Department for Business, Energy & Industrial Strategy

NON-MARKET IMPACTS OF INVESTMENT IN RESEARCH AND DEVELOPMENT

BEIS Research Paper

Contents

1. Executive summary

This report summarises the existing evidence on non-market impacts arising from investment in technology-related research and development (R&D). The aims are to help better understand: (i) the non-market impacts likely to arise from such investment; (ii) the strength of underlying evidence relating to these; and (iii) how they might vary by technology or science area.

Non-market impacts refer to outcomes, goods or services that are not directly exchanged or transacted within a market. Given that non-market impacts are not transacted within a market, no *market prices* are directly observed for the outcome / good / service, accordingly, the price / size / value of the non-market impact is usually estimated or predicted. However, evidence shows that these non-market impacts can be of material value. Consequently, by not factoring non-market impacts into decisions, one risks making sub-optimal choices as the benefits / costs of an investment option are not being considered in full. For example, investments may not be made because they do not appear worthwhile – but once non-market impacts are taken into account they are worthwhile.

Following from the above, BEIS commissioned Economic Insight to undertake a literature review of non-market impacts. The primary goal of this has been to develop typologies of non-market impacts; and to understand how non-market impacts might vary by technology area. Our findings are as follows:

- **Non-market impacts are generally found to be highly relevant to the technology areas considered within the scope of our work.** Consequently, this reinforces the need for relevant stakeholders to consider (and where possible evaluate) them within decision-making.

- **The relevant literature base identifies a broad spread of potential non-market impact types** (some 35 types, split across 7 higher-level non-market impact categories).

- **The literature base from which we have identified non-market impacts is of good quality.** We find that, based on a scoring scale out of 6, the papers we reviewed scored 3.7 out of 6 in terms of robustness; and 4.1 out of 6 in terms of relevance. In identifying non-market impacts, we further applied a threshold such that papers that scored below 3 on the *robustness* criteria were not included in our analysis. As such, we are confident that the non-market impacts identified in our work are credible.

- **The prevalence of specific types of non-market impact varies considerably across individual technology areas.** This is an important piece of evidence for stakeholders, as it can be used to help inform: (i) *where* and *when* they should consider non-market impacts; and (ii) *what* those non-market impacts are likely to be.

2. Project objectives and context

As part of its Industrial Strategy, the UK is set to increase its investments in R&D to equal 2.4% by 2027. Additionally, it has set 'Grand Challenges' for the UK to be at the forefront of the industries of the future, which are: (a) AI & Data Economy; (b) Clean Growth; (c) Future of Mobility; and (d) Ageing Society.[1]   To ensure that the optimal investment choices are made, non-market impacts need to be understood.

Project objectives and scope

Economic Insight was commissioned by the Department for Business, Energy and Industrial Strategy (BEIS), to undertake a literature review relating to the potential **non-market impacts** resulting from investment in R&D in innovation, technology and science. The two main objectives of the study were as follows.

- To identify the key 'types' of non-market impacts associated with investment in technology and innovation related R&D.

- To provide some assessment of how these impacts vary across key technology / science areas (including in relation to their prevalence).

The science areas and example technologies / studies included in the scope of our work are:

- Agriculture
  - Crop sensors.

- Arts and humanities
  - Studies on the impacts of art consumption on the society.

- Clean and flexible energy
  - Energy efficient technologies.

- Digital
  - Collaborative communication platforms.

- Healthcare and medicine
  - Telehealth.

- Manufacturing materials and construction
  - Nano-technology.

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[1] 'Industrial Strategy White Paper: Building a Britain fit for the future', HM Government (2017).

- Robotics and Artificial Intelligence;
    - Surgical robotics.

- Satellites and space technology
    - Earth Observation.

- Social sciences
    - Studies on the drivers of societal wellbeing.

- Transport and driverless vehicles
    - Ultrasonic sensors

Key context to our work

The key context to our work is as follows:

- The UK Government's Industrial Strategy is set to increase R&D investment as a percentage of GDP.

- Data shows that the UK has under-invested in research and innovation historically, relative to other OECD countries.

