emissions is at its greatest in urban areas. But urban mobility is a complex animal, and the fact that responsibilities are spread among many different stakeholders can make coordination and consensus difficult to achieve. Technical solutions exist — the main barriers to further ITS deployment in cities are rather organisational, institutional or financial.

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[132] ITF (2010) Transport and Innovation: Unleashing the Potential. International Transport Forum Available: http://people.hofstra.edu/jean-paul_rodrigue/downloads/Transport%20and%20Innovation_Leipzig_Summary_JPR.pdf

[133] Giannoutakes KN and Li F (2012) Making a Business case for Intelligent Transport Systems: A Holistic Business model Framework. Transport reviews, 32(6) pp781-804

[134] IBM (2007) Delivering Intelligent Transport Systems – Driving integration and innovation. Transport systems white paper, available: http://www-935.ibm.com/services/us/igs/pdf/transport-systems-white-paper.pdf

Failure	Source	Scale	Description
		down	Very few journeys are made using one mode of transport alone. Passengers view journeys from end to end and consider comfort, cost and time as they make choices before and during those journeys; the circumstances can change through a journey, so up-to-date information is vital –indeed its provision is already a growing market. Yet industry, government, authorities and operators all work in individual silos – even the new information systems tend to work on only one form of transport. Businesses know that to deliver the required commercial, technical and social solutions they must work across and between these silos. There is currently a market failure with little or no interface or interactions between businesses.
Institutional	EU 2011	Slowing down	Liability issues raised by the provision or use of ITS applications represent another potential barrier to the wider market penetration of some Intelligent Transport Systems. Liability issues have notably hampered the market introduction of intelligent integrated safety systems, with legal questions regarding product/manufacturer liability and driver responsibility. For advanced driver assistance systems, for instance, the liability risks may be highly complex — the term ‘defective product’ is used in the EU product liability directive not only in a technical sense but is also linked to human factors including system requirements such as dependability, controllability, comprehensibility, predictability and misuse resistance, which in turn brings in human–machine-interaction safety issues.
Infrastructural	EU 2011 See also ITF 2010 See also IBM 2007	Slowing down (showstopper for some specific products)	Intelligent digital maps are a basic requirement for a whole range of ITS tools. The problem has been that the road data needed to produce them is not always available, accurate or reliable, with a lack of rules for timely updates. This hinders Europe-wide interoperability and the development of advanced — including safety-related — ITS technologies. The challenge is to ensure easy access to the digital road databases maintained by thousands of European road authorities in a standardised, non-discriminatory and transparent way. […] Like other highly complex systems, integrated ITS applications need a strategic framework — or ‘system architecture’ — as a basis for choices concerning their design and deployment, as well as for investment decisions. An ITS architecture needs to cover technical aspects plus the related organisational, legal and business issues. The ability to integrate systems in this way greatly increases their potential. However, despite the research efforts that have been made towards building a European ITS architecture (notably through the KAREN and FRAME projects — http://www.frame-online.net), only a limited

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[135] Transport Systems Catapult (2013) Five Year Delivery Plan to March 2018 - Driving the UK’s global leadership in Intelligent Mobility, promoting sustained UK economic growth and wellbeing. Available: https://ts.catapult.org.uk/documents/2157668/0/Five+Year+Delivery+Plan/17da4867-9309-455a-afa6-f92abfac357e?version=1.0

Failure	Source	Scale	Description
			number of EU Member State administrations have developed or are using an ITS architecture to deploy IT systems and services. In addition, the interoperability, continuity of services, multimodality and urban aspects of ITS architecture have generally been overlooked, and need to be duly addressed.

Civil aviation

Challenge led area

High value manufacturing

Having assessed the relatively generic field of car manufacturing, as well as the service and infrastructure-based field of ITS, aeronautics presents a useful final example of a transport sub-sector, with a range of barriers to innovation distinct from those outlined here so far.

The significance of the aerospace sector can hardly be overestimated: the sector supports over 230,000 jobs in the UK and contributes £24bn per annum to the UK economy.[136] Innovation in this sector has furthermore been acknowledged as generating considerable spillovers into other sectors.[137] With consistent increase in air travel over the past decades, a trend that is highly likely to continue and increase as emerging economies become an ever more significant passenger-base, the potential growth by 2031 for the civil aerospace market is in excess of US$4.4tn.[138] More specifically, it is forecast that nearly 27,000 new large civil airliners (with a market value of $3.2 trillion) will be needed by 2030 and by 2020 there will be a global market for around 9,500 civil helicopters (worth around $50bn).[139]

Aside from this importance of the aerospace sector overall, as well as its contribution to the UK economy, it is further worth noting that the UK has the second largest aerospace industry in the world, with 17% global market share. However, this strength derives in large part from investments in research made in the 1970s and 1980s, and there is a strong sense in the literature that there is a danger that the UK may start to rest on these laurels. However, as the large emerging economies contribute ever more to demand and passenger-base in global civil aviation, they likewise also present increasing levels of competition: given the overall significance and projected growth of this sector, many countries are engaged in supporting and fostering their own industries in this field.[140] The

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[136] see eg Aerospace infographic: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/225327/aerospace-sector_infographic.pdf

[137] National Aerospace Technology Strategy (NATS) (No date) SBAC, DTI and Aerospace Innovation and Growth team. Available: http://www.enviro.aero/Content/Upload/File/NATS%20brochure.pdf

[138] see Aerospace infographic: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/225327/aerospace-sector_infographic.pdf

[139] ADS (2012) Reach for the skies: A Strategic Vision for UK Aerospace. ADS, The Aerospace Growth Partnership, and the Department for Business, innovation and Skills. Available: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/31807/12-954-reach-skies-strategic-vision-uk-aerospace.pdf

[140] Ibid, p3

importance of successful innovation in this field is therefore clear. However, there is an especially broad range and severity of barriers to innovation in this area.

The barrier that features most prominently and consistently in the literature is an increasing skills shortage, ranging from new employable graduates in the field to senior technicians and postgraduates with the required research expertise. Various reasons are given for this in the literature, ranging from inadequate education systems to a preference among engineering graduates to specialise in other fields where there are perceptions of better opportunities and higher salaries. At present, this is already a considerable barrier to successful innovation, but if continued, this trend may make innovation in civil aviation ever less likely.

The second highly significant barrier relates to scale and risk. Aeronautical research and innovation is extremely costly, with especially long development cycles. In the first instance, this carries very high risks for the firms themselves. However, it also creates difficulty for funders outside the firm to decide whether the risks in providing finance are worthwhile. The highly competitive market additionally disincentivise long-term gambles.

A possible solution to some of the excessive financial risks of innovation might be found in pooled research and innovation projects, and consequently pooled risk and resources. This could be a suitable approach for many potential research and innovation projects, especially because the literature frequently notes that the industry has become increasingly fragmented: very rarely are entire aircraft built from scratch by a single company; there is instead an ever more complex supply chain emerging, as more sub-components require ever more component-specific expertise. Innovation in this area would therefore benefit from more concerted efforts, in order to pool risk and expertise alike. However, the literature also frequently notes that the supply chain is fragmented, with little formal coordination or overarching research collaboration. Not only does this mean that the sector as a whole requires coordination and public support – given the long innovation cycles, the literature additionally highlights that a long-term strategy exists for the sector, which different actors in the supply chain can rely on when contemplating whether to embark on major innovation projects.

Additionally, for some select areas of innovation, specifically radical innovation involving new types of fuel and power for aircraft, a key barrier already highlighted earlier in the context of low-carbon car manufacturing is once again present, namely the path-dependency of present re-fuelling infrastructures, which would require complete overhaul for new products requiring different infrastructures to take hold. Though in certain cases this is a show-stopping factor, it only applies to relatively few and specific types of products. Aside from this issue, civil aviation is overall a sector of huge importance to the UK economy, but where barriers to innovation are such that a major long-term sector strategy is necessary, which needs to help mitigate risks, coordinating the network of the supply chain, and counteract the serious skills shortage.

Table 18 Failures in the civil aviation market

Failures	Source	Scale	Description

Failures	Source	Scale	Description
Character of science and technology	Innova 2011[141]	Slowing down	Respondents [of the survey] rated R&D costs, technical risks, long development cycles […] as affecting innovation to 'a large extent'. Also the availability of funds for innovation inside and outside to firms is perceived as affecting innovation considerably. […] a long technology development cycle, combined with high capital investments and low profitability in the airline sector put pressure on innovation investments which are largely focused on later stages of the development cycle. This factor is further amplified by the cyclical nature of the sector.
Market power	AGP 2013 ADS 2012	Slowing down	Barriers to [market] entry are high Access to finance represents a risk to the industry: the nature of aerospace programmes, with heavy up-front investment costs, and long timescales to make a return, makes it hard for finance providers to understand risk and deters them from lending. It is also clear that there needs to be greater understanding of the types and availability of finance available to support business
Externalities		No evidence found	
Information asymmetry		No evidence found	
Capabilities	AGP[142] 2013, see also Raytheon 2012 ADS	Slowing down (in future potentially show-stopper)	The current performance of the UK aerospace industry in investment in skills is below what it should be, and is most pronounced in relation to the use of apprenticeships. Only 15% of aerospace companies offered apprenticeships in 2009, whereas the UK manufacturing average was 18%. A variety of barriers prevent or deter employers from investing in training, including inability to source from local providers the standard of engineering courses required; access to finance to support training.

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[141] Innova (2011) Sectoral Innovation Watch – Space and Aeronautics Sectors, final sector report. DG Enterprise and Industry, EC; Available: http://ec.europa.eu/enterprise/policies/innovation/files/proinno/sector-report-space_en.pdf

[142] Aerospace Growth Partnership (AGP) (2013) Lifting Off: Implementing the strategic Vision for UK Aerospace. Available: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/142625/Lifting_off_implementing_the_strategic_vision_for_UK_aerospace.pdf

Failures	Source	Scale	Description
	2012 See also Raytheon 2012[143]		The UK aerospace sector suffers from a shortage of skilled engineers, particularly at senior technician, graduate and postgraduate level.
Network	ADS 2012; See also Innova 2011; See also Raytheon 2012; See also NATS No date	Slowing down	Given this increasing global competition, the performance of the UK supply chain needs to improve at a faster rate than seen previously, if we are not to be overtaken. This includes suppliers adopting and maintaining continuous improvement plans for productivity, quality and delivery; taking opportunities to develop and incorporate product and manufacturing technology improvements; and having highly capable financial and supply chain management skills. […] moreover, the UK aerospace supply chain needs to have the ability to influence product design and functionality of future aircraft and engines. This will require early engagement with R&D networks during design processes. […] There may, in addition, be a requirement for some element of consolidation, clustering or simplification in the future UK aerospace supply chain in order to reduce complexity, enable investment in necessary R&D and encourage risk-sharing collaboration with smaller companies. Delivering a detailed exploration of this proposed requirement will be another key piece of work for the AGP.
Institutional	CAA 2011[144] See also Innova 2011	Slowing down	Government has an important role to play in shaping the future of UK aviation by providing a robust framework that sends credible signals about the long-term direction of policy. Given the long lead times involved in delivering aviation infrastructure and in developing new technologies, this policy stability will be crucial to generating the investment necessary to deliver Government's objectives.
Infrastructural	Innova 2011	Show-stopper (in select cases)	To prevent technology lock-in two parallel research efforts should be pursued at the same time: •drop-in alternatives of kerosene - renewable fuels that can be added / used in the current kerosene infrastructure. •revolutionary aircraft power systems -fuel cell / hydrogen that require a new infrastructure and hence pose considerable barriers

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[143] Raytheon (2012) How can the UK Maintain leadership in Aerospace manufacturing? Raytheon, Airbus and the Royal Aeronautical Society. Available: http://www.raytheon.co.uk/rtnwcm/groups/rsl/documents/datasheet/rsl_debate_parlimentary_recept.pdf

[144] Civil Aviation Authority (CAA) (2011) Department for Transport Consultation: Developing a Sustainable Framework for UK Aviation, Response by the Civil Aviation Authority, October 2011; available: http://www.caa.co.uk/docs/589/UK_CAA_Response_To_Sustainable_Aviation_Framework.pdf

Health and Care

Regenerative Medicine

Challenge led area
‘8 great’ technology

Regenerative medicine is a key area with potential for innovation that has been identified by the Policy Exchange think tank as one of the ‘8 Great Technologies’. The exact definitions of the field are not always fully congruent in the literature, but overlap sufficiently in order to speak of a reasonably well-defined field. Not a discipline in itself, regenerative medicine covers several fields, and is generally acknowledged to include advanced therapies based on cells, tissue engineering, developmental and stem cell biology, gene therapy, cellular therapeutics and new biomaterials. Summarising these various components, a textbook definition of regenerative medicine has been noted as a therapeutic interventions, which “replace or regenerate human cells, tissues or organs, to restore or establish normal function.”[145]

Regenerative medicine is a topic of crucial importance, not just as a source of economic growth in and of itself, but also in terms of the wider benefits and changes that could be generated through innovation in this field. In the context of the economic crises of recent years, public health systems are coming under increasing financial pressure, heightening the need for new forms of treatment and therapy that can be more efficient than existing ones. For example, cell based products are often more expensive than existing alternatives due to high cost of manufacturing and distribution.[146]

The ageing population especially in developed countries is adding to this pressure considerably. Most significantly, there is a strong necessity to shift wherever possible from palliative and therefore inevitably long-term treatments to curative treatments. This is especially the case for conditions where the latter currently does not exist, such as neurodegenerative diseases, and additionally for conditions such as diabetes, where the growing problem of obesity has led to increased demand and pressure on health systems. Especially for these areas, regenerative medicine has been highlighted as a key source for solutions. Besides the economic advantages that would be yielded by the UK becoming a leading player in this field, the benefits to public health, as well as the heightened capability of the healthcare system to provide curative rather than just palliative treatment for several key conditions provide significant grounds to consider the potential for innovation in this field.

Stem cell research – the scientific foundation of regenerative medicine – has been conducted in various forms since the 1940s. In this sense, the field has a considerable history. However, it was not until the 1980s that the unique characteristics specifically of embryonic stem cells were understood. This marked the beginning of extensive political debates in all parts of the world about the moral implications of obtaining embryonic stem cells. This has resulted in marked differences across the globe regarding the legality of

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[145] Mason C, Dunnill P. (2008) A brief definition of regenerative medicine. Regen Med, 3:1-5

[146] Martin P, Hawksley R and Turner A (2009) The Commercial Development of Cell therapy – Lessons for the Future? EPSRC – remedi; institute for science and society, university of Nottingham

stem cell research using human embryos. Several major industrialised countries have banned or severely restricted this type of research, including Germany, Austria and Italy, whilst many northern European countries are more permissive. The United States, currently the leading nation in both research and innovation in this field, is a particularly marked example, with some states enforcing an outright ban and others putting in place permissive regulation and financial support. In the case of the UK, there was initially cautious legislation in the form of the 1984 Warnock report followed by the Human Fertilisation and Embryology Act in 1990. The latter was subsequently amended significantly in 2001 and 2008/9, resulting in what has been termed a "…strict but facilitating regulatory regime for human embryonic stem cell based regenerative medicine."[147]

The comparatively permissive regulatory framework in the UK presents one immediate advantage for regenerative medicine in this country. Indeed, the UK has emerged as one of the strongest countries in terms of research output on the subject of regenerative medicine. Though the US is the undisputed leader in this field, only Germany and Japan rival the UK in terms of amount and quality of published research, indicating that there is a strong research base to build on. However, there are some significant bottlenecks in the UK in terms of translating this research into marketable products. These variously fall into the categories of market power through lock-in effects, information asymmetries, and capability and infrastructure failures. However, these various sub-components are linked, and are centred on one key problem, namely that large portions of regenerative medicine have not yet been proven to work effectively, thus falling short of a clear rationale for treatments of this type to replace existing treatments on the scale demanded by national public health systems such as the NHS.

The companies that have been involved in regenerative medicine tend to be relatively small and the backgrounds of the personnel tend to be considerably more focused on science and research rather than development and market knowledge. An international survey showed that 85% of firms in this industry have fewer than 100 employees. This may in large part be due to the relative novelty of the field, with regulation and legality being too uncertain in too many countries for large-scale commercial activities beyond research-led endeavours to take hold. Thus, the same survey highlighted a very high level of company failure and problems with firm growth.[148] The literature in the field consistently notes that there is effectively a breakdown in communication between end-users and researchers, which goes a long way in explaining the poor performance of commercial activities alongside highly successful research activities. But whilst research on the science of stem cells is considerable, there is limited evidence on whether products based on the research would be effective, both in terms of successful treatment and cost. This would be necessary in order to provide the NHS with a clear rationale to replace standardised, tried and tested existing treatment on the scale required by such a large infrastructure. Lack of understanding of user needs has effectively led to a breakdown in the marketability of an otherwise extremely promising field, with a clear case for public intervention and support to bridge these barriers. Without a concerted effort to help

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[147] BIS (2011) Taking Stock of Regenerative Medicine in the UK. Office for Life Sciences, Department of Business, Innovation and Skills & Department of Health. July 2011, available: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/32459/11-1056-taking-stock-of-regenerative-medicine.pdf, p. 8

[148] Martin, P (no date) Innovation challenges in regenerative medicine: some inconvenient truths. Institute for science and society, university of Nottingham. Available: http://www.york.ac.uk/res/sci/events/FinalConfPres/Martin.pdf

produce the research confirming efficacy and effectiveness of the developed products, as well as enabling firms to access skills and knowledge of end-user needs, successful innovation in this field is likely to remain hampered.

An additional factor compounding this major problem stems from a recent decrease in private investment in the pharmaceutical sector more generally. This decline may in part be explained by the kinds of inefficiencies and impasses considered above.[149] However, another significant factor here is the ‘patent cliff’ of 2011/2012, where patents for several market-leading pharmaceuticals expired more-or-less simultaneously, leading to an overall drop in revenues in the sector. This in combination with more general moves across the sector away from catch-all, ‘blockbuster medicines’ towards more wider ranges of targeted therapies where profits are more widely spread over different products, has led overall private investment to move away to other sectors. Though the main barrier to successful innovation discussed above is of a structural nature and could therefore only be mitigated to a limited extent through private investment, this issue of a shift away from investment in pharmaceuticals is an additional compounding factor worth noting here, as it decisively augments the already significant rationale for public support for innovation in the area of regenerative medicine.

Table 19 Failures in Regenerative Medicine

Failure	Source	Scale	Description
Character of science and technology	EPSRC 2009[150]	Slowing down	Whilst evidence [on cost-effectiveness and positive clinical outcomes] is slowly being accumulated, a lack of evidence has made it hard to overcome other factors. A major constraint on establishing the required evidence base is a lack of private or public funding for appropriate studies. Companies have little incentive to fund research of this sort if sales are only likely to be modest.
Market power	VALUE[151] 2012	Slowing down	A major challenge facing the regenerative medicine industry is the need to access adequate levels of funding in a timely fashion. However, access to capital is an increasing challenge as global biotech investment trends have shown a steady decline over the past years, reflecting the impact of the economic crisis, increased competition by other sectors such as the technology sector that generate favourable returns over short-time scales, volatile IPO (Initial Public Offering) markets and increasing regulatory demands for clinical safety and efficacy.
Externalities		No evidence	

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[149] BIS (2011) Taking Stock of Regenerative Medicine in the UK. Office for Life Sciences, Department of Business, Innovation and Skills & Department of Health. July 2011, available: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/32459/11-1056-taking-stock-of-regenerative-medicine.pdf , p6

[150] Martin P, Hawksley R and Turner A (2009) The Commercial Development of Cell therapy – Lessons for the Future? EPSRC – remedi; institute for science and society, university of Nottingham

[151] VALUE (2012) Regenerative Medicine: Navigating the Uncertainties. VALUE final report, March 2012. TSB Project No. 100809. Available: http://www.biolatris.com/Biolatris/News_&_events_files/ /VALUE%20Final%20Report.pdf

Failure	Source	Scale	Description
		found	
Information asymmetry	EPSRC 2009 Remedi 2010[152]	Show-stopper	The main reason for lack of uptake is that many cell therapy products have limited or unknown clinical utility in practice. For a clinician to use a cell therapy routinely it needs to meet a number of criteria, including be shown to be efficacious, easy to use, fit into established services and patterns of care, be cost-effective and better than currently available alternatives. One of the reasons for lack of utility is due to poor product specification and design. A number of first generation cell therapy products were developed without significant input from clinical end-users. As a consequence, they were difficult to integrate into routine practice.
Capabilities	Martin no date see also Remedi 2010	Slowing down	This industry is strongly concentrated around small, science-based firms. On one hand, this has led to strong capabilities in terms of developing products in this highly complex and skill-intensive sector, but has also resulted in poor understanding of user needs, as expertise in existing companies does not have a focus on this, whilst the small size of companies creates additional difficulty in creating this focus.
Network		No evidence found	
Institutional		No evidence found	
Infrastructural	BIS 2011; see also Remedi 2010	Slowing down	A qualitative study for BIS also highlighted that trained support staff were needed alongside engineers, Good Manufacturing Practice (GMP) production staff and Qualified Persons (QPs) to release finished cell-based products to deliver products effectively. Overall, it was felt that the number of staff (both clinical and non-clinical) with the necessary core skills and knowledge to deliver regenerative therapies was limited. Other related issues include problems with the storage and short shelf-life of autologous products and the long lead time in clinicians receiving products.

Assisted living

Challenge led area

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[152] Williams D, Archer R and Dent A (2010) Building a Viable Regenerative Medicine Industry – A Guide for Stakeholders. Remedi. Available: http://www.lboro.ac.uk/research/lcbe/pdf/building%20a%20 viable%20regenerative%20medicine%20industry.pdf

The TSB recognises that an ageing population in addition to presenting a number of challenges, also presents significant opportunities to enhance and extend the contribution of human capital. The changing demographic profile provides additional labour, a continuing knowledge resource and a social resource. The challenge becomes how to retain older adults healthy and engaged in society.[153]

The answer lies in being able to redesign services around individuals so they can live independently for longer. Assisted living involves promoting independence and dignity through the integrated uses of services and technology.

The developments in assisted living technologies present significant opportunities to combine enhanced patient experience and quality of life with increased efficiency and improved health outcomes. In the UK alone there is a potential £1bn cost saving with the use of tele-health (heavily incorporating telecare), just one of the core assisted living technologies.[154]

In terms of potential demand, a projected 75m will be over the age of 65 in Europe.[155] In terms of expenditure the global assisted living technology market is expected to grow from £6.2 billion in 2010 to £14.3 billion by 2015. In the UK, this equates to a telehealth market worth £35.7 million expected to grow to £70 million by 2015[156] and an even bigger telecare market worth £106 million in 2010 and expected to grow to £252 million by 2015. Barriers towards adoption however, may limit the growth potential. These can occur at both the demand side and the supply side.

Buyers of assisted living technologies may not necessarily be those who use them. Information asymmetry is an issue for buyers. In the case of central purchasers such as Clinical Commissioning groups, GPs or local authorities in terms of social care, there is a lack of awareness of the effectiveness and benefits of assisted living technologies.[157]

Moreover, market trends indicate that the market is increasingly orientated around assisted living in homes.[158] Private individuals, particularly younger members of the ageing groups, offer market opportunities directly. On the demand side there is evidence that the key themes are, firstly a lack of awareness of assisted living technologies; secondly a need for more accessible information to inform consumer choice, particularly in terms of where and what to buy.[159] The potential exists to increase adoption and acceptance of

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[153] see eg. Biddle M (2012) Active and Healthy Ageing – A Technology Strategy Board view. Presentation at TSB event for N8 Research, 21st November 2012

[154] BIS (2013) The Smart City Market: Opportunities for the UK. BIS Research paper no:136, Department of Business, Innovation and Skills. Available: *https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/249423/bis-13-1217-smart-city-market-opportunties-uk.pdf*

[155] Assisted Living Technology: A market and technology review, 2012

[156] Deloitte (2012), Primary Care: Working Differently, Telehealth and telecare – a game changer for health and social care https://www.deloitte.com/assets/Dcom-Angola/Local%20Assets/Documents/uk-ls-telehealth-telecare.pdf

[157] BIS (2013) The Smart City Market: Opportunities for the UK. BIS Research paper no:136, Department of Business, Innovation and Skills

[158] Ibid.

[159] COMODAL (2012) Unlocking the potential of the younger older consumer: Consumer preferences and the assisted living market. Research findings from the COMMODAL project. Available: *http://www.sehta.co.uk/wp-content/uploads/2012/04/FINAL_Unlocking-the-potential-report.pdf*

assisted living technologies by moving beyond the ‘medical model’, where consumers accept the advice on solutions from medical experts as they expect them to know the best solution, towards a quasi-retail model, where consumers purchase assisted living products in much the same way as other goods and services. This could widen access and reduce stigmatism of assisted living technologies. The potential is large with expenditure by private consumers in 2008 exceeding that of local authorities, with £244m private expenditure compared to £177m spent by local authorities. With the potential market growing the gap is likely to grow further.[160]

A significant barrier to the market achieving potential growth arises from issues of standardisation and interoperability of equipment and the extent to which solutions are provided over open platforms. As with many network technologies open access to the platform can increase the availability of solutions and applications, generating potential positive network externalities.[161] Relatively short lifecycles for technology can lead to a degree of lock-in. Evidence suggests that the costs of switching are too high as low levels of interoperability mean that changing equipment can mean having to change the whole infrastructure.[162]

International variation in medical regimes can impede potential market growth as suppliers incur additional costs to tailor technologies to conform to different standards or regulations.[163]

A consequence of different market structures and regulatory issues could also impede growth for UK firms, particularly SMEs. There is a perception that the UK environment for patenting software and methods is more difficult than is the case in the US. Larger corporations can draw on larger resources to pursue differentiated strategies to optimise IP, while UK firms have limited resource to pursue such strategies in the different markets.[164] The UK supply market continues to be fragmented and, while there has been some trend towards mergers and acquisitions, firms are dwarfed by the global market players (Barlow et al). Future business models may be more orientated around particular groups of players, each potentially involved in all or a number of the elements of the value chain, greatly restricting the capability to lead progress towards standardisation.[165]

A further important consideration is that of NHS Reform and the integration of health and social care services. The integration of health and social care is important for many reasons but particularly for the development of assisted living technologies, important for the transition of the system to one where people are able to live independently for longer. In the past, significant issues have existed around the functional specialisation and distinctness of public services, such as health and social care where older people (and the taxpayer) may be served best by integrated services but where the historical separation between the services has created particular working approaches/technical systems that

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[160] Ibid.

[161] Ibid.

[162] Barlow et al (2012) Developing the capacity of the remote care industry to supply Britain’s future needs Health and Care Industries Research and Innovation Centre

[163] BIS (2013) The Smart City Market: Opportunities for the UK. BIS Research paper no:136, Department of Business, Innovation and Skills.

[164] Ibid.

[165] Barlow et al (2012) Developing the capacity of the remote care industry to supply Britain’s future needs Health and Care Industries Research and Innovation Centre

are not easily connected due to certain incompatibilities. This has led to the diffusion of these innovations within the NHS often being slow and in some cases failed[166] and so a strategic approach to innovation was put forward in the UK Strategy for Health Innovation and Life Sciences, to be included in NHS reforms, following a review by the NHS Chief Executive of the adoption and diffusion of innovations across the NHS, published in 2011 to help overcome this barrier.

Table 20 Failures in the Assisted Living market

Failure	Source	Scale	Description
Character of Science and technology		No evidence found	
Market power		No evidence found	
Externalities		No evidence found	
Information asymmetry	BIS 2013[167] COMODAL 2012[168]	Slowing down	"Low awareness amongst CCGs, GPs, and their equivalents internationally, of the proven benefits and capabilities of assisted living technologies" "Trust in the information or advice given is also important. Some people have faith that a care professional such as an occupational therapist would know the 'best' solution for them. Much of this may arise from the 'medical' model approach towards ageing and disability, where attitudes towards assistive living products and services are different to other products and consumers (or 'service users') look to others to know what is best. Consumers may lack trust in private retailers' independence and there are anecdotal reports of negative experiences, such as people being sold unsuitable products. Charities report concern that retailers, under pressure to increase profits, may pressurise users to top up their prescriptions. For high street suppliers of assistive living products, it seems that retailer accreditation may be important to ensure that 'individuals don't have advantage taken of them"
Capabilities		No evidence found	

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[166] NHS (2011), Innovation, Health and Wealth: Accelerating Adoption and Diffusion in the NHS http://webarchive.nationalarchives.gov.uk/20130107105354/http:/www.dh.gov.uk/prod_consum_dh/groups/dh_digitalassets/documents/digitalasset/dh_134597.pdf

[167] BIS (2013) The Smart City Market: Opportunities for the UK. BIS Research paper no:136, Department of Business, Innovation and Skills

[168] COMODAL (2012) Unlocking the potential of the younger older consumer: Consumer preferences and the assisted living market. Research findings from the COMMODAL project

Failure	Source	Scale	Description
Network	BIS 2013	Slowing down a lot	"Standardisation and interoperability of equipment to which open platforms are utilised"
	Barlow et al 2012[169]		"Suppliers are particularly concerned about the fragmentation of remote care purchasing, particularly in the NHS, which makes it difficult for them to negotiate and deliver substantial projects." "Suppliers felt that the flow of information, cash and resources across boundaries in health and social care continues to be a significant barrier to investment" "Re-procurement of remote care technology is estimated to be necessary every three and five years, when equipment reaches the end of its lifecycle. However, service providers argue it is not easy to change suppliers. …..changing suppliers can mean changing the whole infrastructure at great expense"
Institutional	BIS 2013	Slowing down	"Disparity in medical regulation regimes globally (and even within Europe)"
Infrastructural	NHS[170] 2011	Show-stopper	NHS reform, integration of health and social care services. 'the acknowledgement that whilst the NHS is recognised as a world leader in invention, the diffusion of these innovations within the NHS has often been slow and in some cases failed'

Stratified medicine

Challenge led area
High value manufacturing

While patient treatment has always been personalised by clinicians based upon individual circumstances and medical history, the greater understanding of molecular basis of diseases has enabled a greater opportunity to narrow categorisation towards individualised treatments.

Stratified medicine[171] (or personalised medicine as it is known in the USA) is the tailoring of medical treatment to the individual characteristics of each individual or groups of patients. It is a multi-faceted approach to patient care that improves the ability to diagnose and treat disease as well as increasing the potential for earlier detection, increasing the effectiveness of treatments. The approach is very research driven, relying on scientific

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[169] Barlow et al (2012) Developing the capacity of the remote care industry to supply Britain's future needs Health and Care Industries Research and Innovation Centre
[170] NHS (2011), Innovation, Health and Wealth: Accelerating Adoption and Diffusion in the NHS
[171] Technology Strategy Board 'Stratified Medicine Innovation Platform'

breakthroughs in the understanding of how an individual's unique molecular and genetic profile make them susceptible to particular diseases. This also enables increased ability to predict the effectiveness and safety of particular treatments for each patient.

The market for stratified medicine is projected to increase significantly, particularly in cancer treatments. Estimates of the costs of treatment for new cancers – including hospitalisation, screening, surgery, radiotherapy, drugs and diagnostics, amounted to $286bn in 2009, although estimates reported by Kings College in 2008 estimated global cancer costs at $895bn. Predicted costs are expected to exceed $1 trillion in 2013.[172]

The molecular diagnostics market is a closely aligned area within personalised medicine. Growth estimates by Price Waterhouse suggest the market will double from $3bn in 2009 to $6bn in 2015, with substantial growth through cancer companion diagnostics.

Progression from new developments to clinical practice, in order to achieve economic potential faces a number of barriers. These can be categorised within our taxonomy of market and systems failures. A theme running through these potential failures is the impact on information asymmetry that the need to integrate new partnerships, arising from the new integration of molecular diagnostics with traditional pharmaceuticals creates. This feeds through into investment decisions and there currently exists potentially socially inefficient levels of investment.

There are significant benefits – both economic and clinical – to stratification. The combination of molecular diagnostics and therapeutic agents is increasingly expected to inform treatment selection by predicting more accurately the safety and efficacy of treatments in specific sub-groups of patients. This has positive social benefits through reducing the overall incidence of adverse events through better targeting of treatments, reducing uncertainty about the effectiveness of treatments and increasing adoption and compliance.

However, a significant barrier arising from externalities in terms of appropriation of investment returns. New personalised drugs narrow the potential market, therefore reducing the volume open to pharmaceutical companies. Furthermore, there is a recognised low level of investment from those who pay the costs of treatments as information asymmetry is an important barrier. It is difficult to identify which combination of diagnostic test, IT and operational systems will actually achieve cost efficiencies. Uncertainty about future revenue streams are further compounded by the continuation of a single pricing model for treatments. The research to identify 'high value' patients may also be hugely costly and complex, reducing research.

There are also significant costs in implementing new diagnostic tests. While individually they are not very expensive, the overall costs can be hugely significant. The view is that the difficulty in tracking much earlier stage and experimental testing creates fear and uncertainty about the overall eventual costs. There is also a lack of longitudinal accounting which would enable payers to capture long-term cost savings from near-term testing.

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[172] Branzen, K (2013) Personalised medicine: a new era for healthcare and industry – a futures study from Life Science Foresight Institute

The issue of data security also presents a barrier as private information must be protected, particularly at early stages of development. For research to truly benefit from the accumulation of genome sequencing data there has to be a high level of enrolment, raising privacy and data protection concerns. Moreover, genomic information on its own is only part of the story. This information is greatly enhanced when linked to clinical outcomes. This would require a secure electronic link between genome databases and health records, raising serious technical, ethical and legal issues.

Established frameworks and legislation are essential to ensure the storage of data is secure. In the UK health providers must ensure they have systems in place to meet the requirements of the Data Protection Act, with severe penalties for breaches in data security. The veracity of data is also a key issue. Test information may be misused, particularly at early stages of investigation and development. which may harm patients.

Because of the complexity, high capital costs and the size of databases being created there is increasing requirement for collaboration among many academic groups, public institutions and industry, often across international boundaries.[173]

Establishing standards in healthcare has always presented challenges. Issues such as quality, cost and continuity of care, patient safety concerns are all important. Issues of informatics and IT systems, as referred above are all barriers to establishing standards. This poses a significant institutional problem among actors in the health sector.[174]

Table 21 Failures in the Future Cities market

Failure	Source	Scale	Description
Character of Science and technology		No evidence found	
Market power	Academy of Medical Sciences 2007[175]	Slowing down	Companies have little latitude to increase price after a drug is marketed – while economists assert that price is the best indicator of value in a well-functioning market, prices are regulated in many European countries and face substantial inflexibility or, as least inertia in the more open US market.
Externalities	The Academy of Medical Sciences	Show-stopper	“Pharmaceutical companies have low incentives to invest in diagnostics that potentially could reduce the size of their market. The traditional business model for the manufacturers of prescription drugs is one of high margin - high risk R&D, with strong IP protection, while for diagnostic research the model

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[173] The Academy of Medical Research (2013) *Realising the potential of stratified medicine. July 2013, available:* www.acmedsci.ac.uk/download.php?i=15909&f=file

[174] Richesson and Krishner (2007) *Data Standards in Clinical Research: Gaps, Overlaps, Challenges and Future Directions* Journal of American Medical Informatics Association, 914: pp687-696 and The Academy of Medical Research (2013) *Realising the potential of stratified medicine*

[175] The Academy of Medical Sciences (2007) Optimizing stratified medicines R&D: addressing scientific and economic issues

Failure	Source	Scale	Description
	2007		tends to be lower margins, platform based with an assumption of high volumes".
Information asymmetry	Jakka and Rossbach 2013[176]	Slowing down	"it is difficult to identify, which diagnostic tests, corresponding assays, information technologies and operational systems will truly save costs; (ii) although individual diagnostic tests or systems may not be very expensive, the overall costs could be amazingly high" "no structures exist that allow payers to assess cost savings from prognostic and preventive diagnostic testing……Furthermore, the high customer turnover of many commercial payers makes it less attractive for payers to reimburse prophylactic tests that minimize the likelihood of a disease occurring much later in life. Also, to differentiate between a diagnostic test that actually saves costs on a long-term basis and tests that create costs, it may be in the interests of payers to delay adopting novel biomarker-based diagnostics since actual cost savings of such tests may not be known until a test has been on the market for some time. Consequently, the generation of high-quality health economics evidence could provide a basis and the confidence that enables payers to faster adopt diagnostic tests and would align physicians' incentives with patient care, clinical practice and outcomes."
Capabilities		No evidence found	
Network	Jakka and Rossbach 2013	Slowing down	"Mining such data will help to generate computational methods and algorithms to predict future clinical needs for each patient and to generate comprehensive profiles of patient groups. Such stratified patient populations and comprehensive systems biology approaches will result in powerful new diagnostics and therapeutics and provide invaluable new insights into prevention. Key to these developments will be the integration of medical data in the context of the dynamic biological pathways and molecular networks in both health and disease that are both actionable and predictive and thus useful to both clinicians and patients".
Institutional	Jakka& Ross-bach 2013	Slowing down	"…establishing standards in healthcare has always been very challenging"
Infrastructural		No	

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[176] Jakka S and Rossbach M (2013) An economic perspective on personalized medicine. The HUGO Journal, 7:1 http://www.thehugojournal.com/content/7/1/1

Failure	Source	Scale	Description
		evidence found	

Creative Industries

Digital services

The types of industries that fall under the category of creative industries include, but are not limited to, audio-visual, music, design, performance, publishing, gaming, radio and architecture industries. Creative industries have an important stake in contributing to productivity by means of (i.) investment in innovation, (ii.) generating knowledge spillovers, (iii.) stimulating competition and UK competiveness, and (iv.) stimulating industry uptake and the creation of jobs.[177] According to the European Commission[178] creative industries are in a strategic position to generate spillovers in other industries because creative industries operate at the intersection of art and business and technology that drive the development of ICT applications, consumer electronics, and telecommunication devices.[179] Overall, the creative industry is a high growth industry. The UK Technology Strategy board (TSB) says that 1.4 million people are employed in the creative industries, which account for roughly 5.3% of UK output. Both at the UK governmental and European governmental there is recognition of the strategic economic potential of creative industry development (aside from social and cultural stakes) and this recognition had led to the establishment of several policies the specifically target creative industries in the UK. At the same time, because the definition of creative industries remains relatively open, there are few specific policies that target creative industries. Much of the creative industry comprises SMEs, hence, several of the policies that influence the development of creative industries are SME policy.

This section outlines the types of market failures that undermine innovation and development in the creative industries. According to BERR the enterprise enablers are: culture, knowledge and skills, access to finance, regulatory framework, and business innovation.[180] Whilst these enablers can promote the development of the creative industries, they can also function as barriers to development. And, these barriers are closely related to some of the failures.

A summary of the market failures that influence the creative industries is in Table 22. In the creative industries, high levels of market power can be an indication of a consumer lock-in effect. The consumer lock-in effect plays a role in, for example, the gaming industry where the demand for games is dependent on the type of games console. The consumer lock-in effect may create a situation of high market power that stifles innovation. Bakhshi et al.[181] argue that market dominance can create 'winner takes it all situations'. As indicated

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[177] BERR (2008) Enterprise: unlocking the UK's talent. HM Treasury, BERR and Unlocking Talent. Available: http://www.berr.gov.uk/files/file44992.pdf

[178] COM (2012) 537 final. Promoting cultural and creative sectors for growth and jobs in the EU. European Commission.

[179] The EC COM(2012) 537 builds on the EC green paper COM(2010)183 on unlocking the potential of cultural and creative industries

[180] BERR (2008) Enterprise: unlocking the UK's talent

[181] Bakhshi, H. Hargreaves, I., and Mateaos-Garcia, J. (2013) A Manifesto for the Creative Economy. Nesta

in Table 22, under these scenarios, at least in the short-run, market power may slow down the innovative capacity of the industry.

Financing difficulty is one type of failure (i.e. externality) that is pertinent to creative industries. Several reports identify that firms which are active in the creative industry experience difficulties in raising capital. As a result of these financing barriers firms may refrain from investing in otherwise profitable activity. As identified by the TSB (pp. 5),[182] the reasons that explain why the creative industries struggle to finance investment include “high risk valuation of intellectual property and content assets”.

The creative industries in the UK benefit from a wide range of financial support to help overcome the financial barrier. One example of financial aid is the Small Business Research Initiative (SBRI) a type of public procurement grant. The SBRI is a type of public private partnerships that support SMEs with technological orientation. Ideas are supported that are expected that have a specific social value. The SBRI requires the company to develop a prototype and to launch the prototype on the market. Alternative financing schemes launched by the TSB include Innovation vouchers (grants for SMEs up to £5000 to partner-up with a knowledge or technology supplier) and the Smart scheme (provides seed funding to early stage companies to e.g. conduct market research and develop a prototype). EU funds include Eurostars, risk-sharing facility, CIP, and as of 2014, Horizon 2020.[183] At an aggregate level, financing difficulties slow down innovation and development.

One major showstopper in the creative industries is that the private sector fails to grasp the value of arts including the value of preserving cultural heritage. Bakhshi, et al.[184] state that “arts do produce value that can be meaningfully assessed and measured by economists, but that they of course produce cultural value which cannot be expressed in monetary units.” In this case, the relation between art and innovation is not evident.

A major constraint to the development of creative industries is the mismatch between the knowledge and skills needed to become a successful entrepreneur in the creative industries and the formal education and training provided. Specifically, BERR argues “business needs innovative people with skills and entrepreneurial drive. The Government has a unique and essential role in supporting business innovation, by ensuring there is a stock of science, technology, engineering and mathematics (STEM) graduates and flexible labour markets for them to enter”.[185] The TSB find that there is a lack of technical skills and experience in digital content creating tools. It is clear that a lack of knowledge and skills slows-down the creative process and development.

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[182] TSB (2006) Creative Industries Strategy 2006-2013. Technology Strategy Board

[183] The Risk-Sharing Finance Facility is a debt-based financial instrument created as a joint programme of the EIB and the EC. It can access two billion euro in capital, of which half is provided by the EC under the Seventh Framework Programme. The programme supports relative high-risk projects by means of financial instruments like loans, guarantees, and equity investment. The Competitiveness and Innovation Framework Programme (CIP) provides innovative SMEs, e.g. operating in creative industries, easier access to finance and business support services.

[184] Bakhshi, H. Hargreaves, I., and Mateaos-Garcia, J. (2013) A manifesto for the creative economy. Nesta. P 77

[185] BERR (2008) Enterprise: unlocking the UK’s talent, p 82

As identified in the EC communication,[186] there are powerful dynamics operating at the intersection of different creative industries. However, spillovers are limited, presumably as a lack of cross-sectoral network and coordination. In response to such network failures, the UK government supports the development of collaborative R&D projects. Knowledge Transfer Partnerships (KTPs) are launched with the intention to increase enhance the creation and transfer of knowledge by providing a network, and thereby stimulating the competitiveness, productivity and performance of business, including those operating in creative industries. This type of partnership programmes intend to link agents producing new knowledge with agents that commercialize knowledge. KTPs establish partnerships between business and (academic) research institutions (and the UK government covers roughly two thirds of the cost for SME participation).

Institutional rules and regulation can both enable the development of creative industries as well as block the development. In particular bureaucracy and red tape can be cumbersome for small business development. Fortunately, the regulatory framework in the UK is one that does not pose serious bureaucratic constraints to doing business. However, social rules may form a barrier to innovation in the creative industry. As highlighted in the BERR report on creative industries, two types of fears inhibit entrepreneurs: fear of failure and fear of dealing with finance. These institutional/cultural constraints can act as long-run barriers slowing down innovation and development in the industry. One perspective is that creative skills must be better installed from early age by integrating the culture of entrepreneurship in to the UK educational system.[187]

Two types of failure have not been discussed: information asymmetry and infrastructural failure. It may be reasonable to assume that overall, for the creative industries, these types of failures are not the most pertinent. At this stage, we have not identified specific examples in the literature linking these failures to the innovative development in the creative industry. However, we cannot entirely exclude the relevance of these failures because the creative industries are heavily influenced by government capital investment. For example, the performing arts are heavily dependent on government subsidies, and changes in this government budget frequently leads to bankruptcy processes (as is experienced in the current crisis). Information asymmetries likewise play a role in the relationship between SMEs and credit extensions. Overall, the relationship between these types of failures and the creative industries needs to be explored more in detail.

In the next section, we specifically focus on the role of intellectual property rights protection in the design industry.

Table 22 Failures in the Creative Industries

Failure	Source	Scale	Description
Character of Science and Technology		No evidence found	
Market power	Bakhsh	Slowing	“One reason for this market dominance is the

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[186] COM (2012) 537 final. Promoting cultural and creative sectors for growth and jobs in the EU. European Commission

[187] See also the 2011 White Paper for Higher Education 'Students at the Heart of the System

Failure	Source	Scale	Description
	i, et al. (2013) pp. 81	down	network effects in Internet platform markets (…) which can create 'winner takes all' situations (…) . In the absence of diversity in demand for different platforms, or of easy interoperability between them, consumers and business competitors can find themselves, at least in the short term, facing unacceptable levels of market power"
Externalities	Bakhshi, et al. (2013) pp. 63 BERR (2008), pp. 48 COM(2012) 537, pp. 4	Slowing down (a lot)	"Barriers to finance in the creative economy" "For a minority of firms, barriers to accessing finance persist" "Access to finance remains a major difficulty: the banking sector does not have the necessary expertise to analyse business models in these sectors and does not adequately value their intangible assets. The financial and economic crisis only makes this situation more critical at the very time when investments are needed to adapt"
Information asymmetry		No evidence found	
Capabilities	Bakhshi, et al. (2013) pp. 96	Slowing down (a lot)	"Today in the UK there is an alarming mismatch between the supply and demand for creative skills, with severe skill shortages precisely in the Internet-related areas where UK business s need to compete"
Network	COM(2012) 537, pp. 4	Slowing down	"Powerful dynamics take place at the borderlines between various sectors (for instance through increased linkages between gaming, film and music) and with other industries (such as fashion, high-end or tourism). However, the sectors and policies are still often organised in sectoral silos, limiting the scope for synergies and the emergence of new solutions and businesses."
Institutional	BERR (2008, pp. 52) BERR (2008, pp. 16)	Slowing down	"Confidence in dealing with finance is not high compared to other aspects of running a business. Some entrepreneurs can therefore lack the skills and confidence to access external finance. As a result businesses can become inadequately capitalised and their survival and growth threatened. Some entrepreneurs have strong perceptions that accessing the finance will be problematic, which discourages them from applying for the finance they need." "Fear of failure is commonly cited as part of the explanation for differences in enterprise and businesses formation rates between the UK and US. 36 per cent of people in the UK compared with 21

Failure	Source	Scale	Description
			per cent in the US say that fear of failure would prevent them from starting a business” Intellectual property rights (see section on design)
Infrastructural		No evidence found	

Note on a sub-sector: Design

Failures in design industries are broadly similar to failures in the creative industries. Producing a full additional analysis for this sub-sector of the creative industries is therefore superfluous. However, it is worth discussing briefly this particular sub-sector, to illustrate further the barriers to innovation in the wider creative sector, and also to point out some key distinguishing features.

According to the Big Innovation Centre, design is a “major driver of innovation, enabling firms to develop more valuable products and services, and streamline their business processes”.[188] Nesta even uses data measuring the development of the design industry as part of its innovation index; reflecting that a big component of innovation in the UK is in intangible (rather than tangible) assets.

In this section we explore the features that distinguish the success of the design industry focussing specifically on the importance of intellectual property. One specific feature of the UK design industry is that it largely is a knowledge-based industry that is heavily dependent on international markets.

The design industry has several niches. One way to categorize branches of the design industry is as follows:

- Architectural and engineering services
- Computer and telecommunications services
- Printing and publishing
- Fashion and craft
- Advanced manufacturing
- Design services (specialized design and technical activities)[189]

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[188] Big Innovation Centre (2012). UK design as a Global Industry. International trade and intellectual property. Big Innovation Centre & UK Intellectual Property Office, p 14

[189] This categorization of the design industry is used in the document: Big Innovation Centre (2012). UK design as a Global Industry. International trade and intellectual property. Big Innovation Centre & UK Intellectual Property Office

Based on this categorization is it clear that whilst part of the design industry takes place in specialized segments of the industry, design also is part of non-design industry. The design industry consists of micro enterprises (e.g. largely in the specialized design services) as well as large multinational corporations operating across the industry (e.g. retail). A relatively large percentage of the design industry workforce is highly skilled. On average, roughly 4% of the total UK workforce works as a designer and the largest percentage of the design workforce is in the area of graphic design.[190]

What makes the design industry of particular interest to the UK economy? A study by the UK Design Council[191] shows that firms that intensively use design outperform non-design intensive firms by 200%. Moreover, 80% of the firms surveyed find that design is important for maintaining competitiveness. An additional reason why the design industry is crucial for future innovation and development is that the design industry is a major contributor to the UK export market. According to the Big Innovation Centre "Around 35% of UK exports come from industries that employ higher-than-average concentrations of designers – when weighted according to the pay of core designers, design accounts for around 2% of UK exports."[192]

Intellectual property rights protection plays an important role in the design industry. Innovation in the design industry is challenged by the high level of complexity of the intellectually property rights system. The failure of intellectual property rights protection is the institutional failure to enable faster, easier, and cheaper protection and enforcement of property. The rationale for intellectual property rights protection is the following. The protection of intellectual property rights gives firms the exclusive right to capitalize on investment in innovative design for a limited period of time, limiting spillovers. As a result, it is expected that firms have greater incentives to engage in innovative actively.

There are four main types of intellectual property rights: trademarks, patents, copyrights, and designs. Trademarks are signs used to market goods and services. Patents are designed to protect inventions e.g. a process innovation, including formulae. Copyright applies automatically to written works such as books but also to clothing designs.[193] 'Designs' in the UK are either registered (more extensive protection up to 25 years of protection) or unregistered (less extensive up of to 15 years of protection and automatic protection). 'Designs' intend to protect the appearance of a product. There are several efforts to consolidate the information in intellectual property rights protection for the design industries: e.g. the Centre for Fashion Enterprise offers specific guidance on the topic for the fashion industry.[194]

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[190] Big Innovation Centre (2012) UK design as a Global Industry. International trade and intellectual property. Big Innovation Centre & UK Intellectual Property Office

[191] Design Council (2011) Design for Innovation. Facts, figures and practical plans for growth; A Design Council paper published to coincide with the Government's Innovation and Research Strategy for Growth, December 2011

[192] Big Innovation Centre (2012) UK design as a Global Industry. International trade and intellectual property. Big Innovation Centre & UK Intellectual Property Office, p 5

[193] Grochala, K (2014) Intellectual Property Law: Failing the Fashion Industry and Why the "Innovative Design Protection Act" Should be Passed. Student Scholarship. Paper 133. Grochala also notes that property law does not apply to clothing, only copyright does.

[194] Centre for Fashion Enterprise (2012) Intellectual property in the fashion design industry

‘Designs’ are a form of intellectual property protection that is particularly relevant for the design industry. A firm that registers a ‘design’ in the UK does not protect the product from being copied aboard. One option is to protect the product across the UK using the ‘Registered Community Design’. Another option is to apply for protection in specific countries separately. Finally, via the Hague system[195] it is possible to apply for protection in over 60 different countries by completing a single application. Similarly, via the Madrid International Trademark System (WIPO) it is possible to register trademarks using a single application worldwide. And, the Patent Cooperation Treaty (PCT) can be used to protect intellectual property on the basis of a single patent in 148 countries (WIPO). The patent application process is especially cumbersome; it takes several years, is expensive and is highly demanding.