- It is possible that this underinvestment may (in-part) be due to a lack of understanding of non-market impacts, relating to R&D across science and technology areas.

- Whilst there is existing evidence relating to the non-market impacts that arise from investing in R&D in science and technology, to date this has not been systematically brought together.

Therefore, the aim of this study is to develop a resource that provides a comprehensive summary of potential non-market impacts arising from R&D related investment. Further relevant background context to this study can be found in Annex A.

Defining non-market impacts and their role in investment appraisal

There is no single agreed definition of non-market impacts. However, there is a board consensus as to the key *elements* that constitute a non-market impact, as reflected in both the HM Treasury Green Book[2] and OECD research.[3] For our purposes, we define non-market impacts as follows:

A non-market impact relates to an outcome, good or service, that is not directly exchanged or transacted within a market. Consequently, no market prices for the outcome / good / service can typically be observed. Non-market impacts arise because of differences between: (i) the private costs and benefits incurred or enjoyed by the firms or customers that produce / consume products and services; and (ii) broader (e.g. social) costs and benefits, which also arise from production and consumption. Importantly, these 'social' costs and benefits are, by definition, not taken into account in private firm / consumer decision-making.

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[2] 'The Green Book: Appraisal and Evaluation in Central Government.' HM Treasury (2011). See Annex 2, 'Valuing Non-market Impacts.'

[3] The OECD has variously defined non-market impacts, including as follows: "Non-market services are those which are provided free or at prices which are not economically significant (i.e., prices which will not significantly affect the amounts that producers are willing to supply or the amounts purchasers wish to buy." See 'Productivity measurement for non-market services.' OECD (1997)

Taking non-market impacts into account in investment decisions

Non-market impacts matter because research shows that they can be of material value.[4] This means that an understanding (and assessment) of non-market impacts can be vital to the robust design and evaluation of policy options, and investment decisions. Without taking non-market impacts into account, one risks making sub-optimal choices. This raises the question of *how* one might best reflect non-market impacts when faced with policy and / or investment decisions.

In our view, there are three steps that one should ideally take, as described below and summarised in the following figure:

- **Step 1: Identify.** When undertaking investment appraisal (particularly in a policy setting context) one should consider what non-market impacts might arise, and why.

- **Step 2: Qualitative assessment.** Where potential non-market impacts are identified, they should be assessed qualitatively within the decision-making process. For example, by drawing on existing evidence in the literature to gauge 'how material' they might be.

- **Step 3: Quantify the non-market impact.** 'Quantify' the relevant non-market impacts; and explicitly include them within the relevant investment / policy decision.

Figure 1: Three steps in considering non-market impacts

Source: Economic Insight

This study is primarily of relevance to Step 1, in that it provides a resource that: (a) identifies a spectrum of non-market impacts relating to R&D; (b) considers the robustness of the evidence relating to those non-market impacts; and (c) assesses how these vary by technology / science area. Consequently, one can think of it as a helpful 'starting point' that can be used as a reference for those engaged in policy or investment evaluation.

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[4] For example, the IPCC's Second Assessment Report concluded that non-market impacts accounted for between 30% to 80% of the impact of climate change. See: 'Estimating Non-Market Impacts of Climate Change and Climate Policy.' Dale S. Rothman, Bas Amelung and Philippe Polomé; OECD (2003).

Step 3 (quantitatively valuing non-market impacts) is not within the scope of our work. Indeed, the valuation of non-market impacts is a highly complex area and typically requires the collection of primary data and evidence (and so, cannot be achieved through a literature review). Given the importance and relevance of this topic, however, the following sub-section provides a high-level overview of the key valuation techniques.

The principles of valuing non-market impacts

There is a considerable literature base setting out best-practice approaches to the valuation of non-market impacts. This includes the HM Treasury's Green Book[5], which provides guidelines as to the appropriate methodologies that should be used for evaluating non-market impacts. These include the following:

- **Stated preference research.** Under this approach, relevant stakeholders are asked to state their willingness to pay (WTP) for the non-market outcome in question; or their willingness to accept (WTA) a 'reduction' in the non-market outcome in question.