The Big Innovation Centre outlines two challenges for the design industry: (i.) lack of enforceability of a global design rights registration system and (ii.) lack of awareness of the range of intellectual property protection instruments that are important for the design industry. According to the Big Innovation Centre “Developing service contracts, licensing designs and protecting design goods is a complex task for any business, and it is even harder to do in international markets. Small businesses often have limited resources to enforce their legal rights, and this may prevent them from exporting. It may also be hard for smaller businesses to select the right type of intellectual property protection, given the diversity of options available”.[196]

Aside from the difficulty of enforcing intellectual property rights geographically, the difficulty of enforcement of property rights protection also has a different dimension. As argued by Grochala, the fashion industry is rampant with counterfeiting. Unauthorized copying is inadequately dealt with, so intellectual property rights protection is not taken seriously in the industry.[197] Similarly Hargreaves argues that designers are sceptical that design rights can be enforced (and hence are sceptical that they are worth any level of investment). [198]

Quite differently, Hargreaves also argues that the intellectual property laws designed to create incentives for innovation are obstructing innovation today for another reason. The argument that the author makes is that innovation is inhibited by stringent copyright protection. Specifically, the advances in digital economy and IT have enabled a rapid sharing of information, which is now ‘blocked’ by copyrights. The mere expansion of available information and its ease of exchangeability have resulted in individuals and companies frequently (involuntarily) breaching copyrights. “Widespread disregard for the law erodes the certainty that underpins consumer and investor confidence”.[199] One view is that more clarity is required about copyrights protection and its limits to enable a cultural shift to greater respect for intellectual property.

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[195] For more information see e.g. WIPO, The Hague treatment agreement Concerning the International Registration of Industrial Designs: Main Features and Advantages

[196] Big Innovation Centre (2012) UK design as a Global Industry. International trade and intellectual property. Big Innovation Centre & UK Intellectual Property Office, p 6

[197] Grochala, K (2014) Intellectual Property Law: Failing the Fashion Industry and Why the “Innovative Design Protection Act” Should be Passed. Student Scholarship. Paper 133

[198] Hargreaves, I. (2011) Digital Opportunity. A Review of Intellectual Property and Growth

[199] Ibid, p 67

Partly in response to the administrative complexity – and often the high costs – involved in protecting intellectual property rights, a substantial part the UK design industry does not rely on property rights protection. As indicated in the Big Innovation Centre report, relative to the economic weight of the UK design industry, UK patent registrations are relatively low.

One explanation for the success of the UK as a major exporter of design is the industries' ability to stay at the frontier of 'knowledge creation'. Knowledge creation, especially, tacit knowledge is not easily copied and spread across the industry.

Financial Services

Digital services

Once perhaps seen as a slow-moving industry, today the financial services industry is dynamic and is a catalyst for technological upgrading and innovation. The types of innovation in the financial services that may resonate strongly include the shift to internet banking, mobile banking, paperless money, and novel payment systems (along with the development of e-commerce and ICT).[200] Additional innovations include the advances in securitization, use of derivatives, and improvements in the diversification of risk. As a result of these innovations, there has been a substantial financial deepening.

Whist these recent developments are positively related to competitiveness and growth (in terms of volume) of the financial sector, the financial services industry is confronted with several major challenges that are currently of crucial importance for the sustainable development of the industry. As frequently argued, the financial crisis has created opportunities to revise the financial services structure, its operations and relevant incentive mechanisms. In this section we focus on these various types of challenges to the industry.

The TSB (in consultation with industrial stakeholders) has defined three groups of challenges that are fundamental for the technological development of the financial services: (i.) technology knowhow and behaviours, (ii.) know-how markets structure and data, (iii) behaviours and trust.[201] The challenges for the financial service industry can be summarised as consisting of physical technology but also of market intelligence. Whilst several of these challenges are not related to failures, as discussed in our context of analysis, there are a few specific examples that are worth describing in more detail.

One of the challenges identified under the category 'technology knowhow and behaviours' is to identify new technologies that can contribute to enhancing capabilities. One example is the need to develop faster flow of high volume market information using models and techniques that are secure. Another of the TSB identified challenges is that of generating more industry-university collaborations with the objective of enhancing data availability and quality. As explained in the document, major difficulties may include that stakeholders are

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[200] See also the work of Berger and Nakata on the effect of ICT and financial service innovations on development in less developed economies. Berger, E. and Nakata, C. (2013). Implementing Technologies for Financial Service Innovations in Base of Pyramid Markets. Journal of Product Innovation Management, 30(6), pp. 1199-1211

[201] TSB (2010) Financial Services Strategy 2010-2013. Technology strategy Board

hesitant to collaborate because of the fear of infringing anti-competition regulations. Another possibility is that stakeholders shield intellectual property from competitors. Both t are possible explanation of why the financial services industry has not sought support from a wider (academic) network. In fact, for the most, the financial industry has little tradition of interacting with academia or research organisations in advancing data possibilities.

According to the TSB, investing in the above described network gap (i.e. network failure) can lead to more knowledge transferring and sharing of best practices. Expected outcomes of improving network cooperation can lead the overall industry to avoid duplicating efforts in addressing common challenges. Moreover, this may also lead to an improvement of the IT architecture and infrastructure relevant for risk modelling.

Several academic papers relate innovation in the financial services to competition levels and competition regulation. For example, Bos et al.[202] build on the work of Aghion and Griffith (2005) to explain the inverse U relationship between competition and innovation in the financial services industry. The authors measure innovation using data on the ability of US banks to “minimize costs through innovations”. The estimations reveal that a positive mark-up (market power) is associated with an optimum level of innovation. The results also reveal that (during 1984-2004) US financial deregulation (whilst increasing competition) lowered innovation potential below the optimum.

Whilst this study on the US financial system suggests that competition in the financial system is ‘too high’ and therefore yields a ‘suboptimal’ level of innovation, there are several rather convincing arguments that there is a ‘too high’ level of market power in the industry. ICAEW[203] for example argues that regulations in the financial sector are stringent and inhibit new competitors to enter the market. In contrast, Kroszner and Strahan[204] find that “many financial innovations have enhanced the liquidity of assets, firms, and markets, improved opportunities for diversification, and increased competition between suppliers of credit”. However, the authors also argue that this increase in financial deepening has substantially increased the concentration of systemic risk within the system and this has caused it to become more vulnerable to crises.

At the same time, several scholars ague that one of the reasons for the depth of the current financial crisis is that the industry is, ‘too big to fail’. Too big to fail refers to the fact that the collapse of a bank has a devastating effect on the financial system and the wider economy, to the extent that government policy has been to intervene with rescue packages to prevent banks from failing. A related problem is one frequently referred to as the ‘principal-agent’ problem where the state cannot motivate the financial sector to align its behaviour with the preferences of the state (and consumers). More specifically, the financial sector, knowing it is ‘too big to fail’ is more liberal in pursuing high-risk activity, based on the understanding that in times of losses the state is likely to provide support. This argument is likewise related to the behaviour and trust challenges identified by the TSB: herd instincts and bonus culture. Bonus culture essentially refers to the high bonuses and rewards that are awarded-especially amongst the higher echelons in the financial

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[202] Bos, J., W. B., Kolari, J. W. ,and van Lamoen, R. C. R. (2013) Competition and innovation: evidence from Financial Services. *Jounal of Banking & Finance*, 37(5), pp 1590-1601

[203] ICAEW (2012). Market Failures, Market Solutions Responsible Providers. Financial Services faculty

[204] Kroszner, S. R. and Strahan, P. E. (2011) Financial Regulatory Reform challenges ahead. American Economics Review, 101(3), pp. 242-246. P242

sector. Thus, whilst those responsible for high-risk activity do not take (full) responsibility for financial losses, they do enjoy high bonuses in times of financial boom and, quite controversially, also in times of financial bust. Under the ambition of creating a more sustainable financial sector, “a change in culture and attitude is needed, with more focus on long-term sustainability. Providing services that meet the economic needs of society should be placed above short-term profits and bonuses”.[205]

The other behavioural challenge identified by the TSB, ‘herd instincts’ is one of the underlying reasons why the collapse of one bank is likely to have a devastating effect on the entire economy. Herd instinct refers to the phenomena that people move in groups without a decisive organization. In reference to the financial sector, this means that groups of individuals move jointly in upward trends generating bubbles and move jointly in downward trends, possibly generating a financial collapse. In downward trends, individuals fear exiting the market too late and incurring losses. Related issues are bank-runs where consumers rush to withdraw their deposits leading to insolvency.

Traditional economic models that are still being used in the financial sector to model risk are based on the assumption that individuals behave rationally. However, for example, herd behaviour can be described as irrational behaviour. E.g. as referenced to above, panic and frenzy can result in a bank run although the bank run, when not restrained, causes banks to become insolvent and inevitable leads to a crash where individuals lose out. One of the challenges for the development of the financial sector is the development of economic models that take into account decision-making processes and irrational behaviour.

The financial system has developed into an increasingly complex system and, partly because of this complexity, the system lacks transparency (generating information asymmetries). The stability of the financial system is dependent on the trust of consumers. New research initiatives aim to better understand the role of trust and trust creation.[206] E.g. as a result of the lack of political foresight and bonus culture, ICAEW similarly argue that “there is a low level of trust in financial services, and a widespread view that finance could serve society better.”[207]

The increased complexity in the financial sector is also creating capacity failures within the sector. One view is that the financial trade has become so specialized that non-specialists within the financial system are not in a position to challenge the trade. The most prominent example is that of the trade in collateralised debt obligations (CDOs) and the fragile real estate market in the US. The combination of the bonus-culture and the lack of

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[205] ICAEW (2012). Market Failures, Market Solutions Responsible Providers. Financial Services faculty, p 1

[206] Additional advances in modelling (that are more controversial to mainstream economics) are that of accounting for fundamental uncertainty.

[207] ICAEW (2012). Market Failures, Market Solutions Responsible Providers. Financial Services faculty, p 1; On the contrary, the work of Ennew et al. (2010) on trust in the UK financial service sector, before and during the crisis years, suggests that the level of trust has remained stable. The authors measured trust with help of telephone interviews asking respondents to rate their level of trust on a five point likerd scale. Measuring trust is highly complex and is possible that the measure used by the authors does not adequately capture the fundamental issues of trust and financial services. Ennew, C., Kharouf, H, and Sekhon, (2011). H. Trust in UK financial services: A longitudinal analysis. Journal of Financial Services Marketing, 16(1), pp. 65–75

transparency in the management of the system are toxic to the system and have been major triggers for the current financial crisis.

In addition, the increase of financial sector regulation has generated perverse incentives in the system. Some regulations are used to the advantage of the big industrial players and have led to large-scale detrimental failures that are not easily detected by outsiders. Kroszner and Strahan conclude that “regulatory reform should not turn back the clock but should, instead, improve the stability of this interconnected financial system by minimizing regulatory arbitrage and increasing transparency”.[208] Because of the severity of the crisis, we argue that the institutional failures (i.e. the bonus culture and the unintended effect of regulations) are showstoppers to desirable innovation within the industry and beyond.

Table 23 Failures in financial services

Failure	Source	Scale	Description
Character of Science and technology		No evidence found	
Market power	Kroszner and Strahan (2011, pp. 242) ICAEW (2012), pp. 4	Slowing down	‘Too big to fail’ “Many financial innovations have enhanced the liquidity of assets, firms, and markets, improved opportunities for diversification, and increased competition between suppliers of credit” Regulations in the financial sector are stringent and inhibit new competitors to enter the market. “In practice, regulation can protect the financial services sector rather than consumers by creating barriers to entry for new entrants or by creating a defence against charges of misconduct by complying with rules”.
Externalities		No evidence found	
Information asymmetry	ICAEW 2012, pp. 1	Slowing down	“In many countries, there is a low level of trust in financial services, and a widespread view that finance could serve society better”
Capabilities	ICAEW 2012, pp. 8	Slowing down	The financial sector has also become highly specialised. Individuals can be experts in narrow areas, but lack understanding of wider aspects. This deep specialism can make it difficult for non-specialists to challenge the experts.
Network	ICAEW 2012	Show-stopper	Lack of cooperation with academia, research, sharing of best-practices
Institutional	ICAEW 2012, pp. 1	Show-stopper	“Bonus culture”

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[208] Kroszner, S. R. and Strahan, P. E. (2011) Financial Regulatory Reform challenges ahead. American Economics Review, 101(3), pp. 242-246. P245

Failure	Source	Scale	Description
	ICAEW 2012, pp. 4		“A change in culture and attitude is needed, with more focus on long-term sustainability. Providing services that meet the economic needs of society should be placed above short-term profits and bonuses”. “Regulation can lead to an emphasis on compliance with the rules rather than meeting the objectives behind the regulation as it is imposed externally”
Infrastructural		No evidence found	

Satellites and Space

‘8 great’ technology
High value manufacturing
Digital services

The space sector can be categorised into an ‘upstream’ and a ‘downstream’ sector. The upstream sector includes companies that provide services that are related to the launch of systems into space including companies involved in the manufacturing of space hardware and academia involved in the development of space hardware. The downstream sector comprises of companies such as satellite operators and academia (e.g. researchers in the field of earth observation) and companies that use satellite technology. Space and satellite technology have become part of everyday life: checking the weather forecast, watching TV, using the internet, travelling, and more. Space and satellite technology also are an important asset to the public sector: in monitoring epidemics, natural disasters and rescue operations, such as the detection of forest fires and deforestation. For example, Lynch et al. argue that in order to prevent the deforestation of the Amazon, illegal logging needs to be monitored using satellite technology and this requires the additional implementation of a more novel type of “radar satellites that can ‘see’ through clouds.”[209]

The UK space agenda is represented by the UK Space Agency, which was set up in 2010 replacing the British National Space Centre (BNSC). The International Space Innovation centre (ISIC) is a separate entity that focuses on research. Since 2013, the ISIC is merged with the newly established Satellite Applications Catapult. Prior to this merger, the IGS report released in 2010 suggests the following:

> *“there is an overall lack of coherency among the disparate stakeholders in Space and policy areas. We attribute this to the lack of horizontal responsibilities between Government Departments, and to the current implementation (centred on a partnership of interests) being insufficiently inclusive”.*[210]

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[209] Lynch J, Maslin M, Balzter H and Sweeting M (2013) Choose satellites to monitor deforestation, Nature 496, pp 293-294

[210] IGS (2010) Space IGS: The Space Innovation and Growth Strategy. Main Report: A UK Space Innovation and Growth Strategy 2010 to 2030, p 58

Similar challenges have been identified regarding the lack of coordination of public funding. Possibly, the restructuring of the UK space landscape intends to overcome such network and coordination failures. As indicated on its website, the Satellite Applications aims

> "t*o become a world-leading centre of business and technology innovation stimulating the development of commercially successful satellite derived products and services, supporting UK businesses of all sizes, in all sectors, to get maximum benefit from their use of satellite technology, and establish links to research groups and like-minded organisations around the world to foster collaboration that delivers commercial success and economic growth."*[211]

Rather than acting as a funding agent, the catapult seeks to stimulate collaborations between different organizations. This catapult may be launched in response to the 'Death Valley' (a type of network failure) identified in the IGS report where R&D solutions fail to be launched in the commercial market (see also IGS, Technologies, Capabilities and Facilities Report (overview) volume 3). By better connecting different agents in the space market, the catapult may speed up the innovation process, contributing to higher growth in the industry and to the overall UK economy.

The document "a UK Space Innovation and Growth Strategy 2010-2030" (Space IGS) outlines the role of the UK space sector in the wider economy. Overall, the space sector is a high growth sector with growth rates around 9%. The UK has a substantial share in the world space market amounting to roughly 6% of the world market. The vast majority of the UK market is captured by a handful of organizations some of which have annual turnovers of more than 3 billion pounds.[212] For example, according to BIS,[213] there are only around 20 satellite builders in the world. There also are some smaller companies with turnovers around 10 thousand pounds active in the UK market. The main reason that most of the space industry is concentrated in the hands of a few providers is that there are substantial barriers to entry. Capital investment in the upstream space sector is largely irreversible (i.e. because investments have little salvage value) and there are few economies of scale in the upstream sector. The downstream space sector does have large economies of scale. This means that extending the use of space applications/technology to additional users has no or low costs.[214] In order to ensure incentives to invest R&D, it is possible to restrict access to space applications. Moreover, as a result of the skewed cost and revenue structure of the industry, organizations are frequently vertically and horizontally integrated.

Overall, it is clear that market power plays a significant role in the space sector, with few players dominating the market. However, because of the characteristics of the industry, the market power is not a showstopper to innovation. Innovation is (in part) dependent on the opportunities created by major players pooling resources.

As already mentioned, the cost with respect to accessing space products such as navigation and internet is close to nil. Also, advances in the sector can have substantial knowledge and technological spillovers to other related and unrelated sectors and

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[211] Ibid

[212] BIS (2010) The Space Economy in the UK: An economic analysis of the sector and the role of policy, BIS Economics Paper No. 3 , p. ix

[213] Ibid p 12

[214] Ibid

industries. It is clear that investment in knowledge and technology involves substantial initial costs. The returns on successful investments is endangered by competitors that are able to use the technology or knowledge to develop similar projects. If innovative produces are difficult to protect there are disincentives in the market to invest in innovation. Technological and knowledge spillovers include computer software and the miniaturization of electronic components.[215] A related complexity is that companies will steer investment to the opportunity that has the largest possible return on investment and not to the opportunity that has the largest ‘social benefit’.

One type of negative externality in the space sector is that of space debris. Space debris refers to the unused satellites and other detritus in space. This type of space pollution is largely undesirable and can also be costly when such ‘unused’ satellite collides with another ‘active’ satellite or when a satellite crashes to earth. The costs of such collision are (usually) borne by the manufacturer of the ‘active’ satellite. Space law, the first treaties were signed in 1967, provides some regulation for satellites in orbit even though the enforcement of such law remains a challenge. The relation between this type of law and innovation is not clear. Another example about the relation between regulation in the field of satellites comes from the work of Sohn, who indicates that in Korea the regulations for satellite and terrestrial digital media broadcasting are inconsistent and have resulted in the failure of both types of broadcasting to the detriment of the development of a national market in this area.[216]

One of the challenges in the space industry is that of an awareness gap of the opportunities in the space industry. The issue of awareness is analyzed in the special IGS report ‘ Raising Awareness’. According to this report, the issue of awareness plays a role in the general public, the public sector, the private sector, and in the education sector. The awareness gap is alike to the concept of information asymmetry and created misalignments of opportunities between different actors. For example, the private sector not realizing the potential of new space technology for their business development. The lack of awareness in the education sector is related to governments’ failure to steer education towards skills required in high growths sectors. The degree to which there is a skills shortage in the UK space sector remains unclear. Following the ‘Size and Health’ survey conducted by BIS skill shortage was not reported by the majority of respondents.[217] The survey respondents that did indicate a skill shortage usually indicated a shortage in engineers. Yet, the IGS reported that on the basis of a BNSC survey indicated a substantial skills shortage in the space market.

Table 24 summarizes the evidence regarding types of market failures that play a role in the (and satellites) sector. Overall, the identified failures slow innovation down. No specific example has been identified regarding the capabilities failure. Yet, as in most sectors that involve technical skills it is unlikely that that are no such failures in the space market. We have identified network failures as a showstopper to innovation. Despite the efforts of the

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[215] Ibid

[216] Sohn, K. (2013) How Some Regulatory Policies can Undermine the Success of a New Technology: A Case Study of Digital Multimedia Broadcasting in South Korea . *Keio Communication Review* No. 35

[217] BIS (2010) The Space Economy in the UK: An economic analysis of the sector and the role of policy, BIS Economics Paper No. 3 , p. 35

UK government to overcome such failure, it is likely that such failures will persist in the future, at times slowing down innovation and at times resulting in missed opportunities.

Table 24 Failures in the Space industry

Failure	Source	Scale	Description
Character of Science and technology		No evidence found	
Market power	IGS 2010, pp. 62	Slowing down	“SMEs feel they are often playing on an uneven field when it comes to competing with large organisations and Government research and development facilities which sometimes compete with them.”
Externalities	BIS, 2010 pp. 44 BIS 2010, pp. 52	Slowing down (a lot)	“The market will not undertake many socially desirable projects” “Space debris is also a source of externality”
Information asymmetry	IGS 2010, pp. 64	Slowing down	“The IGT has investigated awareness issues affecting Space and has found there is an awareness gap which, unattended, will act as a barrier to the future growth of the sector.”
Capabilities		No evidence found	
Network	IGS 2010, pp. 61 IGS 2010, pp. 61 IGS 2010, pp. 59	Show-stopper	“Technology concepts originating in R&D often emerge in the form of technical papers and patents but are unable to grow in maturity through development and qualification phase due to an effect commonly known as Death Valley. The problem is simply that emerging Science side technologies receive little push from their originators who have no responsibility for exploitation or industry.” “Funding for Space research and development is derived from multiple sources including UK Research Councils European Space Agency and Regional Development Agencies (RDAs). The current diverse funding streams inevitably leave gaps that preclude continuous and efficient progress through the stages of innovation, development and industrial implementation”. “The underlying difficulty for BNSC is that it cannot force each partner to take a wider policy view to achieve a greater synergy, and nor is it empowered to draw down budget from a central source or appropriate it from Departments. There is a tendency for Departments to resort to brinkmanship in the run-up to, and during, ESA Ministerial meetings”
Institutional		No	

Failure	Source	Scale	Description
		evidence found	
Infrastructural	BIS, 2010 IGS 2010, pp. 68	Slowing down	Some indication of shortage of engineers. “The UK Space industry is displaying skills gaps within the existing workforce as well as difficulties in recruiting sufficient new employees. A 2008 BNSC survey indicated that two thirds of vacancies for experienced staff and half of vacancies for graduates with applied degrees were not filled at the first attempt. New employees often lack the skills needed to help them make a more positive contribution to the business and existing employees are missing skills that would make the business more efficient and competitive.”

Technologies and sub-technologies

Having assessed barriers to innovation at the level of sectors and subsectors, specifically challenge-led areas and development areas, the analysis now turns to a conceptually different set of sectors, namely those centred on specific kinds of technologies rather than specific areas of social, political and economic life. Many of the following sectors fall under the heading of ‘enabling technologies’, i.e. general purpose technologies that may find application in any of the more substantive fields assessed so far, as well as a host of others. Specifically, the following sections will cover nanotechnology and advanced materials, ICT, electronics, photonics and electrical systems, and biosciences.

The distinction between Enabling technologies and the rest of technological fields is a concept that can be traced back to the literature of the late 90s on General Purpose Technologies (GPT). GPTs are technological domains that allow for large, generalised leaps in technical progress and economic growth. They are characterised by their pervasiveness, as they are mainly used as inputs by other downstream applications, rather than on their own. This pervasiveness means that any development or any investment in R&D and innovation in such technologies spreads through the entire economy, bringing generalised productivity gains.[218] In order to correctly classify a technological domain as a GPT or an enabling technology it has to satisfy a set of requirements:

- It is a single, recognisable generic technology
- Initially has much scope for improvement but comes to be widely used across the economy
- Has many different uses
- Creates many spillover effects

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[218] T F. Bresnahan, M Trajtenberg (1995) General Purpose Technologies "Engines of Growth?" Journal of Econometrics, Annals of Econometrics, vol. 65, no. 1, pp. 83-108

Such technologies feed into many different industrial value chains and are often multidisciplinary in nature.[219] As a result, they create value along the whole chain and have the potential to enable innovation in processes, goods and services. In recent years, both the UK and the EC as a whole have positioned themselves to be heavily invested in supporting research and innovation in such fields. The Technology Strategy Board's overall strategy, Concept to Commercialisation,[220] complements the thematic approach of supporting promising areas with the focus on enabling technologies, as areas that are key to add flexibility in the way new market needs can be addressed. The four enabling technologies that are at the core of TSB's support are: Advanced materials; Electronics, Sensors and photonics; Biosciences; and ICT. In turn, the EC has defined a list of the most strategically relevant Key Enabling Technologies (KETs),[221] consisting of: Nanotechnology; Micro- and Nano electronics, including semiconductors; Industrial biotechnology; Photonics; Advanced materials; Advanced manufacturing technologies. The divergences between the list of enabling technologies of the different individual member states and the list of KETs of the EC can be explained by the strengths and limits of their research and industrial landscapes. China, Japan and the US are also focusing on their own sets of enabling technologies, which include biotechnology, ICT and nanotechnology amongst others.[222]

Due to their intrinsic characteristics, and taken as an aggregate, innovation in enabling technologies exhibits common types of market and systemic failures that can slow down or stop development in these fields. This is especially true for a subset of them; those more related to the industrial manufacturing world (nanotechnology and advanced materials), forming the basis of competences such as high value manufacturing. These three areas have very high barriers to market entry and innovation.

Nanotechnology and Advanced Materials

Enabling technology
'8 great' technology
High value manufacturing

The British Standards Institution (BSI) defines nanotechnology as the "Design, characterisation, production and application of structures, devices and systems by controlling shape and size in the nano-scale, which covers the size range from approximately 1nm to 100nm". In addition, nanotechnology can also include any technology that incorporates or employs nano-materials or involves processes performed at the nano-scale. Nanotechnology has been characterised as a young but emerging general-purpose technology[223] that combines all the classic basic sciences and has a realistic potential to spur innovation in many vital fields such as healthcare, energy,

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[219] EC (2012) A European strategy for Key Enabling Technologies (KETs) – A bridge to growth and jobs. European Commission. Jun 2012

[220] Concept to Commercialisation – a strategy for business innovation 2011- 15. Technology Strategy Board 2012. Available at: www.innovateuk.org

[221] EC COM (2009) 512 final. Preparing for our future: Developing a common strategy for key enabling technologies in the EU

[222] EC (2005) Creative system disruption: towards a research strategy beyond Lisbon. Synthesis report of the key technologies expert group, September 2005

[223] Christine M. Shea, Roger Grinde, Bruce Elmslie (2011) Nanotechnology as general-purpose technology: empirical evidence and implications. Technology Analysis & Strategic Management. 23(2)

environment and manufacturing. It is increasingly becoming a widely used pervasive technology and exhibits scope for continued technological improvement.

Estimates for the size of the global market for nanotechnologies range widely, depending on their scope. For example, the EC[224] expected a global market size of around $27b by 2012-2015, while the TSB[225] expected the market for nano-enabled products to be around $81b around the same period. More recent estimates set the global market for nanotechnology at $20.7b in 2012, with total sales expected to reach $48.9b in 2017, increasing at an annual growth rate of 18.7%.[226]

The UK has existing commercial strengths in nanotechnology. It is home to the third highest number of nanotechnology companies in general and is also third in number of companies focused in applying nanotechnology to healthcare.[227] In addition, it has renowned expertise in nano-optics and nano-scale materials and has the fourth largest number of nanotechnology patents applied for globally. Finally, the UK plays a leading role in the development of international nanotechnology standards through the BSI.

In terms of research and innovation policy, the UK government has had a historically longstanding focus on the nanotechnology field. In 2002, the Government published the Taylor Report[228] and committed £90m funding between 2003 and 2007 to fund the Micro and Nano Technology Manufacturing Initiative. In 2007 the TSB took on responsibility for the network of MNT Facilities and carried out a strategic review in 2009. This review informed the TSB's Nanoscale Technologies Strategy 2009-12.[229] In parallel, the Government launched its cross ministerial UK Strategy for nanotechnologies in 2010.[230] Currently, the TSB's work is focused on a number of market and technology application themes and nanotechnology is no longer considered a homogenous industry or a single sector.[231] Nanotechnology is pervasive across all TSB sectors and programmes and, at present time, the TSB manages a portfolio of at least £16.8m in projects involving nanotechnology. Moreover, the Nanotechnology Strategy Forum (NSF) acts as an expert advisory body, incorporating the views of industry, regulators, academia and NGOs with the aim to promote discussion and engagement on strategic issues, in order to advance nanotechnology industries responsibly in the UK.

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[224] EC (2012) A European strategy for Key Enabling Technologies (KETs) – A bridge to growth and jobs. European Commission, June 2012

[225] TSB (2009) Nanomaterials and Markets 2008-2015, Nanopost, quoted in Nanoscale Technologies Strategy 2009-12, Technology Strategy Board, September 2009

[226] BCC Research (2012) Nanotechnology: A Realistic Market Assessment.

[227] E&Y (2008) Nanotechnology in Medicine, New Perspectives for the Life Sciences Industries. Ernst & Young; European Biotechnology Centre.

[228] New Dimensions for Manufacturing A UK Strategy for Nanotechnology. Report of the UK Advisory Group on Nanotechnology Applications submitted t o Lord Sainsbury, Minister for Science and Innovation by Dr John M Taylor, Chairman. June 2002.

[229] Nanoscale Technologies￼Strategy 2009-12. Available at: https://www.innovateuk.org/documents/1524978/2139688/ Nanoscale+Technologies+Strategy/edd99ea8-bb87-4643-b4d8-9cb87e244c90

[230] HM Government (2010) UK Nanotechnologies Strategy: Small Technologies, Great Opportunities. March 2010.

[231] Nanotechnology Strategy Forum (NSF). Third meeting minutes - 25 June 2013

Advanced materials have also a pervasive nature. They are used in almost all manufacturing industries and underpin many key business sectors. Improving the properties of materials has historically been one of the most recurrent industrial innovation activities. Nowadays, the term ‘advanced materials’ usually refers to materials whose structure has been modified or improved at the micro or nano scale level to satisfy particularly demanding requirements of specific applications. Such requirements may require special properties in terms of functionality, performance, reliability, user friendliness or health and environmental compatibility. Although it is increasingly common to tailor materials to specific applications, it is also true that many advanced materials that have been developed in the last decades are characterised by having a myriad of application areas (i.e. graphene, carbon nanotubes, advanced superconductors and composites, etc.).

The expected size of the global market for advanced materials was estimated at around $150b for the period 2012-2015. In the UK, businesses whose core activity is to produce, process and recycle materials have an annual turnover of around £197bn and contribute GVA of £53bn. Around 75% of European entrepreneurs have seen their material costs rise over the last five years and a majority of them expect this trend to continue.

Uncertainty in future availability of affordable raw materials and energy puts at risk the continued development in this area and can put whole industries at risk. As a result, it is safe to say that sustainability from an economic, environmental and social perspective is one of the main challenges of the development of advanced materials. Advanced materials also suffer from long and capital-intensive development cycles, where sustained collaboration between multiple disciplines of the research base and the industrial world is key in order to ensure that new ideas can eventually lead to tangible improvements. The cost of developing and manufacturing products, together with intense competition from low-cost manufacturing overseas and a fragmented supply chain dominated by SMEs are other challenges that businesses face when developing and testing new designs and materials.

Advanced Materials was identified by the TSB as a priority area and a 2008-2011 strategy[232] was put in place, focusing on advanced materials for three challenge areas: energy, sustainability and high value markets. Advanced materials are an integral part of the competency in high value manufacturing and, subsequently, the strategy was integrated into the more general enabling technologies strategy 2012-2015.

Both nanotechnology and advanced materials have very high barriers to market entry and innovation and are characterised as knowledge intensive and associated with high R&D intensity, rapid innovation cycles, high capital expenditure and highly-skilled employment. As a result, they are bound to have similar market/system failures.

Table 25 provides an overview of market/system failures that have been identified in the literature for industrial enabling technologies. It comprises issues that affect the topics of nanotechnology, advanced materials and high value manufacturing. In some cases, the

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[232] TSB (2008) Advanced Materials. Key Technology Area 2008-2011. Technology Strategy Board. Available at: http://www.nibec.ulster.ac.uk/uploads/documents/advanced_materials_strategy.pdf

failures in the literature refer to a particular case in one of these specific technological fields, but in most cases the same issues can be sensibly extrapolated to the other areas.

For the most part, private investors find it difficult to invest in higher-risk, early-stage innovation across the two areas.[233] This makes it hard for entrepreneurs and innovators to develop their ideas to a level of technological readiness that can attract more market oriented funding. Moreover, new developments often require further work across several of such areas. As a result, substantial R&D investment is required before any technical and market feasibilities can be assessed and any productivity gains realised. In order to be a first mover and keep the advantage, these investments need to be sustained and properly recouped over time. Due to the pervasiveness of enabling technologies, second movers usually can benefit from free-rider effects and take advantage of the resolution of technological or market uncertainties by the first mover, who carries all the costs and risks.

Two challenges hinder access to risk capital for nanotechnology and advanced materials. First, funding for early stage and fundamental research and development is usually focused on technological novelty, rather than on the potential market impact. While such funding is necessary, the technologies developed with such support are typically at a level of technological readiness where they still need a lot more work before they can be commercialised. Secondly, actors such as banks, venture capital funds and business angels are very reluctant to invest in such high-risk projects due to the financial crisis and the availability of areas with a lower and clearer risk-reward profile (such as clean tech). As a result, companies usually agree that funding for basic research is relatively easy to obtain[234] but lack risk capital for stages such as prototyping, testing and scaling up to production volumes or facilities. In some cases, the precondition to secure such funding elsewhere is the relocation of the company outside its country of origin.

Market power failures in nanotechnology and advanced materials are the result of the inherent technological complexity and of the economies of scale and scope involved in recouping R&D and innovation investments in such areas. As a result, SMEs have a pressure to specialise and mainly play roles as specialised knowledge suppliers to large companies. In turn, large companies use their organisational and financial muscle to deploy such technologies in new products, dealing with issues such as global supply chain management and access to raw resources. While this kind of “division of labour” can be beneficial to overcome fragmentation, it can also push power from SMEs and consumers to large corporations that can dictate the pace of technical advance and appropriate most of the margins for high value added products.

With regard to capability failures, both nanotechnology and advanced materials also suffer from a generalised lack of skills. However, in the case of industrial technologies other issues exacerbate this failure. First, there is a lack of prospects for finding highly skilled manufacturing jobs due to industry outsourcing and offshoring. Second, there are high barriers to entry for new entrepreneurs in terms of capital investment. Unlike the start-ups

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[233] TSB (2012) Concept to Commercialisation – a strategy for business innovation 2011- 15. Technology Strategy Board. Available at: www.innovateuk.org

[234] Peter Bjørn Larsen, Els Van de Velde; Eveline Durinck, Henrik Noes Piester, Leif Jakobsen and Hanne Shapiro (2011): Cross-sectoral Analysis of the Impact of International industrial Policy on Key Enabling Technologies. Published by European Commission, DG Enterprise and Industry

in the digital economy, it is very difficult for a young entrepreneur to start a nanotechnology or advanced materials venture due to the comparatively large capital investment required. The same holds true for companies in the biotechnology domain. These situations can lead to a negative feedback loop whereby degrees traditionally linked to industrial jobs are less demanded in favour of those that allow graduates to find jobs or start their own ventures more easily.

Table 25 Failures in nanotechnology and advanced materials

Failure	Source	Scale	Description
Character of science and technology	Bresnahan et al, 1995[235]	Slowing down (a lot)	“Our analysis shows that the characteristics of GPT's imply a sort of increasing returns to scale phenomenon, and that this may have a large role to play in determining the rate of technical advance; on the other hand this phenomenon makes it difficult for a decentralized economy to fully exploit the growth opportunities offered by evolving GPT's. In particular; if the relationship between the GPT and its users is limited to arms-length market transactions, there will be "too little, too late" innovation in both sectors.”
Market power	DTI, 2011[236]	Slowing down (a lot)	Size matters: “SMEs play an important role in providing inputs and innovative solutions especially to large companies. However, SMEs may lack the organisational and financial capacity to place new products on the global market. Large companies are thus more likely to be better capable of deploying KETs for innovation advance.”
	DTI, 2011	Show-stopper	“Knowledge about manufacturing is often necessary in order to exert sufficient control over the entire value chain to commercialise a technology. In the last decade, commodity production has increasingly been outsourced to Asia, leading to a lack of mass volume production in Europe.”
	ZEW & TNO, 2010[237]	Slowing down (a lot)	“The European market for nanotechnology is fragmented, resulting in a lack of critical mass. This makes the commercialisation of nanotechnology less effective compared to markets in the US, which are more unified and less fragmented.”
Externalities	Bresnahan et al, 1995	Slowing down (a little)	“The vertical externality is closely related to the familiar problem of appropriability, except that here it runs both ways, and hence corresponds to a bilateral moral hazard problem (Holmstrom, 1982, Tirole, 1988). Firms […] have linked payoffs; the

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[235] T F. Bresnahan, M Trajtenberg. General Purpose Technologies "Engines of Growth?" (1995) Journal of Econometrics, Annals of Econometrics, 65(1) pp. 83-108

[236] Peter Bjørn Larsen, Els Van de Velde; Eveline Durinck, Henrik Noes Piester, Leif Jakobsen and Hanne Shapiro (2011): Cross-sectoral Analysis of the Impact of International industrial Policy on Key Enabling Technologies. Published by European Commission, DG Enterprise and Industry

[237] ZEW and TNO (2010) European Competitiveness in Key Enabling Technologies. Centre for European Economic Research (ZEW) and TNO

Failure	Source	Scale	Description
			upstream firm would innovate only if there is a mechanism […] that allows it to appropriate some of the social returns. The trouble is that [...] implies that the private incentive for downstream innovation is too low. For appropriability in the familiar range it is clear that neither side will have sufficient incentives to innovate."
	Ruttan, 2008[238]		"The key technical assumptions are generality of purpose and innovation complementarities. "Our model is a stylized set of related industries with highly decentralized technical progress centered around the GPT […] These translate in a world of imperfect appropriability in two distinct externalities: the "vertical" externality between the GPT and each application sector, and the "horizontal" one across application sectors" (Bresnahan and Trajtenberg 1995: 88). This results in a divergence between the social optimum and the decentralized Nash equilibrium because of the complementarities between the two conventional externalities and the positive feedbacks that are generated"
Information asymmetry	ZEW & TNO, 2010	Slowing down (a little)	Norms and values: "Because of the very nature of nanotechnology and its environmental, health and safety concerns, cluster network organisation have to establish a certain work ethic to address these issues. Furthermore, external communication and public relation of these organisations have to be clear to ensure market acceptance and the deployment of nanotechnology." "What this cluster lacks is a higher utilisation of knowledge for practical applications. Next to information deficits of companies, which do not see the potential of nanotechnology" "European companies are also reluctant to approach venture capital funds, unlike companies in the US. This is a cultural challenge, which is hard to change through policy initiatives."
Capabilities	DTI, 2011	Show-stopper (especially in manufacturing)	Access to talent: "The importance of skilled labour for competitiveness is widely acknowledged, but demographic developments and limited interest of young people in studying natural sciences and engineering are reducing the talent pool in Europe. The limited access to talents in Europe may spur off-shoring of knowledge intensive activities such as R&D to other world regions." "High tech companies in the EU in KET-related industries are concerned about their access to high-skilled labour and access to R&D facilities, and many research institutes mention difficulties in attracting PhD students in science and technology. This, combined with an

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[238] Ruttan, V. W. (2008). General Purpose Technology, Revolutionary Technology, and Technological Maturity

Failure	Source	Scale	Description
			increased focus and high investments in higher education in science and key technological areas in China, India, Japan, Korea, and the US, is a growing threat and a challenge for Europe not least due to different demographics in Europe and its competitors.”
	ZEW & TNO, 2010		“An essential success factor for KETs is a highly skilled labour force and a thick labour market (Wolfe, 2008). […] A main challenge is to train students in cross-disciplinary fields which are particularly important for research in KETs. A lack of skilled people is a severe problem as it may jeopardise current and future KET developments. The problem becomes more acute when compared to the efforts of emerging economies (such as China, India and may south- east Asian countries) to catch up with Western economies in education levels.”
Network		No evidence found	
Institutional	DTI, 2011	Show-stopper	Gaps in the continuous support to all firms in the value-chain: “The multinational companies have substantial funds and are likely to carry out most R&D internally, the SMEs benefit from a large range of public support opportunities at both European level and in the Member States. However, many mid-cap firms […], which do not come under the SME definition, face many of the same challenges encountered by SMEs, such as lack of internal means to ensure the deployment of KETs. Company representatives from the mid-cap category of firms interviewed for this study state that it is very difficult to obtain funding for deployment activities. R&D projects with a high potential may remain unexploited because national funding schemes will not allow inclusion of foreign companies.”
	Royal Society, 2004[239]		“Recently, a distinction has been made between a 1st and 2nd Valley of Death. The 1st refers to the difficulty that technological innovators face in raising funds for the development of their products, and the 2nd refers to the difficulties in deploying new products after development. The 2nd Valley of Death is determined by government regulations and market support mechanisms, which tend to differ between countries. In theory the deployment of products will take place in the countries providing the most favourable production and market conditions. If conditions are not competitive in Europe, the technologies developed in Europe (and

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[239] Royal Society (2004) Nanoscience and nanotechnologies: opportunities and uncertainties. The Royal Society

Failure	Source	Scale	Description
			thus often funded by European governments) may be deployed in countries outside Europe. If this holds true, Europe could be funding the development of new technologies, and the benefits would primarily be accrued in other world regions in the form of jobs and socio-economic growth.” “Alongside purely technical barriers to progress are those relating to regulation such as classification and standardisation of nano-materials and processes, and the management of any health, safety and environmental risks that may emerge. Appropriate regulation and guidance informed by scientific evidence will help to overcome some of these barriers, and there are already discussions between industry and regulators on the above issues. Until these regulatory measures are in place, industry will be vulnerable to reduced consumer confidence, uncertainty over appropriate insurance cover (Swiss Re 2004) and litigation should some nano-materials prove to be harmful. These issues will be of particular importance to the smaller, more innovative companies.”
Infrastructural		No evidence found	

ICT

Big Data

Enabling technology
‘8 great’ technology
Digital services

‘Big Data’ generally refers to datasets that are impractical to analyse with traditional database tools due to their size, variety and speed of creation. The origins of the Big Data concept can be traced back to what was known as the “information explosion”, a term that was first used in 1941 according to the Oxford English Dictionary.[240] Back then it was already noticed that the volume of information generated by society doubled at an ever-increasing rate and that this would present several challenges in the future. The term Big Data was coined during the mid-90s by people at SGI, then one of the most prominent American manufacturers of computing for the 3D graphics industry. Later on, with the advent of information technologies for all and the Internet the conceptual idea of information overload became a practical consideration for all of us, due to our limited capacity to cope with the volumes of data that were being continuously generated. More recently our ability to generate, communicate, share, and access data has experienced

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[240] Press, G (2013) A Very Short History Of Big Data. Forbes. Available at: http://www.forbes.com/sites/gilpress/2013/05/09/a-very-short-history-of-big-data/

another revolution, made possible by the use of mobile devices loaded with sensors and by the use of social networks. Some 90% of the world's digital data have been created in the past two years[241] and the rate of expansion does not show signs of stopping.

Nowadays, the term Big Data is used as a more vague concept, encompassing not only large datasets but also the hardware and software needed for their analysis. This includes all the solutions that deal with the capture, curation, management, processing and analysis of these large datasets. What constitutes Big Data is always changing, as the “Big Data" of fifteen years ago would not qualify as Big Data by today's standards, thanks to the development of new tools and the advancement in available computational power. The definition of what constitutes Big Data also varies by sector, depending on the software tools and sizes of datasets commonly used in a particular industry.

The current Big Data market reached $11.59b in 2012 and has been projected to reach $18.1b by the end of 2013, an annual growth of 61%.[242] In this market we can distinguish between Big Data vendors, companies offering services related to the deployment of big data technologies and Big Data practitioners. Although continuous growth is to be expected from vendors and associated services, Big Data practitioners are the ones who are expected to provide more value going forward, especially in vertical markets such as retail, media, financial services, aviation and medicine.

Consumers unwittingly produce most of the data being generated today. When we communicate, make payments, take pictures or simply move from one place to another we are constantly generating data that are collected and processed somewhere else, usually with a commercial purpose. Part of what makes the concept of Big Data so compelling to industry is the promise of allowing companies to find answers to questions they previously did not know to ask. The use of big data and analytics tools to improve business results has already made an impact in the business results of large IT players and in shaping and making possible some of the successful business models of the Internet economy. These tools can be as varied as

- Recommendation Engines
- Sentiment Analysis
- Risk Modelling
- Fraud Detection
- Marketing Campaign Analysis
- Customer Churn Analysis
- Social Graph Analysis

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[241] BIS (2013) Big Data: Transforming the data revolution into new products and services – Accelerating the commercialisation of technologies. Available at: www.gov.uk/bis/industrial-strategy

[242] Jeff Kelly, David Floyer, Dave Vellante, Stu Miniman. (2013) Wikibon: Big Data Vendor Revenue and Market Forecast 2012-2017

- Customer Experience Analytics

- Network Monitoring

In 2011, a McKinsey study[243] analysed the impact and potential benefits of big data in five domains: healthcare in the United States, the public sector in Europe, retail in the United States, and manufacturing and personal-location data globally. The study concluded that Big Data could unlock more value in each sector by increasing margins, improving efficiency and quality and reducing expenditures. Potential additional benefits for the public sector are support to policy decision-making processes at all scales and reductions in fraud and errors.

Accenture's recent analytics study[244] reports that a third of the surveyed enterprises larger than 1,000 employees in the US and UK are already using analytics and Big Data across the board. In addition, two thirds of them have created new management positions (such as "Chief Data Officer") to lead data management in the last 18 months. However, there is a whole sector of companies where the uptake of these solutions is still slow, such as in non-IT SMEs and in industries with very tight margins. These companies are still reluctant to undertake Big Data projects due to unclear return on investment, lack of specific business use cases, lack of access to skills and concerns over the maturity of the available products and services. If such companies do not have the necessary skills on board to select vendors to support Big Data initiatives they will be unable to evaluate the products and services on offer in the context of how best to monetise Big Data to achieve competitive advantages. This is an on-going obstacle for these businesses that poses a barrier to the adoption of a sustainable culture of data-driven decision-making.

On the side of the citizen, user and consumer, the promises of Big Data raise both utopian and dystopian ideas.[245] Will large-scale datasets and tools help to create cheaper, more personalised services and access to public goods? Or will these innovations cause a new wave of privacy incursions and invasive marketing? Will data analytics help us understand online communities and political movements? Or will it be used to track dissent and suppress speech? Big Data can help communities build resilience in the face of environmental, political, social and economic stresses by providing useful feedback loops of information and knowledge.[246] However, the collection and use of massive datasets can create new vulnerabilities and risks, enabling discrimination against individuals, skewing evidence, and creating dependencies on centralised infrastructures. For example, people with lower levels of income and education are not accessing or creating online content nearly as much as the more educated middle-class population. If journalists, academics and policy makers rely on Big Data analytics in future they risk ignoring issues important to many poor and working-class people. Should this situation persist, some authors have

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[243] McKinsey Global Institute (2011). Big data: The next frontier for innovation, competition, and productivity

[244] Accenture (2013) Analytics in Action: Breakthroughs and Barriers on the Journey to ROI. A Perspective from Accenture Analytics, with Findings from a Survey of Analytics Practitioners

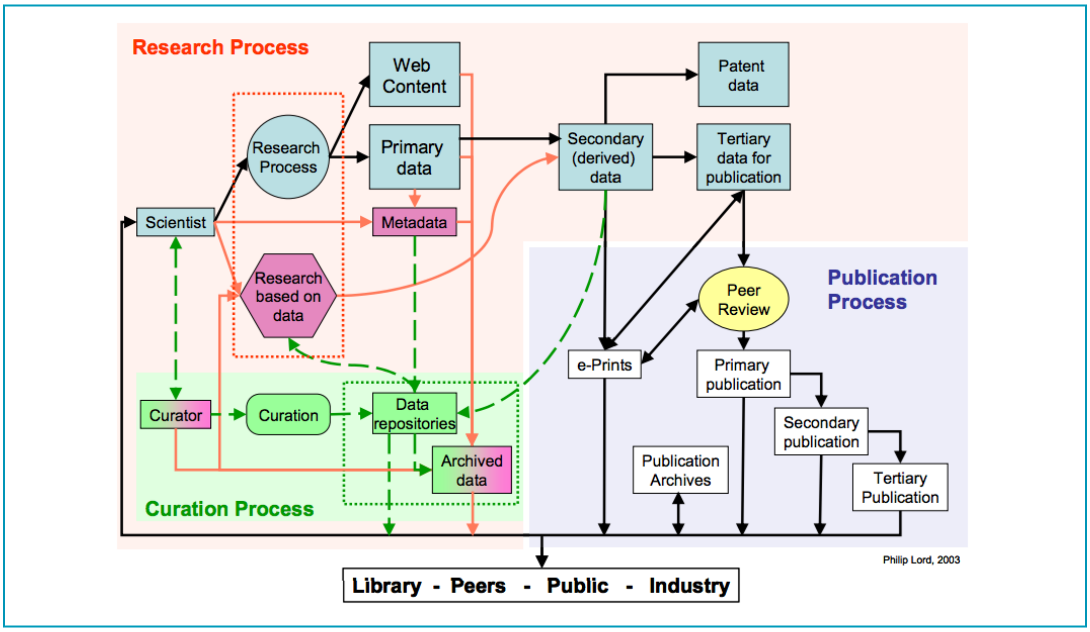
[245] Danah Boyd & Kate Crawford (2012) Critical questions for big data. Information, Communication & Society, 15:5, 662-679

[246] Kate Crawford, Gustavo Faleiros, Amy Luers, Patrick Meier, Claudia Perlich and Jer Thorp (2013) Big Data, Communities and Ethical Resilience: A Framework for Action. Big Data, Communities and Ethical resilience: White paper. Oct 2013, available: http://poptech.org/system/uploaded_files/66/original/BellagioFramework.pdf

already reframed the concept of the Digital Divide[247] and identified a Big Data Divide,[248] where the ability or not to exploit these innovations increases the gap between the information-rich and the information- poor. Proposing actions that aim to tackle these barriers and failures is a good way for government to get involved in ensuring that Big Data and innovations derived from it reach all sectors of the population and the economy. In addition, measures can be implemented to educate and protect the citizen and consumers with regard to the fair and legal use of the data that is collected.

Science has also been transformed by accelerating change in IT, mainly due to the huge increases in computing power and network bandwidth, accompanied by an explosion in data volumes and information. On the research front, this information overload caused by the creation of huge volumes of scientific data is commonly labelled as the Data Deluge.[249] Big Data innovations and developments have transformed the way of performing research, with data-based research becoming more important and increasing needs for data sharing, collaboration and cross-disciplinary work, much of it international. This new way of conducting research (Figure 8), labelled e-Science, e-Research or Big Science (especially when large research infrastructures are present), is much more intensive in the use of shared research expertise, large instruments and infrastructures, computing resources, and access to collections of primary research data and information. This creates a new series of challenges and barriers that need to be tackled if this transition to data based science is to be successful.

Figure 8 Research, curation and publication process of e-Science



Source: From Data Deluge to Data Curation. P Lord, A Macdonald, L Lyon, D Giaretta. UKOLN (2003).

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[247] Chinn, Menzie D. and Robert W. Fairlie (2004) The Determinants of the Global Digital Divide: A Cross-Country Analysis of Computer and Internet Penetration. Economic Growth Center

[248] Crawfard K (2013) The Hidden Biases in Big Data. Harvard Business Review. Available at: http://blogs.hbr.org/2013/04/the-hidden-biases-in-big-data/

[249] Hey, T. and Trefethen, A. (2003) The Data Deluge: An e-Science Perspective, in Grid Computing: Making the Global Infrastructure a Reality (eds F. Berman, G. Fox and T. Hey), John Wiley & Sons, Ltd, Chichester, UK

Government-level, overall strategies for data stewardship and data infrastructure are needed so that research administrators can refer to them and support researchers in their evolving roles and duties with regard to data management. In order to extract maximum value of scientific data, public policy can, in addition to supporting new technological development, tackle critical issues such as data ownership, stewardship, curation, sharing, privacy, legal and ethical issues.