- **Revealed preference techniques.** These refer to methods that allow one to 'infer' the value stakeholders attach to the non-market outcome by observing their behaviour (as above, this could be WTP or WTA). Prominent examples of this include hedonic pricing and travel cost methods.

  – Under **hedonic pricing methods,** the value of the non-market impact is inferred from an analysis of other assets, goods or services, which may be impacted by the non-market good / service in question. For example, if the asset is houses, one might consider the various individual attributes which, collectively, *determine the value of house* – one of which may be the non-market good of interest, say. One then collects data regarding house prices by location and / or over time, along with data for the other underlying factors that influence house prices. In turn, statistical techniques can then be applied to 'isolate' the impact of the non-market good / service on house prices – which, ultimately, gives an implied value of the non-market good or service.[6]

  – Under the **travel cost method,** the value of non-market goods or services is inferred from the *distances* people will travel in order to 'consume' the non-market good / service in question. Here, values are inferred based on the 'costs' incurred in travelling – taking into account, for example, direct travel costs, but also the time spent travelling.[7] For example, in the water industry, the value of clean beaches is sometimes estimated using this method.

- **Experimental economics** is an approach that 'bridges' the gap between stated and revealed preference techniques. Here, the principle is that values are inferred from observing consumer / stakeholder behaviour (as per revealed preference).

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[5] 'The Green Book: Appraisal and Evaluation in Central Government.' HM Treasury (2011). See Annex 2, 'Valuing Non-market Impacts.'
[6] For further information see 'Hedonic Pricing of Agriculture and Forestry Externalities' La Goffe; Environmental and Resource Economics (2000).
[7] For further information see: 'Combining Contingent Valuation and Travel Cost Data for the Valuation of Nonmarket Goods.' Cameron; Land Economics (1992).

However, rather than observing behaviours 'in the real world', experimental economics refers to where one 'creates' a choice framework and setting for participants – and then observes decision-making in that setting.[8]

- **Benefits transfer** refers to inferring the value of a non-market good or service from previous studies or evidence. The validity of this clearly depends on the robustness of the existing research and the similarity of both the non-market good / service in question to the one of interest – but also the similarity of the 'setting' and 'context' in which the valuation occurred.

These are referred to as 'market based' approaches to valuing non-market impacts. This is because they are attempting to derive the value of the non-market good / service by estimating *how* it would be valued in a market setting. The advantage of the above approaches is that they are *conceptually consistent,* allowing comparisons to be made to 'scale' the likely order of magnitude of non-market impacts. In practice, however, at a detailed level there can be considerable variation in how the techniques are applied; and / or the timescales over which impacts are appraised. Consequently, it is rare that any two estimates of non-market goods / services are directly comparable. As a result, care must be taken in how the results of existing studies are interpreted.

There are alternatives to the above, such as subjective well-being or 'welfare' approaches, which have received considerable attention in recent years. One example of this is the life satisfaction approach – which is based on deriving values for non-market goods / services / outcomes based on 'how satisfied' people say they are with their lives (e.g. the ONS Integrated Household Survey). However, at present it is generally accepted that these techniques are not yet suitable for valuing non-market impacts. Indeed, this is consistent with the Green Book, which explicitly states that such methods are *"not sufficiently accepted as robust enough for direct use in Social Cost Benefit Analysis."* [9]

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[8] For more information see: 'Using Choice Experiments for Non-Market Valuation.' Alpizar, Carlsson and Martinsson. Göteborg University (2001).

[9] 'The Green Book: Appraisal and Evaluation in Central Government.' HM Treasury (2011). See Annex 2, 'Valuing Non-market Impacts'; page 58.

3. Overview of our method and literature analysis

In this chapter, we provide a brief overview of the method we used to identify and review the literature. More detailed information regarding these issues is contained in the annexes to this report. We provide specific cross-references where appropriate.

Method summary

A full description of our methodology is provided in Annex B. However, in summary, our approach consisted of four main elements, as summarised in the figure below.