All research intensive countries are positioning themselves to capitalise on the competitive advantages that Big Data is bringing about for scientific discovery. In 2010, the EC report from the High level Expert Group on Scientific Data[250] explored the main policy implications and challenges of the scientific data deluge. The report sets out a vision for scientific e-infrastructure in Europe by 2030, supporting seamless access, use, re-use, and trust of scientific data. In this vision the data become the main infrastructure and asset, on which science, technology, the economy and society can advance. This report contains the following set of policy recommendations, aimed at removing the existing barriers to achieve such vision

- Develop an international framework for a Collaborative Data Infrastructure
- Earmark additional funds for scientific e-infrastructure
- Develop and use new ways to measure data value, and reward those who contribute it
- Train a new generation of data scientists and broaden public understanding
- Create incentives for green technologies in the data infrastructure
- Establish a high-level, inter-ministerial group on a global level to plan for data infrastructure

In the US, the Obama Administration launched in March 2012 a “Big Data Research and Development Initiative” in which six Federal departments and agencies announced more than $200m in new commitments to improve the tools and techniques needed to access, organise and extract new knowledge from huge datasets.

In the UK, BIS launched a government strategy to put the UK at the forefront of extracting knowledge and value from data. The UK’s data strategy[251] was one of the outcomes of the information economy strategy published in June 2013 and was carried out in partnership with industry and academia. The strategy discusses the following aspects, with the aim of setting the direction and leadership for UK’s data capability:

- Human capital: a skilled workforce, and data-confident citizens
- The tools and infrastructure which are available to store and analyse data

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[250] EC (2010) Riding the wave. How Europe can gain from the rising tide of scientific data. Final report of the High Level Expert Group on Scientific Data. European Commission. October 2010

[251] BIS (2013) Seizing the data opportunity: a strategy for UK data capability

- Data as an enabler: the ability of consumers, businesses and academia to access and share data appropriately

BIS' strategy includes measures to build capability in the commercial, academic and public sector, strengthen skills focused at schools, higher, further education and continued professional development and to ensure that the UK's infrastructure and R&D environment supports improved data capability.

To sum up, Big Data is currently at the heart of modern science and business. Getting to grips with the ever increasing amounts of generated data and the desirability of unlocking the information hidden within it are now a key themes in most enterprises, as well as in most scientific disciplines. From the cited list of relevant documentation, the following failures and barriers with a particular impact in the Big Data domain have been identified (Table 26).

Table 26 Failures in Big Data

Failure	Source	Scale	Description
Character of science and technology		No evidence found	
Market power	Kelly et al, 2013	Slowing down (a little)	Consumer lock-in The development of Big Data platforms and tools by some large vendors are based on closed, locked-down solutions instead of open frameworks. This can limit the interoperability with competing and complimentary products and reduce customer choice. High cost of market entry/exit For smaller companies, investments in Big Data technologies might be too large and benefits might still be unclear (see information asymmetry)
Externalities	Boyd, Crawford, 2012, see also Bellagio, 2013	Slowing down (a little)	Decisions by individual consumers to withhold data may have large negative externalities for society's overall ability to reap the benefits of Big Data, and decisions by individual businesses may have large negative externalities for citizens' privacy.
Information asymmetry	Kelly et al, 2013 Boyd, Crawford, 2012	Slowing down (a little)	Lack of understanding among enterprises on how to extract value from Big Data and unclear ROI Organizational resistance to adopting Big Data analytics-driven decision-making to replace "gut instinct"-style decision-making. Lack of best practices and related technologies for managing Big Data as a corporate asset, including

Failure	Source	Scale	Description
			data quality, data governance, and security platforms and tools. For the public sector: Reticence and concern of the citizens with regard to ownership, privacy and acceptable limits of use of the information collected (see Institutional)
Capabilities	Mckinsey, 2011; see also Kelly et al, 2013; see also Accenture, 2013; see also BIS, 2013; see also EC, 2010	Show-stopper	Insufficient labour market skills, knowhow and ability to capture innovative opportunities. Enterprises interested in leveraging Big Data must be prepared to deal with too few skilled Big Data practitioners and raw, immature technology. In the scientific world immature technology is a given but access to skills still represents a problem. This shortage is in part because the discipline of data science is still not well defined, as it encompasses a blend of changing functional areas. In order for Big Data to truly gain mainstream adoption and achieve its full potential, it is critical to overcome the skills gap.
Network	Boyd, Crawford, 2012	Slowing down (a little)	Lack of trust can cause a sub-optimal flow of information and level of cooperation between users and managers of Big Data systems.
Institutional	Mckinsey, 2011 Boyd, Crawford, 2012	Slowing down (a little)	Rules and regulations regarding legal, ethical and privacy issues. This affects both the commercial world as well as government. In the case of research, ownership, access rights, and ethical issues are important to speed up adoption. Defining 'who pays' and 'who does what' with regard to preservation and curation of data is also necessary to increase adoption and establish good processes for data management.
Infrastructural	BIS, 2013 EC,	Slowing down (a little)	In the case of supporting public research, most of the research infrastructures that deal with big data are unlikely to be funded and maintained through the project funding of specific research groups. Big Science is based on large research infrastructures of national and international strategic importance (i.e. grids, supercomputers, digital repositories, etc.). A failure to support them can lead to a slow down to the shift to data based e-Science. Opening up Big Science infrastructures to companies without sufficient funds to implement

Failure	Source	Scale	Description
	2010		them on their own can help reduce the Big Data divide and increase collaboration and knowledge transfer, increasing innovation.

Cyber security

Enabling technology
Digital services

Cyber security is an area of crucial importance within the broader ICT sector, not just as a key area of economic activity in its own right, but also in terms of its significance to all other sectors that draw on ICT in any form. Whilst data protection and data safety was until relatively recently squarely in the realms of the state, with government intelligence and databases the key forms of data to be secured, from the 1970s onwards, the growth of information economies led to increasing involvement of the private sector in this field, both in terms of producers of privacy and security-enabling products, as well as in terms of consumers. UKTI highlights cyber security as one of the key sub-sectors of ICT in the UK. Products and services centred on authentication, authorisation, trust, identity management, cryptography, cryptanalysis, computer security (largely defence against malware), human aspects of security, privacy, information hiding, anonymity, digital rights management and watermarking all fall under this heading. With this definition, the UK cyber security market is currently estimated to be worth £2.8bn.[252]

While cyber security is therefore an area of considerable importance in terms of its own size and value this is dwarfed by the scale of economic and social damage that its products seek to mitigate. Cyber crime is a much acknowledged and debated problem, leading the UK government – among many other countries – to devise a cyber security strategy with considerable attached funds and personnel.[253] Cyber crime can take many shapes, including, but not limited to, identity theft, fraud (both often linked to stealing money), government, military and industrial espionage, spreading propaganda, recruitment and fundraising for terrorist activities, attacking digital infrastructures, web sites and online services for commercial and political reasons alike (‘hacking’). Given this breadth, the targets of cyber crime can range from governments themselves and large corporations via smaller organisations, right down to private individuals, including vulnerable individuals of all kinds. The purely economic annual cost of cyber crime is estimated by UKTI as £26.9bn.[254] This is however likely to be a conservative estimate: whilst loss incurred through corruption, apprehension or destruction of data, as well as apprehension of money through fraud and identify theft can be measured, the existence and prevalence of cyber crime has additionally made consumers cautious. Given the known risks, many potential consumers in the digital sphere are reluctant to conduct online purchases and other forms of e-commerce, thus stifling many opportunities for new economic activity and business growth.

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[252] See UKTI ICT sector opportunities: http://www.ukti.gov.uk/pt_pt/investintheuk/sectoropportunities/ict.html?null
[253] Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/60961/uk-cyber-security-strategy-final.pdf
[254] See UKTI ICT sector opportunities: http://www.ukti.gov.uk/pt_pt/investintheuk/sectoropportunities/ict.html?null

The need for a well-functioning, innovative and efficient cyber-security industry is therefore abundantly clear. The continuing damage wrought by cyber crime is in itself a clear indication that this is currently not in place. Responding to this, there is a growing body of literature and research on cyber security and its apparent shortcomings. Much of this literature does not relate exclusively – or even chiefly – to innovation, but covers the area in much broader terms, including aspects such as differences in laws on and policing of cyber crime, where national differences complicate arrest and prosecution of cyber criminals. However, a substantial portion of this literature does focus also on barriers to successful innovation in cyber security. There are some problems worth highlighting initially before turning to the main barrier.

First, in the case of some types of products, the existence of relatively few, relatively ubiquitous companies and product types, can allow cyber criminals to re-commit an initially laborious criminal action with ease. Once a weakness has been identified in a security system, everyone who uses that system becomes vulnerable. Perversely then, the more commercially successful and widespread a security system or product becomes, the greater the criminal incentive to try and bypass it, and the greater the likelihood of its eventual failure.

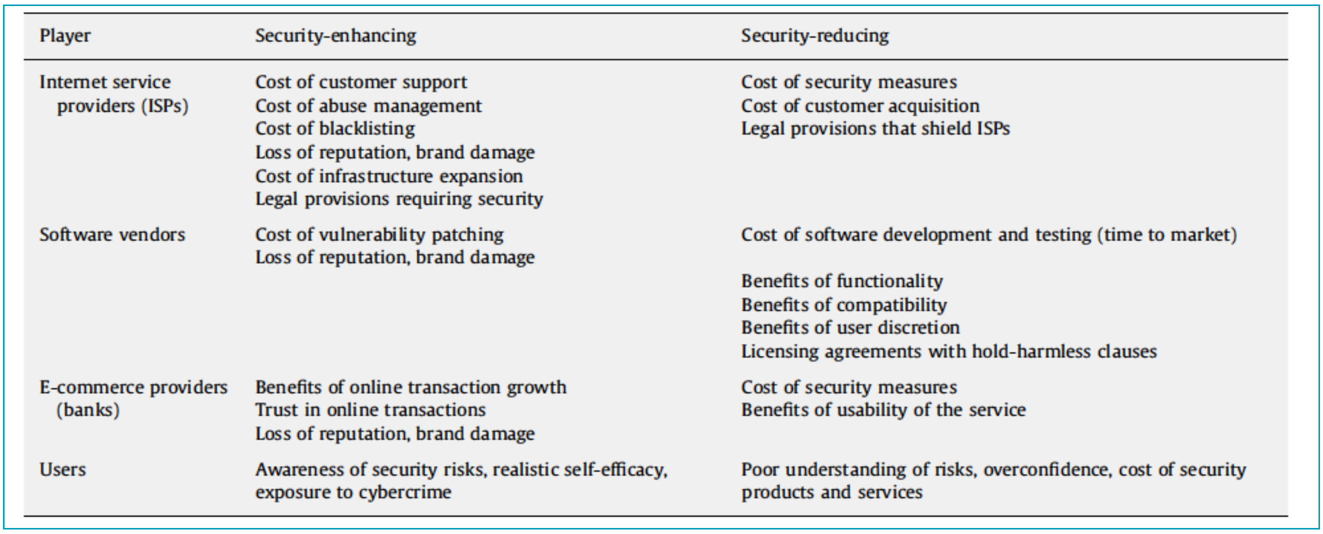
Second, the common practice of elaborate disclaimers, especially on software packages, has led to institutionalised unaccountability, where producers cannot be held to account in the event of the software failing to keep its promise of protection and security. This lack of accountability does not encourage the creation of reliably robust security systems, especially where less robust systems are significantly easier and less costly do develop. This problem is compounded by the fact that the cyber security market rewards first-to-market products, creating incentives for rapid development of products rather than optimisation.

Third, there are some issues of inappropriability. Throughout the ICT sector, new technologies spread quickly, meaning that companies other than the initial innovator will swiftly benefit from the original innovation. The literature highlights some additional externalities at the level of the consumer, where their safety is not simply ensured by acting alone and using high quality cyber security systems, but also by being part of a wider network of users who also take security seriously: interacting with many other users who are exposed to threats in turn increases the security threat to an individual user within that network, no matter how well they are protected. Both the production and consumption side of cyber security are therefore embedded in wider networks characterised by significant externalities, making simple cost-benefit analyses problematic for all parties.

Though significant, these three issues do not feature especially widely in the literature and apply only to certain types of product within the wider cyber security industry. There are conceivable measures of public support to mitigate them. However, across the literature, there is a much more ubiquitous barrier to innovation in the sector, which is variously highlighted by all sources used to assess the sector in this report. The fundamental source of these barriers is the fact that, unlike with most other ICT-related products, the vast majority of consumers have no understanding of how cyber security products work, do not gain any significant understanding once they start using them and are additionally unable to gauge whether or how well a product works until it fails.

To illustrate: most ICT tools are intended for individuals who have a certain level of expertise or knowledge in the function that these tools are supposed to fulfil, i.e. office or desktop publishing programmes will generally be used by individuals who, professionally or privately, have some knowledge of writing, editing, designing, or printing. Cyber security products do not follow this paradigm – they are not intended for particular groups with an interest or expertise in the details of security systems. Put simply, the vast majority of consumers of cyber security products 'just want it to work', whilst having little or no understanding of what exactly 'it' does and being unable to verify whether or not 'it' is in fact working until damage through malware, security breaches, etc. actually occurs, and even in such a situation the consumer can hardly verify whether the product was weak and unable to stop a simple and unsophisticated threat, or whether its high quality was circumvented by a particularly skilled and innovative cyber criminal.

Table 27 Barriers and opportunities in cyber security innovation



Player	Security-enhancing	Security-reducing
Internet service providers (ISPs)	Cost of customer support Cost of abuse management Cost of blacklisting Loss of reputation, brand damage Cost of infrastructure expansion Legal provisions requiring security	Cost of security measures Cost of customer acquisition Legal provisions that shield ISPs
Software vendors	Cost of vulnerability patching Loss of reputation, brand damage	Cost of software development and testing (time to market) Benefits of functionality Benefits of compatibility Benefits of user discretion Licensing agreements with hold-harmless clauses
E-commerce providers (banks)	Benefits of online transaction growth Trust in online transactions Loss of reputation, brand damage	Cost of security measures Benefits of usability of the service
Users	Awareness of security risks, realistic self-efficacy, exposure to cybercrime	Poor understanding of risks, overconfidence, cost of security products and services

Source: Bauer van Eeten 2009 p 711, based on in-depth qualitative study of 57 professionals in the IT sector with high exposure to cyber threats

This key distinguishing feature of the cyber security sector highlights almost insurmountable information asymmetries: the nature and function of the products is such that consumers simply cannot tell the difference between a good product and a bad product. Companies are thereby completely disincentivised to engage in large and costly development programmes. Large sections of the market have been taken over by freeware/ open source programmes, while those that do charge for their products tend to build their reputation through marketing and advertising rather than through especially high quality new products. The literature frequently notes that a possible solution to this would be a robust and comprehensive testing and certification system for cyber security products. Whilst such systems already exist, they tend to lack coordination, participation and reliable authority located beyond the industry itself. This is one immediate possible form that public support in this sector could take.

This issue furthermore leads to some problems around externalities: robust and reliable cyber security systems tend to have an effect on user interfaces of the products and services they are designed to protect. They may impose several additional checks and longer and more elaborate login-procedures; they may require more processor speeds or system memory, and may easily take up a larger amount of network space and connection speed than less sophisticated programs and systems. Given users' general lack of understanding of these systems, this trade-off most commonly plays out strongly in favour of easy user interfaces, i.e. most companies will sacrifice security for ease of use. This issue has been pointed out in the case of financial services, as well as for the providers of digital infrastructures themselves.

Table 28 Failures in the cyber security market

Failure	Source	Scale	Description
Character of Science and technology		No evidence found	
Market power	Bauer and van Eeten 2009[255] p 712 ENISA 2008[256] see also Anderson and Moore 2006[257]	Slowing down Slowing down	As software is typically installed in many versions, configurations, and contexts, the cost of patch development can be very significant. From the perspective of software vendors it may therefore be advantageous to invest in security upfront rather than have the follow-up costs of patching. However, given the complexity of modern software packages and the benefits of short time-to-market, it will not be economical to invest to the point where all potential flaws are eliminated. […] Time-to-market is lengthened by software testing and the cost of software development is increased. In industries with network effects and first-mover advantages, such delays may result in significantly reduced revenues over the product life cycle (Anderson & Moore, 2006). Thus, the more competitive the software market segment, the lower the incentive to improve security beyond a minimum threshold. Lack of diversity is a common complaint against platform vendors […]; lack of diversity makes successful attacks more devastating and harder to insure against. Homogeneous architectures share common vulnerabilities, and this increases the variance of the loss distribution due to security incidents. Such high variance undermines many firms' confidence in technology and makes them reluctant to invest.
Externalities	Kox and Straath		A second problem is related to the external effects, or externalities, of investments in security. ISPs may not be able to capture the full benefits of their

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[255] Bauer, JM and van Eeten MJG (2009) Cybersecurity: Stakeholder Incentives, Externalities, and Policy Options. Telecommunications Policy 33 pp.706-719

[256] ENISA (2008) Security Economics and the Internal Market. Authored by Ross Anderson, Rainer Boehme, Richard Clayton and Tyler Moore; commissioned by the European Union Agency for Network and Information Security. Available: http://www.enisa.europa.eu/publications/archive/economics-sec

[257] Anderson R and Moore T (2006) The Economics of Information Security. Science, 314(5799), pp610-613

Failure	Source	Scale	Description
	of 2013[258]		investments in cyber security, for example because part of the potential benefits is for customers of other ISPs.
	Ibid		A […] problem arises for core infrastructure providers (so-called backbone providers) who are responsible for the resilience of the Internet against shocks like natural disasters and massive DDoS attacks. Many end users expect that the Internet is available at all times and this requires sufficient spare capacity in the backbone. However, the organizations responsible for the backbone infrastructure only capture a fraction of the benefits of redundant capacity, and may be inclined to invest less than is socially optimal.
	Bauer and van Eeten 2009, p713	[overall:] slowing down a lot	…financial service providers are to a considerable degree able to manage risks emanating from their customer relations. However, they need to make choices balancing enhanced security and the growth of their electronic business. In principle, they could use highly secure platforms to conduct e-commerce transactions. Such an approach would likely have detrimental effects on users as it decreases the convenience of conducting business. Financial organizations thus face a trade-off between higher security and migrating transactions to cost-saving electronic platforms.
	Powell 2001, [259] see also ENISA 2008		If firms share security innovations and confront a common problem, individual firms may fail to deal with the problem because they hope they will get the benefit when another firm creates a security innovation to solve it. Because of this incentive to free ride firms may not innovate as quickly as they should.
Information asymmetry	Kox and Straathof 2013 p 2/3; See also		A first problem is information asymmetry between two economic agents. For example, end users may not be able to verify whether an Internet Service Provider (ISP) gives correct information about its security performance. This uncertainty makes end users reluctant to pay for security. For ISPs this means that their investments in cyber security do not give them an advantage over competitors;

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[258] Kox H and Straathof B (2013) Economic aspects of Internet security. CPB Background Document. Available: http://www.cpb.nl/en/publications

[259] Powell, B (2001) Is Cybersecurity a Public Good? Evidence from the Financial Services Industry. Independent Institute Working Paper Number 57. Available: http://www.independent.org/pdf/working_papers/57_cyber.pdf

Failure	Source	Scale	Description
	ENISA 2012[260]; See also Bauer and van Eeten 2009; See also ENISA 2008 Anderson and Moore 2006 ENISA 2008	[overall:] show-stopper	additional security will only increase costs. ISP's can try to escape this mechanism by investing in a reputation of providing high degree of security. As building a reputation requires substantial investments, market concentration will increase and competition might be reduced. Insecure software dominates the market for the simple reason that most users cannot distinguish it from secure software; thus, developers are not compensated for costly efforts to strengthen their code. Another instance of asymmetric information found in the information security market is a lack of data sharing about vulnerabilities and attacks. Companies are hesitant to discuss their weaknesses with competitors even though a coordinated view of attacks could prompt faster mitigation to everyone's benefit. In the USA, this problem has been tackled by information-sharing associations, security-breach disclosure laws and vulnerability markets. There has been discussion of a security-breach disclosure directive in Europe. We assess these options later.
Capabilities		No evidence found	
Network		No evidence found	
Institutional	ENISA 2008	Slowing down	Firms seeking to manage risk often do so by externalising it to less powerful suppliers or customers. The most obvious example is the way in which software and service suppliers impose 'shrink-wrap' or 'click-wrap' licenses on customers disclaiming all liability, including for security failures, and in some cases also taking 'consent' to the installation of spyware. This is a public policy issue as it removes a major incentive for the emergence of a market for more secure languages and tools, and for the employment of professional software engineering methods. […] Another example is the problem of mobile phone security; mobile phones have a long and complex supply chain, starting from the intellectual property owners, the chipmaker, the software supplier, the handset vendor, the network operator and brand from which the customer buys service. Each of these players seeks to have others bear the costs of security as much as possible, while using security mechanisms to maximise its own

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[260] ENISA (2012) Incentives and barriers of the cyber insurance market in Europe. Available: http://www.enisa.europa.eu/activities/Resilience-and-CIIP/national-cyber-security-strategies-ncsss/incentives-and-barriers-of-the-cyber-insurance-market-in-europe

Failure	Source	Scale	Description
			power in the chain.
	Anderson and Moore 2006	Slowing down	Although vendors are capable of creating more secure software, the economics of the software industry provide them with little incentive to do so. In many markets, the attitude of 'ship it Tuesday and get it right by version 3' is perfectly rational behaviour. Consumers generally reward vendors for adding features, for being first to market, or for being dominant in an existing market and especially so in platform markets with network externalities. These motivations clash with the task of writing more secure software, which requires time-consuming testing and a focus on simplicity.
Infrastructural		No evidence found	

Robotics and Autonomous Systems

Enabling technology
'8 great' technology
High value manufacturing

In the UK, robotics and autonomous systems, also abbreviated as RAS, are regarded as crucial drivers of job creation and growth. In 2013, the UK government allocated £35 million towards the development of RAS centres of excellence. Some basic examples of robots are vending machines, robot pets, and oil and well bore robots. Application areas have shifted from focus on the automotive and production sector to a wide range of sectors such as high-tech manufacturing, space, domestic, health care and medical technology, agriculture and more. One example of the more novel types of application of robots in agriculture is that of using robots to remove weeds from arable land. An example of an application in the health sector is the EC funded project to develop a customizable robot companion for people with memory problems or impaired mobility. Advances in ICT technology contribute to the development of future upgrading and or generations of robots. Specifically, cloud computing is expected to initiate the generation of 'ubirobots' that can share knowledge by connecting to cloud infrastructures.[261]

The International Federation of Robots (IFR) estimates that the total world market of robot systems in 2012 was 26 billion dollars. In the EU, the big players in robotics are Germany, Italy, Sweden, and Finland. In 2011, the world market for robotics was spilt between 28% in the EU, 16% in the Americas, and 56% in Asia and Australasia. The biggest world players are Japan, Korea, and China.[262]

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[261] Chibani A, Amirat Y, Mohammed S, Matson E, Hagita N and Barreto M (2013) Ubiquitous robotics: recent challenges and future trends. Robotics and Autonomous Systems, 61, pp 1162-1172

[262] Innoboro (2013) Robotics in Europe. Data from Innoboro

Despite the recognition of the widespread potential of RAS, there are several failures that inhibit a rapid take up of RAS. In this section we discuss some of these failures and, where possible, we indicate the relevant RAS market in which the failure applies.

One of the challenges identified by the UK government in the field is lack of cooperation between industry and academia. This is an underpinning motive for the launch of the UK catapult programme. The amount of industrial activity that is organized in cluster environments is still below its potential. There is a vast amount of academic research in the field, e.g. including robot programming, robot learning, robot control, robot simulation, and various application areas for autonomous systems. Nonetheless, the links between advanced research and the commercialisation of RAS products appear weak.

Forge and Blackman evaluated the challenges in the EU market.[263] Figure 9 (see also Forge and Blackman) presents the predicted trend lines (2010-2020) of different RAS product markets with respect to their general level of acceptance. On the vertical axis are noted differing degrees of acceptance ranging from low level of acceptance and to high level of acceptance and commercial possibilities. More specifically, on the lower bound: entry-level specialized and niche minority technology that remains costly. At mid-scale: major growth competences with non-robotic processes and/or technologies. And on the upper bound: accepted with market pricing as a mainstream technology. Overall, the different RAS product markets are expected to follow a positive trend line with most product markets reaching commercial production potential by the year 2020. Today, the medium and large companies operating in the industrial manufacturing of RAS are already at this level of production. The professional service market is similarly already at a rather mature level. This professional service market includes: professional maintenance robots and pipeline robots. Quite differently, small and micro sized companies operating in manufacturing still have substantial potential to grow in the field and to *adopt* RAS solutions in the work environment. Depending on the future development of the market there is however, the possibility that this market too reaches a sustainable commercial basis by 2020.

The JRC identified several key aspects that currently hinder the uptake of RAS by smaller size companies across Europe. First, access to financing remains a major challenge and thus either robotics must become cheaper for smaller companies to adopts RAS solutions and/or smaller sized companies much come to understand the potential of robotics as a key asset to their production. At the same time, smaller companies working in the field of RAS development require support to cross the 'valley of death' from having developed a RAS model or prototype and launching the product on the market. There may also be resistance from within companies to introduce labour-saving robots. This fear is also linked to the lack of awareness about the potential and technological possibilities of RAS to small firms. Because the market is novel, the market knowledge about robotics is low. Additionally, there are some learning costs to make use of RAS; such learning costs include the knowledge on how to install, tailor, programme, and maintain the RAS. At a more

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[263] Forge S and Blackman C (2010) A Helping Hand for Europe: The Competitive Outlook for the EU Robotics Industry. JRC Scientific and Technical reports

fundamental educational level, in some subfields of RAS, there is a chronic shortage of skilled engineers (TSB), as well as technicians and researchers.[264]

Domestic services and care support for the elderly and medical and health care more broadly appear to be robotics markets with significant potential for growth. One of the current barriers is that the current cost of production is too high for commercial markets. Similarly, according to the JCR (2010), medical robots are currently only used in niche markets. Further technological development is necessary to make these products affordable at a larger scale. There are also suggestions that there is a need for a cultural shift towards an integrated life-style between man and robot. The study by Vaussard et al.[265] for example, analyzed the interaction between domestic robotic vacuum cleaners and the household and found that people tended not to trust the operations of roots that they could not monitor.

Moreover, according to JCR, road vehicle management RAS will not deployed on a large scale in the near future for reasons such as safety, acceptance and liability. Mahbub reviewed the barriers to RAS development in the construction industry[266] and identified the lack of standardisation as a significant barrier to the RAS take-up in the industry. This may be related to rapid development in RAS. As a result of the rapid changes in the industry there may be a high level of uncertainty regarding the types of RAS solutions that are worth investing in and some companies fear that they cannot ‘keep-up’ with the rapid developments. More standardization is required to reduce the uncertainty over investments. Additionally, Mahbub identified that there is a high level of industry fragmentation, which creates first mover disadvantages in the industry. Mahbub argues that companies refrain from investing because they fear that they are not able to capture the benefit of the investment. Finally, the high level of dynamics and changing conditions of the construction sites also acts as technological barriers to the take-up of RAS solutions.

In addition to the issues related to standardization and safety, an additional regulatory failure in the robotics industry is that the patenting rights and protection could be improved for the innovation of RAS solutions (JCR, 2010).

Figure 9 Failures in the RAS market

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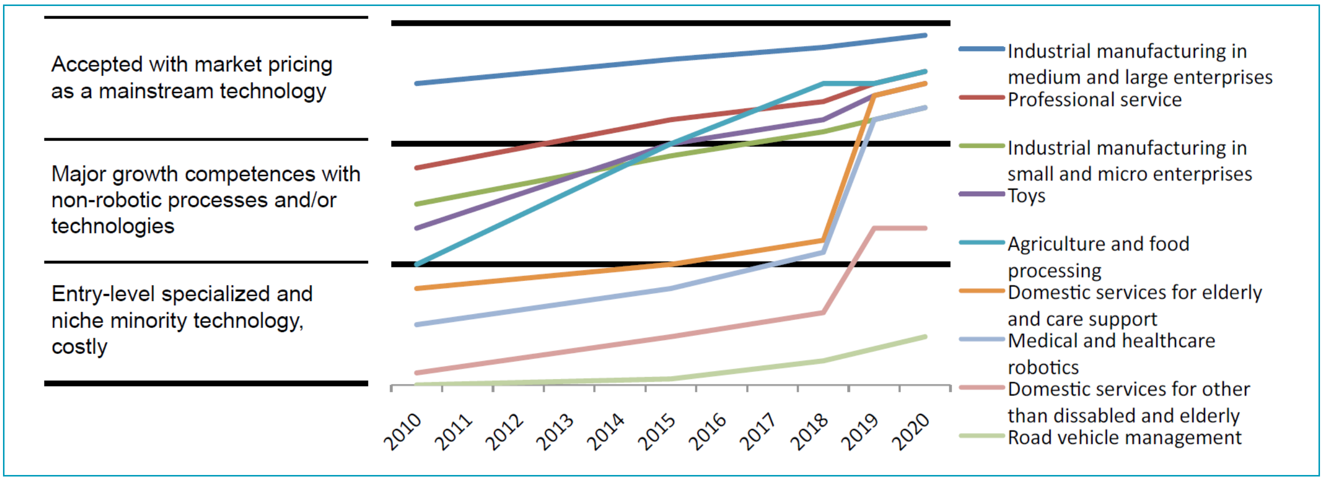
[264] Forge S and Blackman C (2010) A Helping Hand for Europe: The Competitive Outlook for the EU Robotics Industry. JRC Scientific and Technical reports

[265] Vaussard F, Fink J, Bauwens V, Retornaz P, Hamel D, Dillenbourg P and Mondada F (2013) Lessons learned from robotic vacuum cleaners entering the home ecosystem. Robotics and Autonomous Systems, 10(2013)

[266] Mahbub R (2008) An Investigation into the barriers to the implementation of automation and robotics technologies in the construction industry. Doctoral thesis, Queensland University of Technology



Source: Adapted from JCR (2010).

It is expected that RAS solutions will become an integral part of various commercial applications in the coming decade as result of future technological advances. Specifically, as a result of technical advances, it is possible that the cost of RAS technology will reduce and robotics will become more affordable. Hence, more actors will be interested in adopting RAS in their workspace and/or domestic lifestyle. The development of RAS market is dynamic and the current failures in the market are not permanent. What may be of greater concern for the UK market is that the UK currently lacks a significant market share. Developing niche competences is an important a priority for the UK if it seeks to compete in the market.

Table 29 Failures in Robotics (in the EU)

Failure	Source	Scale	Description
Character of Science and technology	JCR, 2010	Slowing down	Technological advances will allow RAS solutions to become accessible at market prices
Market power		No evidence found	
Externalities	JCR, 2010	Slowing down	Need for seed capital to adopt RAS solutions in the workplace, Support for SMEs to cross the ‘valley of death’
Information asymmetry	JCR 2010, pp. 99	Slowing down	“Lack of sufficient communication on robotics capabilities to raise awareness in the market”
Capabilities	JCR 2010	Slowing down	Lack of skills and absorptive capacity in SMEs to adopt RAS solutions in the workplace.
Network	JCR 2010 Mahbub (2008)	Slowing down (a lot)	Too few clusters, networking between different actors. Construction industry (amongst others) is fragmented.
Institutional	JCR 2010, pp. 99	Slowing down	Lack of technical standards “The EU robotics industry does hold valuable patents for robotics but does not have a complete set for all

Failure	Source	Scale	Description
			applications, so its IPR holdings could be stronger”
Infrastructural	JCR, 2010	Slowing down	There is a low level of education and skills in RAS markets; e.g. engineers, technicians and researchers.

Electronics, Photonics and Electrical Systems

Enabling technology
High value manufacturing

Electronics, photonics and electrical systems (EPES) are a set of key enabling technologies, with considerable strengths in the UK. The UK EPES sector employs around 330,000 people in terms of manufacturing alone and an additional 235,000 in distribution and sales of resulting goods. EPES accounts for 10% of UK manufacturing and the sector generates £29bn a year in revenues. However, not just a significant sector in its own right, the EPES sector produces an extremely wide variety of products and components that are crucial for innovation, growth and development in several other key sectors, including healthcare, transport, energy, built environment, security and environmental sustainability. It furthermore has considerable overlap with the ICT sector, meaning that several important product markets fall into both these categories.[267] Though it is commonly assumed that EPES manufacturing in the UK is a shrinking industry due to production moving increasingly to emerging and developing economies, this is in fact only the case for individual components and products which do not require highly specialised skill. With a host of new and emerging technologies, there are large areas of the sector where highly specialised skill levels are required, resulting in the visibly strong UK manufacturing base. Even as basic research in this field continues to produce bases for new innovations, there are plenty of prospects for the UK EPES sector to build on an already strong capability.

Nevertheless, there are several barriers to successful innovation in the EPES sector. Given the sheer breadth of this sector, it is perhaps unsurprising that barriers to innovation can be pointed to with relative ease. Summarising the general sector challenges, TSB notes on its EPES home page

> *The main challenges for the electronics sector in the UK include the prohibitive cost of product development and manufacturing (particularly for early-stage companies), a fragmented supply chain, a general lack of vertically integrated companies that can realise products with an internal supply, and a fiercely competitive global market.*[268]

This assessment of the situation is confirmed by the evidence on the EPES sector. Short product-cycles, capital intensive market entry and fierce global competition pose significant obstacles to innovation. Development of new products is further disincentivised by the medium and long-term inappropriability, stemming from the fact that once production has become standardised, it swiftly moves to locations with cheaper labour costs, allowing several companies without a strong R&D base to benefit from the new product. A lack of

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[267] See Technology Strategy Board, Electronics, Photonics and electrical Systems homepage: https://www.innovateuk.org/electronics-sensors-and-photonics; see also Technology Strategy Board, Electronics, Photonics and electrical Systems – Key Technology Area 2008-2011, available: http://www.efutures.ac.uk/sites/default/files/EPES%20Strategy.pdf

[268] See Technology Strategy Board, Electronics, Photonics and electrical Systems homepage: https://www.innovateuk.org/electronics-sensors-and-photonics

coordination in the form of overlapping R&D activities in several disparate and often small facilities is likewise frequently acknowledged. This is accompanied by a perceived skills shortage, though other reports note that those with the appropriate skills to engage in development in this field struggle to find work in industry. In conjunction, these two observations highlight an especially significant lack of coordination and communication between the academic sector and commercial research in this sector.

There are some other minor points, such as one specific EU directive requiring collectively financing certain forms of waste disposal in the sector, increasing the burden on smaller firms and market entrants and thereby further obstructing innovation from these smaller players.

However, in addition to this array of factors inhibiting successful innovation, a key feature worth highlighting here that is not readily captured by an enquiry into sector-specific market and system failures is the connectedness of EPES to other sectors. In certain instances, EPES can genuinely be understood as a stand-alone sector, for instance in the case of many consumer electronics. However, the reports on the sector consistently note that products from this sector usually find application in different sectors (e.g. health, transport, sustainability, etc.) and are moreover often combined with other ‘enabling technologies’, most frequently with ICT. This means that although there are some general factors inhibiting innovation across the EPES sector, each individual innovation will then additionally be hampered by barriers in the sector in which it is to find its application.

The evidence on the EPES sector thus highlights that there is a range of barriers to innovation, and that public support especially to improve coordination and cooperation between existing commercial research facilities, as well as between academia and commercial development would make a significant difference to the UK’s ability to be better placed in the fiercely competitive global market. However, the EPES sector is also an especially good example of the special status of enabling technologies, where the marketable products resulting from the innovation process are additionally dependent on the barriers to innovation that exist in sectors beyond EPES itself. Illustrative examples of this are photonics for the health sector, where in addition to the barriers outlined here, the challenge of conducting trials in large-scale national health systems presents further barriers. On a different note, an innovative product consumer electronics might include not just the electronic/ photonic hardware, but also software and possibly advanced materials. The emergence of the final product will therefore be obstructed by barriers from all three ‘enabling technologies’ combined.

Table 30 Failures in the Electronics, Photonics and electrical systems (EPES) market

Failure	Source	Scale	Description
Character of Science and	INNOVA 2011[269]		The electrical and optical equipment sector is highly capital-intensive, especially the electronics subsector.

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[269] INNOVA (2011) Electrical and Optical Equipment Sector – Sectoral Innovation Watch, Final sector report. INNOVA, European Commission; available: http://ec.europa.eu/enterprise/policies/innovation/files/proinno/sector-report-electrical_en.pdf

Failure	Source	Scale	Description
technology	 Photonics 21 2006[270] Photonics 21 2006	[all:] slowing down a lot	[…] Radical innovation makes the capitalisation on R&D investments more uncertain. The fabrication of test devices for R&D laboratories is expensive and requires highly developed expertise. It can only be carried out in state of the art facilities: piecemeal funding in individual university-based groups is rarely effective. A major challenge for the future of photonic components research is that, as technologies move to smaller dimensions, as well as to heterogeneous material combinations, the research infrastructure is becoming more capital and maintenance intensive. It is no longer possible for a small or medium sized research unit to do independent research in the photonic components field.
Market power	INNOVA 2011; see also EC 2009[271] INNOVA 2011; see also EC 2009	[all:] slowing down	The majority the products in the subsector optical equipment, medical devices specifically, are tailored for specific target groups (e.g. illnesses or uses). Markets are therefore highly segmented and national markets are often too small for extensive R&D investments to be worthwhile, for efficient, capital-intensive production techniques to be implemented and for the necessary turnovers to be achieved (Thumm, 2000). The technological cycle in the electrical and optical equipment sector is very short. Innovative products which may become mature and being produced low-cost countries locations (European Commission, 2006a). This makes it hard for firms to capitalize on their R&D investments. The semiconductor industry is an example of an industry that has been affected by the dramatic changes in the conditions of global competitiveness (ELECTRA, 2008; ESIA, 2006).
Externalities	INNOVA 2011; see also EC 2009	Slowing down	…due to the rapid technological cycle, products which are innovative may become mature and being produced in low-cost countries locations. In addition to production, innovation activities are increasingly off-shored to R&D facilities in low-cost countries (OECD, 2008b). This shortens the innovation cycles for firms, requires more radical innovation (which can increase the uncertainty of demand) and increases the negative

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[270] Photonics21 (2006) Towards a Brighter Future for Europe – Strategic Research Agenda in Photonics. Photonics21, European Technology Platform. Available: http://www.fp7.org.tr/tubitak_content_files/270/ETP/Photonics/sra_april.pdf

[271] EC (2009) Investing in the Future of Jobs and Skills: Scenarios, implications and options in anticipation of future skills and knowledge needs: Computer, Electronic and Optical Products. TNO, Submitted to the European Commission, DG Employment, Social Affairs and Equal Opportunities; available: http://ec.europa.eu/social/BlobServlet?docId=3268&langId=en

Failure	Source	Scale	Description
			consequences of legacy innovations…
Information asymmetry		No evidence found	
Capabilities	INNOVA 2011, see also Photonics 21 2006	Slowing down	A lack of highly skilled and educated human resources can slow down innovation in the E&O Equipment Sector (Wintjes &Dunnewijk, 2008; EITO, 2007; European Commission, 2006a; European Commission, 2006b; Eucomed, 2007). Among the skills that are mentioned as necessary, are: engineering, science, technology management, project management and business management. Specifically, strong academic skills and knowledge on core engineering studies is needed. In the Optical subsector, there is a shortage of medical engineers, such as medical Informatics specialists (Eucomed, 2007)
Network	INNOVA 2011; see also EC 2009	Slowing down	Several sources report that European ICT research lacks coordination, cooperation, technology transfers to businesses and funding (see i.e. EITO, 2007; Wintjes & Dunnewijk, 2008, ESIA, 2006; European Commission, 2009b). For example, coordination should reduce overlap in national research programmes. European Technology platforms, Joint Technology Initiatives and joint national programmes aim at the (further) development of European centres of excellence, such as the European Institute of Technology. In the European Semiconductor industry, R&D programmes and co-operation fall short of a coherent and consistent concept for stimulating R&D investment (ESIA, 2006).
Institutional	INNOVA 2011 Photonics 21 2006	[all:] Slowing down	According to the European Directive 2002/96/EC, the costs of processing historical waste have to be financed by all producers that are in the market. Therefore, new market entrants have to pay for waste that is caused by the large existing manufacturers. In this way, there is criticism that this Directive creates incentives for large manufactures to produce excessively in order to discourage entrance, and to spread the costs among existing and new producers (Mock and Perino, 2008). A structural weakness at present is that many photonic component researchers, after having completed PhD research and possible post-doctoral research experiences, have great difficulty to find positions in industry in which they can build upon their research expertise. The present industry in Europe cannot absorb this considerable and highly valuable human capital that is continuously lost to the sector. European industry has over the past decades considerably decreased the amount of long-term oriented research in photonic components. Central research laboratories hardly exist anymore and most of the on-going research has a rather short time horizon.

Failure	Source	Scale	Description
Infrastructural		No evidence found	

Biosciences

In a 2009 document the EC outlines the role of key enabling technologies (KET) in contributing to innovation and sustainable industrial development throughout the EU.[272] The KETs identified are nanotechnology, micro- and nano-electronics including semiconductors, advanced materials, biotechnology, and photonics. These technologies are recognised as playing important roles in increasing the level of competitiveness of EU industries e.g. stimulating investment in upstream and downstream industries. This section outlines the types of market failures that undermine development in the field of (industrial) biotechnology. As part of biosciences, biotechnology is closely related to advances in technology and innovation.

Industrial Biotechnology

Enabling technology
High value manufacturing

Biotechnology can be broadly defined as the use of biological resources (plants, algae, micro-organisms) with the objective of developing new materials, chemicals and forms of energy. The possibilities of applying biotechnology in industry are vast and can be found, for example, in industries such as (bio)plastics, agri-food, automobile, skin care, and medicine. Expected benefits of industrial biotechnology take-up include advancing into more sustainable and cleaner technologies, increased productivity and economic development. Industrial biotechnology is not a self-standing industry; instead it is a key underpinning technology that has applications in several different industries (see also BERR and BBSRC).[273] The biotechnology industry is a major contribution to the development of traditional sectors such as food industries but also is a catalyst for the development of new sectors, including biofuels. This non-industry specificity aspect is key to describing the function of biotechnology (as well as some other KET) in industrial development. According to BERR

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[272] EC SEC (2009) Preparing for our future: Developing a common strategy for key enabling technologies in the EU. Available: http://ec.europa.eu/enterprise/sectors/ict/files/communication_key_enabling_technologies_en.pdf

[273] BERR (2009) IB 2025: Maximizing UK opportunities from industrial biotechnology in a low carbon economy. Report to government by the industrial biotechnology innovation and growth team
NB: BBSRC is a non-departmental body that was established in 1994 and it is one of seven UK research councils (RCUK) funded by the Government's Department for Business, Innovation and Skills (BIS). BBSRC supports initiatives of scientists and research students in the UK. The role of BBSRC is to contribute and support research initiatives on and related to biotechnology and to encourage university-business collaborations.

> *"…parts of the sector depend crucially on the availability of land to grow biomass, and on technology breakthroughs to ensure feedstock and production costs that are comparable to current petrochemical alternatives."*[274]

Land access challenges in industrial biotechnology are related to the high volatility of prices of commodities such as food and oil. The (future) price of e.g. argi-food stemming from biotech engineering is dependent on the world price of food. And, the uncertainty over such world prices creates additional tension and competition over land access. The additional uncertainty over technological breakthroughs hampers the industrial development. Aside from difficulties related to land-access and volatile market prices, market failures too are a culprit to high levels of uncertainty in the biotech industry. An overview of the different market failures that impact industrial biotechnology is presented in Table 31.

Even though the potential from technological advancement in biotechnology is vast, its benefits are sometimes controversial. Monsanto is one of the pioneers in the biotechnology industry, in the field of genetically modified organisms (GMOs), where it has a patent position so powerful as to enable the company to maintain a dominant position in the market. Critics of companies such as Monsanto, argue that, as a result of patent protection, the biotech market lacks competition and disregards environmental and health hazards. Nonetheless, large multinationals such as Monsanto are also in a position to contribute to further developments and applications of biotechnology.

Excessive market power may block the technological advancements and application of biotechnology in *several* different industries. Yet, without protection during early stage investment the return on investment for industrial leaders is compromised. As argued in the TINA report on bioenergy, insufficient protection of intellectual property can result in firms investing below capacity, hence slowing-down development. It is important to note that SMEs active in downstream industries may be willing to pay for investment in development in the field of biotechnology but often such actors often do not bear the cost. For one, it may not be clear ex-ante who will benefit from the cost of investment and the returns on investment in biotechnology take many years to materialise. Overall, the potential of industrial biotechnology is dependent on patent protection to better enable the exploration of innovation opportunities.

The types of issues regarding information asymmetry that are identified in the literature (BERR) involve that of a lack of policymaker and consumer understanding of the benefits of industrial biotechnology, which is slowing-down the take-up, and commercialization of bio-tech solutions. BERR likewise identifies that one of the market constraints in the field of biotechnology is a lack of skills, i.e. at every level, which hampers the flow of new ideas into the communization and industrial up-take.

Both at the UK level and at the European level, network failures are identified challenges in the biotechnology industry.[275] As a result of industrial fragmentation and coordination it is difficult to coordinate the actions in research, industries, and policy. Within industry,

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[274] Ibid, p32

[275] Ibid; see also European Commission (2010) The Knowledge Based Bio-Economy In Europe (KBBE): Achievements and Challenges

there is a communication gap between industries and between upstream and downstream supply chains. Overall, network challenges substantially slow down the innovative process.

An additional challenge in industrial biotechnology is that of developing industrial standards. Specifically, following a document of the European Commission (2010, pp. 6), “industry finds it difficult to seek authorisation for novel food products, because of the lengthy procedures and the uncertainty of the outcome.” We categorize this type of failure as an institutional failure because it reflects a shortcoming of regulation (at the regional and international level) to provide industry reliable market access. This type of uncertainty is expected to slow-down innovation in industrial biotechnology.

Finally, based on the literature survey, we identified some infrastructural failures related to the biotechnology industry (see Table 31). These failures entail “a lack of publicly funded business support schemes” in terms of equipment and demonstration facilities.[276] The early testing of ideas is key to a successful launch and commercialization of biotech produce. This means that some initiatives in the field are stillborn.

Table 31 Failures in the biotechnology industry

Failure	Source	Scale	Description
Character of Science and technology		No evidence found	
Market power			
Externalities	TINA, bioenergy pp. 27	Slowing down (a lot)	“Spill-over effects reduce the benefits of engaging in early stage RD&D, due to the challenges of retaining IP benefits, and gaining the full market value from these investments. Investors are hence less willing to invest sufficiently in these pre commercial technologies, creating an investment ‘valley of death’ in the area of RD&D between early stage conceptual technologies and commercial application”.
Information asymmetry	BERR (2009, pp. 45)	Slowing down (a lot)	“Lack of understanding of IB and its potential – among businesses, consumers and policy makers (…) the main initial barrier to public acceptance of IB is a lack of knowledge or understanding of such new technologies.
Capabilities	BERR (2009, pp. 44)	Slowing down (a lot)	“Improvements in skills are required at every level. In particular, Masters level training is needed in the UK to deliver appropriate interdisciplinary IB skills, to transcend traditional disciplinary boundaries and enable shared strategies and collaborative thinking at each stage of the product or process development lifecycle. In addition, skills are needed to scale up production (‘from genes to tonnes’) to generate wealth from IB. (…) Students at A level and degree level need greater competence in basic laboratory skills than they currently show, so that they are capable, for example,

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[276] BERR (2009) IB 2025: Maximizing UK opportunities from industrial biotechnology in a low carbon economy. Report to government by the industrial biotechnology innovation and growth team

Failure	Source	Scale	Description
			of preparing their own solutions rather than depending on those prepared by lab technicians.”
Network	BERR (2009, pp. 44, 45); European Commission (2010, pp. 6)	Slowing down (a lot)	“Companies and centres developing IB products and processes and the chemistry-using industries that will generate the rewards of IB are not well connected in the UK.” “Research in health, food and diet-related diseases is both complex and fragmented”
Institutional	European Commission (20120, pp. 6)	Slowing down (a lot)	“Industry finds it difficult to seek authorisation for novel food products, because of the lengthy procedures and the uncertainty of the outcome”
Infrastructural	BERR (2009, pp. 43, 45)	Show-stopper	“Equipment and facilities for demonstrator projects suffer, in particular, from a lack of publicly funded business support schemes. The demonstrator risk/reward profile is not attractive enough for private investors or large corporates. As a result, there is a shortfall of such facilities in the UK. Companies often go overseas to prove their ideas (…). There is a particular shortage of demonstration facilities for fermentation, for certain key areas such as upstream pre-treatment of biomass and for certain downstream operations.” “The adoption of IB is also hampered by lack of expertise in IB in most UK university Technology Transfer Offices. Technology transfer (early-stage university research and commercialisation) requires the ability to value the related intellectual property. Lack of this ability in relation to IB is impeding the flow of ideas from universities into commercial deals.”

Synthetic Biology

Enabling technology
‘8 great’ technology
High value manufacturing

Synthetic biology is a technology area centred on the design and artificial creation of biological organisms. Classified as one of the ‘8 great technologies’, it is a field that is in its infancy, as well as having exceptional potential for future economic activity and growth. Conceptually, this field combines the disciplines of biology and engineering to move decisively beyond the creation of artificial molecules typical of chemical engineering, towards the creation of microorganisms. Existing uses of this technology in the UK include creation of artificial microorganisms converting biomass such as crop residues into butanol, to convert carbon monoxide into fuels, and generally to enable more targeted, effective fermentation processes.[277] The Technology Strategy Board notes that applications of synthetic biology include new ways of making high-value materials, such as fine chemicals and pharmaceuticals, renewable energy sources, processes for detecting and addressing environmental contamination, and increasing agricultural productivity, with projected global market opportunity figures cited in the region of $10bn by 2016.[278]

The literature notes frequently that although this technology is relatively new and in large parts still at the experimental stage, the plethora of known potential uses outlined above has already triggered considerable commercial interest. Moreover, alongside the US and China, the UK is generally acknowledged to be a scientific leader in this field. Moreover, though there are some acknowledgements of a need to ensure there are more skilled researchers in the field, these are relatively rare and, despite the general concerns over a lack of STEM graduates and researchers, it does not amount to the severe skills shortages noted in some other sectors. A further frequently noted key advantage of this technology is that development is comparatively inexpensive and can be done in relatively small facilities without the need for the extensive supply chains characteristic of larger, heavy industrial equipment (e.g. civil aviation, robotics, satellites, etc.).

However, despite all these key advantages, the literature highlights some important barriers to innovation in this field, which fall into the categories of institutional and network failure, as well as barriers relating to the character of the technology. However, rather than constituting completely separate and unconnected issues combining into a collected set of barriers, a large part of the problems identified all hinge on the wider implications of synthetic biology, and the regulations that are a place as a consequence of the controversy surrounding it.

First, the notion of artificially creating life-forms has ethical implications and does not sit well especially with more religious sections of society, as well as those fearing dystopian futures, where life is reduced to mechanical building-blocks that can be assembled and re-assembled at will. These implications have led to public doubts on synthetic biology, triggering considerable political caution and regulation of development in this field.

Second, there is a much more immediate concern about dual use – the simple fact that synthetic biology could easily be misused for the development of devastating biological weapons and artificial varieties of disease (‘bioterrorism’). These concerns have already triggered extensive deliberation and research in the field of biosecurity, in conjunction with further regulation of research and development in the field.

In addition to issues around biosecurity there are also issues around environmental biosafety: releasing artificial life-forms into the environment entails the risk of unintended consequence in terms of effect these life forms may have on the environment. The literature generally acknowledges that these risks are hypothetical, with no knowledge as

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[277] Policy exchange, ‘8 great technologies’, available: http://www.policyexchange.org.uk/images/publications/eight%20great%20technologies.pdf

[278] TSB Synthetic Biology homepage: https://www.innovateuk.org/-/tools-and-services-for-synthetic-biology

to how long any unintended effects might take to be noticeable, but likewise, these concerns act as an additional driver of policy and regulation.[279]

Governments have generally been swift to regulate this sector, with much regulation relying on the precautionary principle. This in itself restricts what R&D can be done, whilst the accompanying climate of public opinion leads to questions around whether there will actually be demand and acceptance of eventual resulting products and technologies. While technological start-up costs are relatively low, the need for extensive work to ensure compliance with existing regulations increases these costs considerably. There is a particular requirement for demonstration projects resulting from the uncertainties in this technology, where currently some information asymmetries exist in terms of both safety and efficacy of new developments. Across the literature, there are calls for better international networking in order to enable more large scale demonstrations, public education and transparent, internationally consistent standards leading to greater trust in and safety of synthetic biology.

There are particular issues with IP, due to the multi-layered nature of synthetic biology. As noted, the field draws on the disciplines of biology and engineering; the latter becomes especially evident by the fact that each developed product consists of microbiological ‘building blocks’, which are then put together in different ways to create different types of organisms. However, if each building block is already protected IP, the assembly of finished organisms can become arduous and costly. Clearer regulations are required detailing at what point the subcomponents of marketable microorganisms are significant enough to qualify for patents and IP.

Table 32 Failures in the synthetic biology industry

Failure	Source	Scale	Description
Character of Science and technology	EC 2010[280]; see also RCUK 2010[281]; see also ESRC 2012[282]	Slowing down	Synthetic biology comes with innovative promises of substantial benefits for health, the environment, resource management and the economy. Nevertheless, it is characterised by large uncertainties, potential risks and it raises ethical questions.

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[279] For a detailed discussion and reference to wider literature on these issues, see IRGC (2009) Risk Governance of Synthetic Biology. International Risk Governance Council, Geneva. Available: http://www.irgc.org/IMG/pdf/IRGC_Concept_Note_Synthetic_Biology_191009_FINAL.pdf

[280] EC (2010) Synthetic Biology: From Science to Governance. A workshop organised by the European Commission’s Directorate-General for Health & Consumers 18-19 March 2010, Brussels. Available: http://ec.europa.eu/health/dialogue_collaboration/docs/synbio_workshop_report_en.pdf

[281] RCUK (2010) Synthetic Biology Dialogue. BBSRC, EPSRC & Research Councils UK, June 2010, available: http://www.bbsrc.ac.uk/web/FILES/Reviews/1006-synthetic-biology-dialogue.pdf

[282] ESRC (2012) Governing Synthetic Biology. Policy Brief, ESRC Innogen Centre, available: http://www.innogen.ac.uk/downloads/AGLS-11-Governing-Synthetic-Biology.pdf

Failure	Source	Scale	Description
	TSB 2012[283]; see also RCUK 2010		Since synthetic biology is a new field, there is much uncertainty surrounding both the risks and benefits of its research and applications. While stringent risk management is crucial for responsible research and innovation, inescapable uncertainty must be acknowledged and accounted for.
Market power		No evidence found	
Externalities		No evidence found	
Information asymmetry	IRGC [284] 2009	Show-stopper [in specific areas]	In the medical field, for example, synthetic biology could aid the development of diagnostics, vaccines and cell-based or pharmacological therapeutics, but pharmaceutical companies are reluctant to invest in the technology without evidence of utility for human health.
Capabilities	TSB 2012	Slowing down (a little)	There may now be a need to streamline the existing education and training programmes and, where appropriate, to introduce new courses to address the industrial translation process and, more generally, to meet the needs of industry.
Network	TSB 2012 TSB 2012	[all:] Slowing down (a little)	Most modern technological products and services exist in complex, and global, supply chains, and it takes time to introduce and have adopted radically different propositions. Each organization along the chain has to evaluate the impact a new technology may have on its operations, and has to satisfy itself that it can assure the quality and delivery of the commercial offering. The establishment of international markets and supply chains requires a number of

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[283] TSB (2012) A Synthetic Biology Roadmap for the UK. UK Synthetic Biology Roadmap Coordination group; technology Strategy Board. Available: http://webarchive.nationalarchives.gov.uk/20130221185318/www.innovateuk.org/_assets/tsb_syntheticbiologyroadmap.pdf

[284] IRGC (2009) Risk Governance of Synthetic Biology. International Risk Governance Council, Geneva. Available: http://www.irgc.org/IMG/pdf/IRGC_Concept_Note_Synthetic_Biology_191009_FINAL.pdf

Failure	Source	Scale	Description
			components to be put in place. Depending on the nature of the project and whether or not it involves an SME, it will be necessary to seek industrial support, funding or partnership. If the project is university based, then a partnership with a large company with international links may be most appropriate. This can most effectively be done via some form of licensing or cooperative research agreement. However, large industries are well placed to identify appropriate research groups to partner with anywhere in the world, so ease of working together in addition to world-class expertise will be important factors in their selection. Smaller companies may require more specific support to access international markets, for example by being assisted in developing some form of showcase programme that would in turn attract the required external investment or partnership.
Institutional	IRGC 2009; see also EC 2010; see also TSB 2012; see also ESRC 2012 IRGC 2009; see also EC 2010; see also TSB 2012 IRGC 2009	Slowing down	Regulation and governance of synthetic biology are in the very early stages of development and the approaches currently under consideration relate mainly to the risks attached to the research itself rather than to the products and other innovations that might eventually emerge from that research. In governing the risks of new technologies, there is a history of decisions taken at the very earliest stages of development having unforeseen and often counter-productive outcomes which are difficult to change in later stages. Different IP cultures and world views are difficult to reconcile when stakeholder interests and incentives are not aligned. A key issue for risk governance is whether the synergies enabled by open sharing can create incentives for rapid diffusion more effectively than the patent system, and what impact the framing of the debate as ‘open source versus commercialisation’ could have on public perceptions of the technology. Worries about potentially restrictive patents in synthetic biology, and attempts to create an

Failure	Source	Scale	Description
			open source ethos in synthetic biology research (if not the development of downstream products) are closely linked to concerns about the monopolisation of the field by commercial companies [ETC Group, 2007]. The governance of new areas of development in life sciences has in the past led to an increasingly onerous and lengthy regulatory process which adds to the obstacles facing new market entrants, and can eventually stultify the entire innovation system. Biomedical technologies focus strongly on patents as a means to protect the very large amounts of financial investment needed to comply with regulatory regimes and bring a product to market [Maurer, 2006]. Patents that present overly-broad and ambitious claims, such as on foundational technologies and biological functions encoded by BioBricks, could inhibit research in synthetic biology.
Infrastructural		No evidence found	

Summary of results

Overall Results

Before reviewing the overall results of this exercise, it is perhaps worth considering the implications of the method. The summary tables below reflect what we were able to find in the literature regarding the 24 innovation areas we identified. Table 33 presents a summary of the different types of failure across the analysed innovation areas. The literature had things to say about most categories of failure in most innovation areas.

Table 33 Summary of failure types

		Character of Science and tech.	Market power	Externalities	Information asymmetry	Capabilities	Network	Institutional	Infrastructural
Energy	*Nuclear Energy*		****	***	*	**	***	****	****
	Renewable energy		**	****	**		***	****	****
	Oil and Gas	***		**	**	*	**	***	**
	Energy storage	**	****	****	***		****	***	****
Built Environment	*Low impact buildings*		***	****	**	**	**	**	**
	Future cities			**		**	**		**
Food	*Agri-science*		**	**	**	**	****	***	**
	Farm-to-fork value chain		****	***	*		****	*	***
Transport	*Low carbon vehicles*	**	**	**		**	**	**	****
	Intelligent transport systems		**		**		***	**	****
	Civil aviation	**	**			***	**	**	****
Healthcare	*Regenerative medicine*	**	**		****	**			**
	Assisted Living				**		***	**	****
	Stratified Medicine		**	****	**		**	**	
Creative Industries			**	***		***	**	**	
Financial services			**		**	**	****	****	
Satellites and space			**	***	**		****		**
Nanotechnology and Advanced Materials		***	***	*	*	****		****	
ICT	*Big Data*		*	*	*	****	*	*	*
	Cyber security		**	***	****			**	
	Robotics and autonomous systems	**		**	**	**	***	**	**
Electronics, Photonics and electrical systems		***	***	**		**	**	**	
Biosciences	*Industrial biotechnology*			***	***	***	***	***	****
	Synthetic Biology	**			****	*	*	**	

Note: *** Showstopper, ***Slowing-down (a lot), **Slowing down, *Slowing-down (a little), “blank” No evidence found

In order to identify patterns across the 24 innovation areas we apply a numeric scale to the different levels of failures. When no evidence was found we indicate ‘0’. Slowing down a little is given the weight ‘1’, slowing down is given the weight ‘2’ and slowing down a lot is given the weight ‘3’. Finally showstoppers are given the weight of ‘4’. Table 34 presents the summary of results using this numeric scale. The 24 innovation areas are sorted in descending order by the sum of scores of the different types of failures for each innovation area. The five ‘challenge-led areas’ – energy, food, transport, built environment and healthcare – are highlighted to help identify patterns. Aside from presenting the total scores for each of sectors, we also present the total frequency count of the types of failures by sector.

There are several caveats associated with the implementation of such scales. We recognize that both the total score and frequency count are crude proxies to assess the role of failures across innovation areas and industry classification. Hence, before the results of this exercise are presented, it is worth pointing out a number of issues.

- First, as already indicated in previous sections, there are several innovation areas where we find less frequent evidence of a given market or system failure, e.g. as is the case for assisted living and cyber security. However, not having identified a given type of failure does not provide a guarantee there are no failures in these sectors. This study, as well as the overall literature, may have failed to document certain failures.

- Second, a lack of evidence of failures may also be an indication that some innovation areas are more dynamic and fast-growing than others and, as a result, we identify fewer failures (or vice versa).

- Third, as evident in the analysis on robotics and autonomous systems, there are several failures in the market that currently slow-down innovation but, as a result of technological change, it is expected that some of these barriers to innovation will disappear within the next five years. The dynamic behaviour between technological development, innovation and failures is likewise an inherent part of other sectors. Basically, this also means that, as a result of structural changes in the economy associated with further technological development, some failures that we have identified as showstoppers will no longer manifest themselves as showstoppers in the short-run, or in the long-run for that matter.

- Fourth, as already suggested in previous sections of this document, the ratings of the importance of different failures are subjective and the scale by which we propose to measure the failures is imperfect. The effect of the failure (show stopper or slowing down) does not reflect the degree to which a failure is critical to the innovative development of the industry. Specifically, failures that block the value chain of innovative processes that are key to further advancement in the industry can be considered more *critical* failures.

Finally, in many of the innovation areas we found multiple failures within a single failure category. Both the total score and frequency count only reflect whether a type of failure was identified and does not reflect the (number of) way(s) by which one type failure restrains innovation. For example, as identified throughout the analysis, several aspects of institutional failures play a role in the creative industries and the financial service industries: cultural aspects, and regulatory aspects.

Despite these caveats associated with implementing a numeric scale we are still interested in learning whether this exercise will reveal any interesting patterns.

We find that, in numerical terms, there is considerable variation in the effect of barriers on innovation across the different areas, with ‘future cities’, big data’, and ‘synthetic biology’ scoring the lowest and ‘energy storage’ scoring the highest. The last column of Table 34 presents the frequency count of the failures for each of the innovation areas. To some extent the frequency count mirrors the pattern of the scores but there are also some discrepancies such as in the case of ‘big data’, which has a relatively low score but a frequency count of 7 – so all but one of the failures were present but in each case only to a modest extent.

Table 34 Innovation areas scored by the effect of innovation failures

	Character of science	Market power	Externalities	Information asymmetry	Capability failure	Network failure	Institutional failure	Infrastructural failure	Total score	Total count
Energy storage	2	4	4	3	0	4	3	4	**24**	**7**
Nuclear energy	0	4	3	1	2	3	4	4	**21**	**7**
Industrial biotechnology	0	0	3	3	3	3	3	4	**19**	**6**
Renewable energy	0	2	4	2	0	3	4	4	**19**	**6**
Agri-science	0	2	2	2	2	4	3	2	**17**	**7**
Farm-to-fork value chain	0	4	3	1	0	4	1	4	**17**	**6**
Low impact buildings	0	3	4	2	2	2	2	2	**17**	**7**
Low carbon vehicles	2	2	2	0	2	2	2	4	**16**	**7**
Nanotechnology	3	3	1	1	4	0	4	0	**16**	**6**
Oil and gas	3	0	2	2	1	2	3	2	**15**	**7**
Civil aviation	2	2	0	0	3	2	2	4	**15**	**6**
Robotics and autonomous systems	2	0	2	2	2	3	2	2	**15**	**7**
Electronics, photonics and e-systems	3	3	2	0	2	2	2	0	**14**	**6**
Intelligent transport systems	0	2	0	2	0	3	2	4	**13**	**6**

	Character of science	Market power	Externalities	Information asymmetry	Capability failure	Network failure	Institutional failure	Infrastructural failure	Total score	Total count
Satellites and space	0	2	3	2	0	4	0	2	**13**	**5**
Regenerative medicine	2	2	0	4	2	0	0	2	**12**	**5**
Stratified medicine	0	2	4	2	0	2	2	0	**12**	**5**
Creative industries	0	2	3	0	3	2	2	0	**12**	**5**
Financial services	0	2	3	0	3	2	2	0	**12**	**5**
Assisted living	0	0	0	2	0	3	2	4	**11**	**4**
Cyber security	0	2	3	4	0	0	2	0	**11**	**4**
Big data	0	1	1	1	4	1	1	1	**10**	**7**
Synthetic biology	2	0	0	4	1	1	2	0	**10**	**5**
Future cities	0	0	2	0	2	2	0	2	**8**	**4**
Total score for the 24 innovation areas	**21**	**44**	**51**	**40**	**38**	**54**	**50**	**51**		

(Major sectors: Red=Energy; Green=Health and care; Blue=Built Environment; Grey=Transport; Yellow=Food)

Table 35 presents the score and frequency count by innovation sector for each of the industry classifications: challenge led areas, enabling technologies, 8 great technologies, high value manufacturing and digital services. The one clearly identifiable trend from this analysis concerns the innovation areas falling into the category of ‘digital services’. All of these innovation areas score relatively low on the ranking, suggesting that barriers to innovation in the digital services are generally lower than elsewhere. Specifically, we found no evidence of failures of the character of science on digital services.

Overall, for innovation areas that are classified as ‘high value manufacturing’ we see no clear pattern of there being systematically more or fewer failures than in other areas (even distribution across the rankings). The same is true for all the sub-sectors and sample-technologies of the ‘challenge-led areas’, as well as for the ‘enabling technologies’ and the ‘8 Great Technologies’.

In addition to the categories of innovation areas that have structured this report so far, two other identifiers were considered: (i) significant high-street or consumer-goods orientation of an innovation area, and (ii) relative novelty of the innovation area. These additional markers to classify and conceptually divide the 24 innovation areas did not appear to be connected to either especially high or especially low barriers to innovation. However, there is one observation that is worth mentioning. Network failures are less frequently identified in sectors relying on newer technologies.

Table 35 Distribution of failures’ score and frequency count

	Total score	Total count	Challenge-led area	Enabling technology	‘8 great’ technology	High value manufacturing	Digital service	Significant and substantive state involvement	Heavily regulated	Significant high-street/ consumer goods orientation	New industry (post ~1980)
Energy storage	24	7	x		x			x	x		
Nuclear energy	21	7	x					x	x		
Industrial biotechnology	19	6		x		x					x
Renewable energy	19	7	x			x		x		x	x
Farm to fork	17	6	x						x		
Agri-science	17	7	x		x				x		
Low impact buildings	17	7	x			x				x	x
Nanotechnology	16	6		x	x	x					x
Low carbon vehicles	16	7	x			x				x	x
Robotics and autonomous systems	15	7		x	x	x				x	
Civil aviation	15	6	x			x					
Oil and gas	15	7	x						x		
Electronics, photonics and e-systems	14	6		x		x					
Satellites and space	13	5			x	x	x	x			
Intelligent transport systems	13	6	x				x	x			x
Financial services	12	5					x		x	x	
Creative industries	12	5					x			x	
Stratified medicine	12	5	x			x			x		x
Regenerative medicine	12	5	x		x			x	x		x
Assisted living	11	4	x					x		x	
Cyber security	11	4		x			x			x	x
Synthetic biology	10	5		x	x	x			x		x
Big data	10	7		x	x		x			x	x
Future cities	8	4	x			x					x

It is quite evident that the role of the State is more prominent in certain sectors than in others. It is also noteworthy that the role of the State in given sectors has changed substantially over the past decade. This generally means that, as certain sectors have become relatively more privatized, the rules of the game have changed. For example, as was detailed in previous sections, the energy sector was previously State-owned and today is governed under regulations, permits, contracts, etc. As a result of privatization, government failures have not disappeared. The most evident example of government failures that we have accounted for are institutional failures and infrastructural failures. Several of the identified institutional failures are examples where regulations create barriers to innovations. Infrastructural failures are usually clear examples of government failure, e.g. where innovations are hindered by the lack of perceived regulatory/political stability. It is important to recognize that the State may have 'solved' a number of market failures (i.e. via policy and regulation). Additionally, based on the market failures that have been identified in this study, there may be substantial scope for the State to play a future role in overcoming failures.

In our analysis we reviewed the degree to which there were more or less failures relative to sectors where there is: (i.) significant state involvement as a customer or user of innovation or (ii.) heavy regulation by the state for example due to public concerns, technological risk or particular moral hazard. We find that infrastructural failures play a prominent role in sectors with heavy state involvement and, for example, infrastructural failures do not play a prominent role in the 8 great technologies. Moreover, one interesting finding is that in sectors with heavy state involvement, we usually identify showstoppers or slowing-down innovation as a result of information asymmetry.

Most and least significant failures

For the most part, the various barriers identified through the literature review have a relatively narrow range of total scores, highlighting once again that all types of failure play a role across a broad range of innovation areas. The exception to this is 'Character of science and technology', which, though playing a slightly more prominent role in the '8 great technologies', is the only barrier never identified as a 'showstopper' and the one with the highest occurrence of 'no evidence found'. The relatively low apparent significance of the character of the science and technology as a barrier to successful innovation is initially especially surprising, given that technological indivisibility – an important subset of this type of barrier – has been used as one of the fundamental arguments for public support of innovation throughout neoclassical literature and discourse. However, in the wider context of the analysis conducted here, two key explanations emerge for the noticeably low score of this barrier.

Table 36 Overall severity of each innovation barrier

Rank	Overall score	Barrier
1	54	Network
2	51	Externalities
3	50	Institutional
4	51	Infrastructure
5	44	Market Power
6	40	Info Asymmetry
7	38	Capability
8	21	Character of science & technology

First, the character of science and technology is an issue implicit throughout the discussions on most innovation areas. All areas considered in this report had at least some, if not all, of the following characteristics:

- New or partially unchartered area of science and technology
- Interdisciplinary character, requiring expertise from several different sources
- Complexity at both research and development phase of innovation
- Large or expansive facilities required for either demonstration, research or assembly

Whilst these characteristics could be applied to most innovation areas considered here, they are generally not understood as barriers to innovation in and of themselves. Rather, the complex and multi-dimensional character of technology and science was implicitly or explicitly assumed in most innovation areas. Consequences of complexity and multi-dimensionality then tended to fall into other types of barriers. ‘Technological character’ for instance frequently necessitated collaboration through large networks, or a particular type of skill-base, infrastructure or facility. Likewise, technological complexity was often a source of information asymmetries between researchers/ developers on one hand and customers on the other. Whilst the character of science and technology is therefore often a fundamental explanatory factor for the severity and/ or importance of network, capability, infrastructural or information failures, it is rarely identified by the literature as a barrier to innovation in and of itself.

A second and related explanatory point concerns the more specific link between indivisibilities – a subset of ‘character of science and technology’ – and the overall highest scoring barrier, network failure. A surprising result is that even in those innovation areas characterised by especially large-scale projects, products and development, these characteristics were rarely pointed to as being significant barriers to innovation in and of themselves. This holds even for those industries, which, in the canonical literature on market failure, have been held up as prime examples of indivisibility, specifically space, civil aviation and energy. However, these large-scale, research-intensive sectors not only share a relatively low instance of barriers relating to the character, size and scope of the technology, but also an especially high level of serious network failures. Indeed, across the case studies of large-scale, research-intensive manufacturing – satellites and space, energy, civil aviation, robotics, food production and agri-science – there is frequent reference to the importance of supply-chains and coordination between manufacturers of various constituent parts and sub-components. There is therefore a strong suggestion that sectors where indivisibility might once have been problematic, specialisation and fragmentation have had a mitigating role, lowering the minimum scale required for successful innovation. Put simply, there is a sense in the analysis that in many cases the indivisible has become divisible, but at the expense of splitting up technologies into networks of sub-components, which may easily become fragmented or un-coordinated. The corollary may be a kind of ‘self-censorship’ via a focus on incremental innovation so that indivisibilities associated with the development of more radical forms of innovation are simply not considered in the literature. Since our approach is based on that literature, of course, we cannot test that hypothesis in this study.

Another failure that seems problematic is ‘capability failure’. This is conceptually different from other failures in the sense that it is a property of the individual firm rather than of the market or of research. In any industry, one might expect to see a mix of more and less capable firms. SME innovation support policy in general is built on the idea that the less capable are perfectible and that social investment in improving their capabilities will increase their innovation and business performance, generating a social return. Since the literature we have studied focuses on industries and technologies, it is not obvious that it would pay much attention to the range of capability possessed by the firms concerned. The main issue appearing under the heading of ‘capability failure’ is skill shortage, which needs to be carefully interpreted.

We can think of this as having two components. One is a result of under-provision of relevant education and training by a combination of the state and industry itself. Because it is cheaper to ‘poach’ skilled labour from competitors than to train one’s own, firms have a disincentive to provide adequate training. This is an externalities-based market failure, for which the state compensates by itself providing education and training. If this fails to keep up with demand, a skill shortage results. The second is a firm-specific inability to identify, recruit or retain relevant skilled people. This can involve a ‘learning paradox’ where lack of internal skill prevents the acquisition of relevant skills from outside; or it can be as simple as the firm not wanting, or not being able, to pay the market rate for skilled labour. Without good information about the markets for very specific skills, it is difficult to tell these situations apart and they are probably conflated in at least some of the literature.

Figure 10 Frequency of the different impacts of failures on innovation, by innovation area

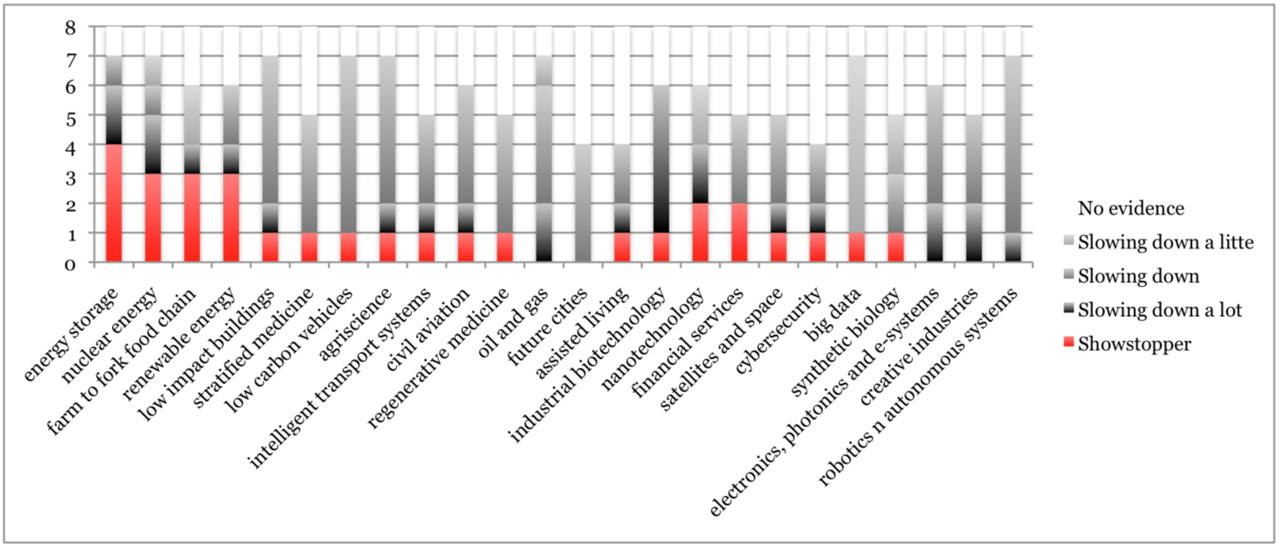
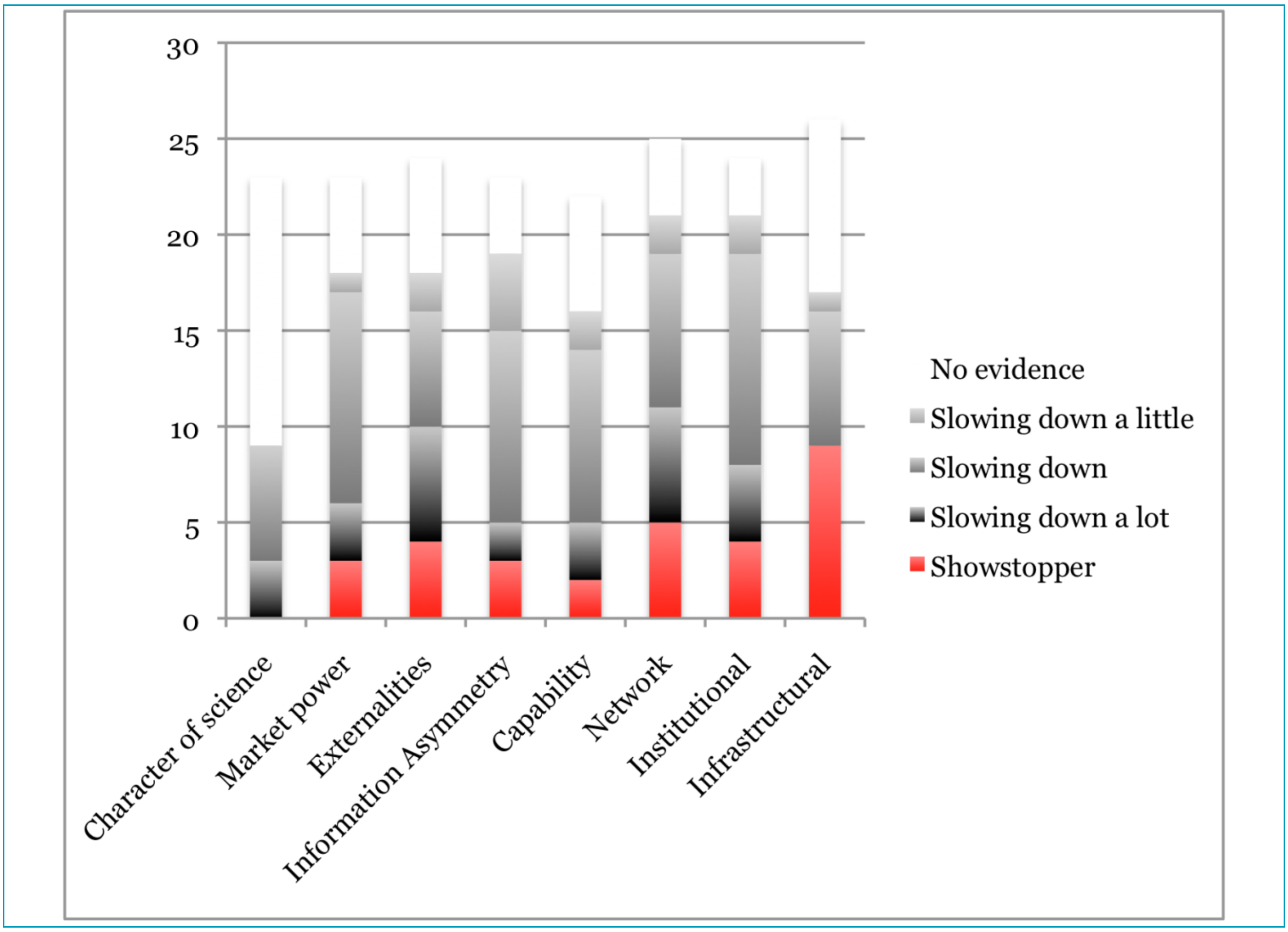


Figure 10 illustrates the frequency of the different impacts of failures by innovation area. In several innovation areas we identified no showstoppers to innovation (oil and gas, future cities, electronics, photonics and e-systems, creative industries, and robotics). In the energy market we did find substantial evidence that there are failures in the market that act as showstoppers to innovation. In many innovation areas there is evidence that there are failures that slow innovation down a lot.

Figure 11 illustrates the variation in frequency of the different impact (showstopper, slowing down at lot, etc.) across the types of failures. There is clear evidence that the showstopper effect of failures on innovation is identified both in the more neoclassical failures and for the innovation system failures. Likewise, we have found evidence that both the neoclassical failures and the innovation system failures can have a slowing-down effect on innovation. Usually, the number of showstoppers identified is lower than the number of identified failures that slow down innovation. The exception is infrastructural failures where we find more showstopper effects relative to slowing-down effects. No evidence has been found that there are showstopper effects for the character of science failure. As illustrated in Figure 10, Externality failures and network failures frequently slow down innovation a lot.

Figure 11 Frequency of the different impact of failures on innovation, by market failure

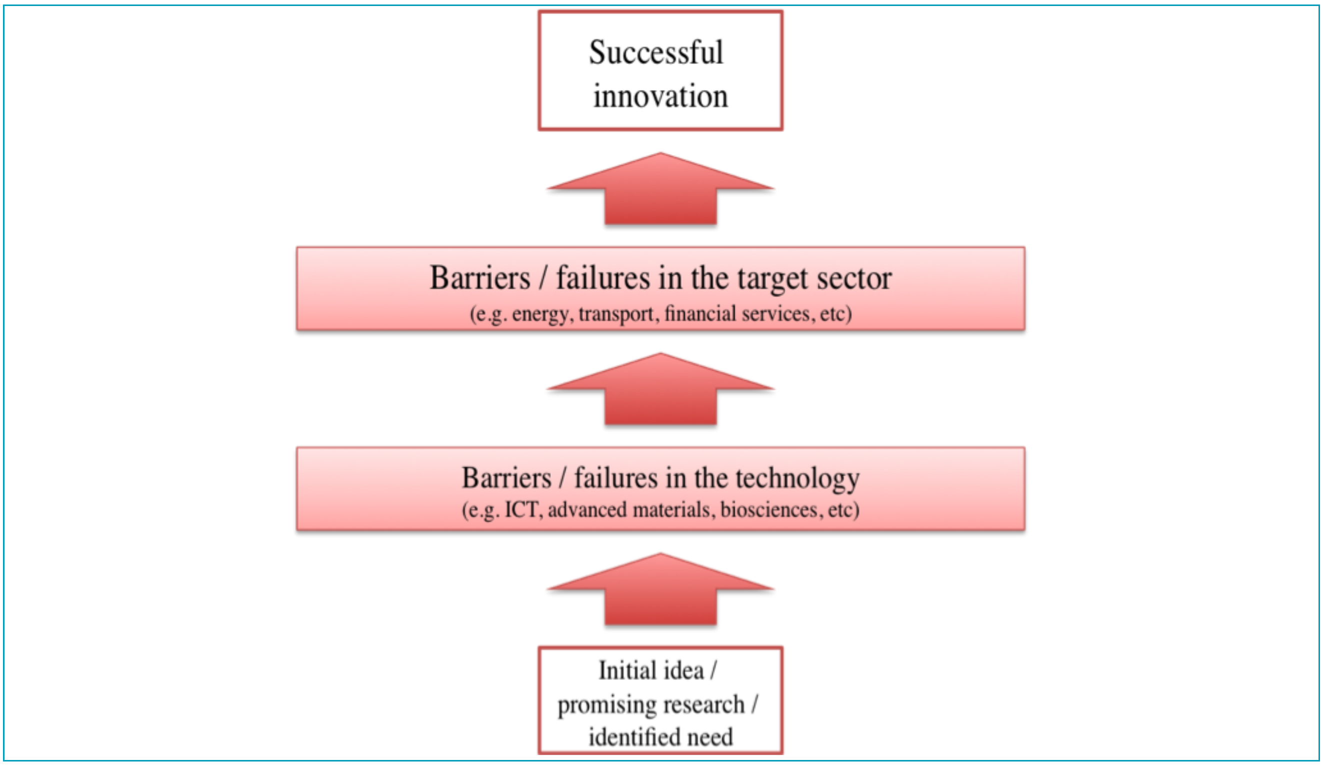


Relationships between different innovation areas

Failures have effects not only on individual technologies or fields but – in cases where technologies are applied across fields – the failures can also be cumulative. In the enabling technologies and many of the ‘8 Great technologies’, the literature frequently notes the various sectors in which general purpose technologies and innovations might be applied. For instance, photonics could find application in any substantive context from operating theatres to supermarkets. Conceptually separating sector-specific innovation areas from technology-specific areas therefore leads to the conclusion that many initial ideas and emerging research strengths must surmount both sector- and technology-specific barriers before successful innovation is possible.

Thus, innovation of photonics products for the health sector will be obstructed by the kinds of barriers noted here in the section on photonics, but will probably also encounter barriers similar to those pointed out in the sample technologies of ‘Health and Care’.

Figure 12 Two sets of innovation barriers



Aside from this additional observation of multiple sets of barriers, there are two additional points worth discussing in some detail, namely credit constraints and skills shortages. Though substantive barriers to innovation, both are problematic in the sense that they can result from several different possible circumstances and can be associated with several of the eight types of innovation barriers considered in this study.

Credit constraints

Two studies in 2013 have focused on analysing issues related to credit constraints for innovation in the UK. The study carried out by the Big Innovation centre[285] consisted on a large-scale survey of SMEs in the UK. The conclusions of this work are that innovative

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[285] Lee N, Sameen H and Martin L (2013) Credit after the crisis. Access to finance for innovative small firms since the recession. Working paper. Big Innovation Centre

firms are more likely to apply for finance for innovation activities and that the gap between SMEs and other firms has widened. However, innovative firms applying for finance are finding it harder to obtain now than before the recession. The study points out that this is due to the general worsening of credit conditions and not due to specific issues affecting the firms.

The London School of Economics report on Growth[286] points out that one of the main failures that causes difficulties for companies to access finance is a generalised short-termism in the capital markets. This short-termism results in underinvestment, especially in long-duration projects and projects with high build or sunk costs, such as infrastructure and high-tech investments. This adds to the general over-reliance on bank finance to constrain growth, especially in innovative SMEs that want to develop long-term strategies or projects with higher private and social returns. The issues of maturity mismatch cut both ways, as bond and debt markets could potentially offer financing instruments with longer time repayment expectations. However, these instruments are skewed towards large businesses and are generally available only for companies with turnovers above £500m.

Our study has covered many different sectors and has analysed the available literature on market and system failures. These failures provide different rationales for the public sector to invest in innovation. As part of the exercise we have also focused on picking up whether specific types of credit constraints were present in all these different areas. Credit constraints are pervasive across many of the sectors that we have analysed but the failures that generate such constraints can be very varied. For example, issues like a general lack of capital for some sectors and lack of access to available capital have fundamentally different sources. In the same way that uncertainty is not a market failure per se but a reason why markets fail, to investigate credit constraints we have to ask why they occur and what people are doing in the different sectors to minimise their impacts.

Great technological challenges are usually affected by neoclassical market failures such as **indivisibility and technological complexity**. Enabling and general-purpose technologies, especially those related to industry, are highly capital-intensive and have long investment return cycles. In this study we have analysed areas such as advanced materials, nanotechnology, electronics, photonics and electrical systems. In such sectors, radical innovations can make the capitalisation on R&D investments more uncertain, which may decrease the amount of capital that is willing to invest. In addition and because of their novelty, these areas require higher-risk, early-stage innovation. The lack of capital makes it hard for entrepreneurs and innovators to develop their ideas to a level of technological readiness that can attract more market oriented funding. The lack of risk capital for stages such as prototyping, testing and scaling up to production volumes or facilities is one of the main reasons why recent policy response in this area is aimed at supporting companies (particularly SMEs) to bridge this ‘valley of death’ in their financing.

Externalities are also one of the reasons why we find credit constraints in some of the areas, causing issues mainly with the availability of sufficient capital. We have observed that, in sectors where there is a large divergence between private and societal returns,

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[286] Besley T, Coelho M and Van Reenen J (2013) Investing for Prosperity. Skills, Infrastructure and Innovation. Report of the LSE Growth Commission. London School of Economics

private investment levels are usually not optimal. Moreover, in sectors where there are substantial first-mover disadvantages -and thus second-mover advantages- there is also a lack of available capital for risky and disruptive innovations.

According to our analysis, credit constraints in the satellites and space sector are mainly a result of first-mover disadvantage externalities. The returns on successful investments are endangered by competitors that are able to free-ride on technological and organisational solutions developed by the first-movers. Difficulty in protecting innovative products for this sector is also mentioned as a secondary failure that has an impact on the available capital. The literature points out that companies react by pooling resources in order to palliate most of these issues. This is interesting and aligns quite well with the fact that, historically, most of the largest space challenges have been addressed thanks to international consortia. Pooling resources is also mentioned as a solution to the excessive financial risks of innovation in the civil aviation sector. Pooled resources imply shared research and innovation projects and, consequently, shared risks and rewards.

For civil aviation other significant barriers that make difficult the access to credit are the low profitability margins (that can be severely affected by oil prices), the heavy up-front investment costs and the long timescales to make a return on the investments. All these factors have been found to be showstoppers for finance providers outside the firms to decide whether the risks in providing finance are worthwhile. On top of that, lack of information on what the best sources of financing are is also mentioned as a secondary factor.

Another one of the sectors that we have studied that is mature, with lower margins and with significant regulation is the food sector, from the agri-sciences to the production and retail of food products. In the case of agri-science, there is also a perceived lack of available funds for innovation, although the available literature does not ensure that there is really a general lack of investment capital. Taking a closer look we see that the main constraints in the agricultural sector come from the fact that farming has become another large-scale capital-intensive sector, although in this case the failures are not due to the size of the scientific or technological problems to tackle. In this case, research and innovation investments in agri-science can be locked into longer investment return cycles than the actors further down the supply chain are willing to tolerate (from the varying requirements of food manufacturers to the changing consumer preferences). These issues discourage private capital from investing in innovation in this sector. Proposed solutions identified in the literature seem to go in the direction of reducing market power failures across the supply chains and improving the public image and visibility of the sector. For the rest of the value chain, including manufacturers and retailers of food products, there is overall enough funding to finance current operations, although issues with access to finance have been pointed out. According to recent studies, these issues are mainly related to unrealistic expectations on the supply side (banks and other lenders) and a difficulty to finance capital expenditures for commercially available new technologies, including scaling up and turnkey solutions. Informational asymmetries have been mentioned as another secondary failure that makes difficult the access to capital in this sector.

Going back to externalities there are other sectors where these have an effect on the availability and access to finance. For example, in the stratified medicine sector **externalities** prevent the full appropriation of investment returns. Pharmaceutical companies may lack incentives to invest in diagnostics that could potentially reduce their markets. In addition, the traditional business model for drug manufacturers evolves from one of high-risk research with strong IP protection to a diagnostic research model with lower margins, platform based and with an assumption of high volumes. Another case of externalities is the built environment sector, which is affected by split incentives, where the investors pay upfront costs for the technology but are not the same actors keeping the benefits. Finally, financing difficulties due to externalities have been also found in the creative industries. Arts produce value that can be measured by economists, but their cultural value cannot usually be expressed in monetary units. Firms in the creative industries have difficulties raising capital due to the private sector failing to grasp the value of arts, including preservation of cultural heritage. In addition, valuation of intellectual property and content assets in this area is considered to be high-risk.

Information asymmetries can cause issues regarding access to finance and, although the end problem is the same, the situation that originates it is different depending on whether the supply or demand side is the party with less/worse information. On the demand side, innovative companies may not know which actors are relevant to approach in order to obtain financing for innovation In addition, they may not know how to best communicate the potential value of their innovations to possible investors or lenders. On the supply side, banks and other business-lending actors (venture capital, business angels, etc.) may not know how to best calculate the potential return on investment of some innovations. In addition, credit suppliers can have an exaggerated risk-aversion due to not understanding some of the more complex technological developments. In many cases this does not outright impede access to capital but it can increase its cost to levels that are generally outside of the reach of innovative SMEs and start-ups.

Credit constraints in the design industries are often caused by information asymmetries. In the case of design the supply side of capital usually does not have the necessary expertise to analyse business models in these sectors and as a result there is not an adequate valuation of their intangible assets. Compare that to the information failures noted in newer, more technological sectors like regenerative medicine. In this case, what hinders investment is a lack of track record and evidence of what kind of developments might be profitable.

In other sectors such as stratified or personalised medicine there is a low level of investment derived from the fact that it is difficult to identify the combination of tests, IT and operational systems that can achieve cost efficiencies. There is also uncertainty about future revenue streams, which are compounded by the single pricing model for treatments. As a result, in this case the lack of financing is caused by an information asymmetry, which may in turn be created by a price fixing that impedes the market to transfer information between parties.

Finally, in the area of robotics and autonomous systems, the available literature states a need for seed capital to adopt these solutions in the workplace although there is no indication as to the reason for this. Many of the solutions in this area are already well tested and in some cases it is a matter of adopting and tailoring solutions that are already in use in other higher technology sectors. As a result, one likely explanation for this lack of capital would be that of an information asymmetry whereby companies are not able to put forward the case for such investments and clearly communicate the productive benefits that these improvements might bring to their processes. However, this should be further investigated as, were it be true, it could be a source of quick productivity gains for many companies.

Network failures as a source of credit constraints have only been noticed in the assisted living sector and information on the possible causes is scarce. However, such network failures may also arise in other healthcare sub-areas, where the procurement processes are known to be complex. When the users of innovations are not the people paying for them and there are contradicting requirements or incentives these lock-in failures are bound to have a negative impact on the confidence of investors trying to enter the space.

Finally we also observe **institutional failures** causing credit constraints for some other areas. These usually come about because rules and regulations are not conductive to a good investment climate for innovation in a specific sector. For example, in the oil and gas energy sector we find issues related to high decommissioning costs, required performance bonds and tax relief issues. On the other hand, for the renewable energy and the low-carbon vehicle manufacturing sector, investor uncertainties are more related to policy uncertainties ahead of new announcements regarding climate change and emissions targets, which are an issue especially when there are long payback periods involved (and in the case of the automotive sector, to the tighter margins involved). Investment in technologies related to the built environment is also very sensitive to regulatory uncertainties. For a sector such as synthetic biology in the biosciences area, capital requirements to finance the start-up phase of companies from the point of view of the technology itself can be manageable. However, in this case the capital constraints are more likely to be found when trying to access finance to ensure compliance with regulations and to adequately protect intellectual property. According to our findings, capital to finance these added costs turns out to be more difficult to find than funding for the technological development itself. Finally, a sector that presents an interesting institutional failure hindering investment is the intelligent transport sector. In this case, we have noted that a need for clarification on matters of liability may be preventing enough capital of entering this space.

So far, we have discussed how credit constraints manifest across the different areas but there are also interesting things to note at an overall level. When analysing all the sectors in aggregate we can observe how sectors are not isolated ‘islands’ of activity, but compete with each other for limited pools of available skills and capital for innovation. We have thus identified cases where one sector exerts its **market power** above another, less-favoured sector. This means that innovations that are key for some sectors may not be materialised due to capital going to other sectors that are overall more attractive because they either have higher margins (i.e. capital going to the biotech and pharma sectors instead of the food sector) or they have a more clear and favourable risk-return profile (i.e. clean tech, as opposed to nanotechnology or advanced materials). Finally, investment trends and “buzz topics” also play a part in contributing to a suboptimal allocation of capital for innovation across the different sectors.

Skills shortages

The costs of education and training, including the training of new scientists, are only partially captured by the private sector and public investment remains highly important. Many of the areas that we have considered exhibit capability failures that usually point to skill shortages, especially of more technically oriented or STEM graduates. This recurring topic is worth of a closer look across the areas. As a result, this section aims to pick up whether these concerns are generally put forward in a vague form or whether there are essential differences in the way skills shortages manifest across the sectors and on whether specific issues are to blame for the skills shortages.

In the credit constraints section we have commented on the fact that sectors compete amongst themselves for limited pools of capital and for skills this is even truer. On the skills side many well-worn stories are told about physics, maths and computer science PhDs going to work for the financial sector in order to make fortunes. Although these stories may look anecdotal, the fact is that this rerouting of skills in limited supply, result of macroeconomic conditions and relative performance of different sectors has an impact on the pace at which key (and often more traditional) sectors are able to hire and have access to the necessary skills to innovate.

For example, in energy there is a more apparent lack of skills in the traditional sectors (such as oil, gas and nuclear) than in the renewable energy sector. In these traditional sectors the skilled workforce may require a longer time to reach maturity and is vulnerable to high turnover rates and obsolescence, requiring constant investment even when companies are finding it difficult to turn a profit. In the case of the oil and gas sector these skills shortages are reported to be more severe in project management, senior managerial and specialist engineering positions.

For sectors such as the built environment (also concerning the development of future cities) the present lack of skills is not situated at the level of the people developing the technology. Skills shortages are on one hand in the lack of trained professionals to work with these new solutions (from builders to suppliers, these collectives bear the reputational risks of poor quality implementations) and on the other hand in the lack of knowledge of elected representatives tasked with legislating or making policy around these developments (i.e. mayors).

In agri-science the lack of scientists in applied fields can be partly attributed to the competition for skills from other sectors and due to the lack of public visibility as an innovative sector. Agri-sciences are characterised by a severe breakdown of the link between basic research and appropriate development due to a breakdown in the level of expertise between scientists doing basic science and farmers. In the food sector, companies generally have access to sufficient skills for creative positions (sales, marketing), but struggle to find suitable candidates for engineering and science positions. Although we have found no definitive evidence, a likely explanation could be a loss to more competitive compensation in other sectors. In this case the lack of skills has also been attributed to the industry’s out-dated image, which discourages students to pursue careers in the food and drinks industry.

For the civil aviation industry, the shortage is not only at the level of skilled engineers but also at the entry-level, which is attributed to the lack of traineeships in this sector and credit constraints that prevent companies to invest in training.

An interesting issue with the shortage of skills in the creative industries (including design) is that the skills shortage refers mainly to the lack of entrepreneurial training, combined with a lack of technical skills in Internet-related areas, more concretely in digital content creation tools.

In the financial sector, access to skills is usually not a problem due to the average high compensation of this sector compared to the others. However, the financial sector has become highly specialised, which can limit the availability of some profiles. In addition, this deep specialism can make it difficult for non-specialists to challenge the experts and to source new talent with new ideas. This very high degree of needed specialisation is also mentioned in the automotive manufacturing sector. The maturity of the sector requires a very high degree of specialisation if one is to contribute in any way to the advancement of the current state of the art (e.g. combustion engines), which difficult the task of sourcing talent that can meet the expectations of companies.

A generalised lack of skills has been noted in areas such as nanotechnology and advanced materials. In this case it not only affects expert engineers but also staff at the manufacturing level. One of the main reasons for this shortage has been attributed to industry outsourcing and offshoring and to the efforts of emerging economies to catch up with Western economies in education levels. The ability to train people with adequate profiles for these cross-disciplinary fields is an on-going challenge that also manifests itself in industrial biotechnology and sub-areas of ICT (such as big data and cyber security). In the big data field, we also find the issue of insufficient ‘practitioners’ within companies, in contrast to other sectors where the shortage is more prominent in the research and development of new solutions. A similar issue is pointed out for robotics and autonomous systems, where the skills shortage occurs mainly in SMEs without people that can adopt these solutions in the workplace.

In regenerative medicine, a qualitative study for BIS highlighted shortages not only in engineers, but also in trained support staff, Good Manufacturing Practice (GMP) production staff and Qualified Persons (QPs) to deliver products effectively. Overall, it was felt that the number of staff (both clinical and non-clinical) with the necessary core skills and knowledge to deliver regenerative therapies was limited.

Finally, for the remaining areas such as the synthetic biology and the satellites and space sectors we have unclear or contradicting statements regarding skills shortages. In the electronics, photonics and electrical systems these contradicting statements seem to be caused by a significant lack of coordination and communication between the academic sector and commercial research in this sector. As a result, these sectors should be investigated more deeply with a focus on skills shortages in order to be able to derive better conclusions about them.

Conclusions

The main purpose of this report is to map the occurrence of market and innovation system failures across a number of technologies and business areas. To this end we have reviewed available literature about the sources of failure as well as about the 24 innovation areas selected for investigation. The literature review led us to differentiate among 8 types of failure, for which we then searched in literature about the innovation areas.

- Market failure – the idea of market failure that focuses on research on the argument that indivisibility, complexity and uncertainty prevent the private sector from making the optimal level of investment in research
- Market failure – market power, where this prevents potential innovators from making adequate return on investment and hence suppresses the rate of innovation
- Market failure – externalities, where innovators' inability to appropriate all the benefits of their innovations reduces returns and leads to under-investment
- Market failure – information asymmetry, where actors optimise locally based on what they know rather than all the available information, leading to outcomes that are sub-optimal compared with the theoretical model of perfect information
- Systems failure – capability failure, where individual firms lack some of the capabilities they need to perform well or at the level of efficiency that economic theory would expect
- Systems failure – network failure, where too tight links among actors tends to cause lock-in or where insufficient links lead to under-coordination among actors
- Systems failure – institutional failure, where hard or soft institutions fail to meet the needs of innovators and therefore depress the rate of innovation; this includes some kinds of government failure
- Systems failure – infrastructural, where needs for policy interventions in the innovation system are inadequately met

We found most of the failures were present in most of the innovation areas we studied. The failure patterns appear to be rather specific to the individual innovation areas, so there were fewer trends than we expected. In many cases failures in technology and application areas risked exacerbating each other. Innovations had to 'run the gauntlet' of technology-related failures only then to be confronted by a new set of failures in applications.

Failures were less important in digital services than elsewhere, perhaps reflecting the facts that these operate within networks whose characteristics have been externally negotiated. (To take an extreme example, App writers can rely on a set of standards and an installed base of whatever 'platform' they choose to exploit. Within this 'safe' world, their imagination can then run free.)

Sectors where the state has been heavily involved are interesting because many of them involve large and complex technical systems (e.g. in transport). One would expect these to involve rigidities and they do indeed involve a large proportion of show stopping failures, but the variety of failure is still rather large. Only some of these are to do with scale.

Infrastructural and network failures are more associated with industries than technologies, probably reflecting the social, multi-actor character of systems of innovation. Skill shortages are a particularly important type of infrastructural failure. In terms of the frequency with which they appear and the severity with which they manifest themselves, infrastructural and externalities failures need to have a fair degree of policy priority. Together with the market failure that leads to under-investment in research, these are in fact traditional areas of state intervention.

Credit constraints did not strongly manifest themselves as failures, but rather as results of other failures. Bankers do not like uncertainty or even risk, so much of the difficulty firms (especially smaller firms) experience in borrowing money is ‘business as usual’. In bad times, bankers become even more averse to risk. While it can be argued that information asymmetry is a cause of credit constraint (because firms ought to know better than bankers what specific risks and uncertainties they face), it is of course also the case that firms’ views are liable to be as optimistic as those of the bankers are pessimistic.

The major surprise from the study is the apparently low importance of traditional research-related market failure and the correspondingly high importance of network and infrastructural failure. As discussed, the small role given to research-related failure may be an artefact of our method – focusing on markets makes ‘pre-market’ activities (related to more fundamental research or with infrequent, large changes in technological system) less visible than other failures. In the innovation systems view, network and infrastructural failures would be those that undermine the interconnectedness of the system – which is seen as one of the most important properties of innovation systems. There is a risk that the change of theoretical perspective also entails a shift in perception: if we use innovation system spectacles we see systemic kinds of failures. It may be that (through the pervasiveness of digital and other large technical systems) the world in which we innovate has objectively become more systemic. The cautious policy prescription would be to ensure that policy does indeed take account of the need for interconnectedness in the system, but not to treat this study as in any way undermining the need for research.

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