Figure 2: Four key stages of our approach
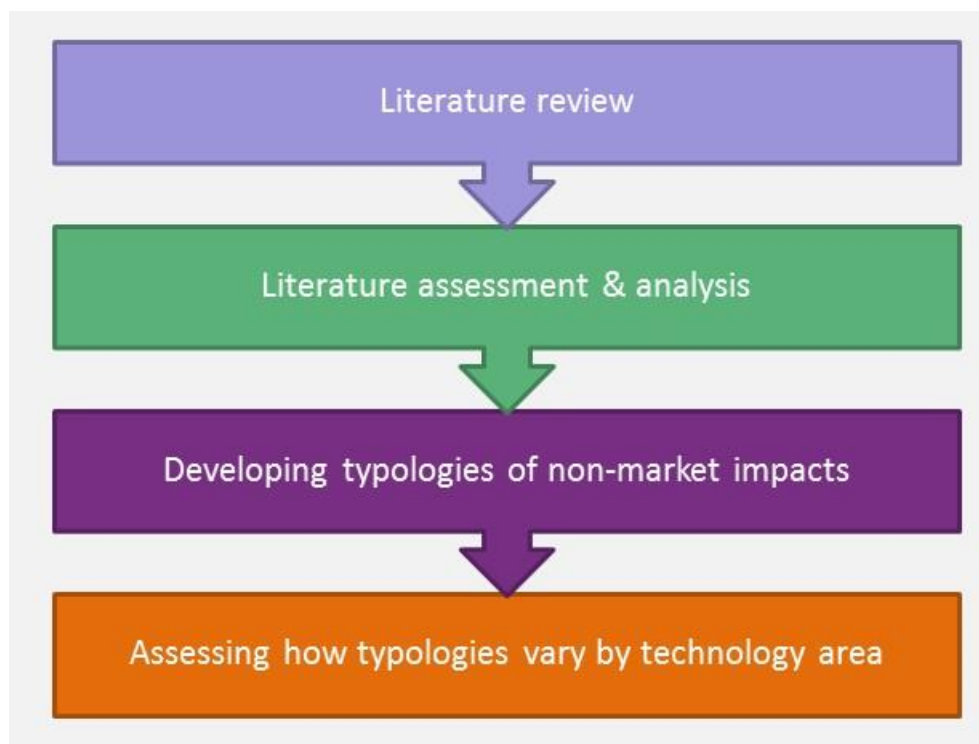
Source: Economic Insight

When conducting a review of the literature, we deployed six different search strategies to identify the papers, which were: 1) research by keyword; 2) research by technology area; 3) research by academics; 4) research by research council/department; 5) typology-driven research; and 6) follow through reference/citation. These search strategies are further explained in Annex B. In total, 94 papers were identified, which were analysed by type; methodology; technology / science area; and publication year – as is further detailed in Annex C.

To ensure the typologies we developed were robust, it was important to assess the 'quality' of the literature. To do this, we agreed a set of evaluation criteria with BEIS

grouped by 'robustness' and 'relevance'. Furthermore, we agreed with BEIS's steering group that the threshold applied to determine which papers will be included in our analysis will be based on the 'robustness' score in isolation of the 'relevance score'. Each paper was scored a: 0; 1; or 2 against each individual criterion. The criteria and scoring benchmarks are shown in the following table (full definitions of each criterion are contained in Annex B).

Table 1: Evaluation criteria

	Characteristic / score	0	1	2
Robustness	**Research method**	Purely conceptual.	Simple empirics / case studies.	Detailed empirics / case studies.
	Type of author/paper	Working paper / consultancy.	Research / other type of institution.	Peer-reviewed academic journal article.
	Objectivity	Direct influence on public policy / funding.	Indirect influence on public policy / funding.	No observed intended influence.
Relevance	**Relevance to technology areas**	Tangentially relevant to technology areas.	Somewhat relevant to technology areas.	Very relevant to technology areas.
	Relevance to UK research	Tangentially relevant to UK research.	Somewhat relevant to UK research.	Highly relevant to UK research.
	Recency	Before 2000.	2000-2009.	2010 onwards.

Source: Economic Insight

4. Typologies of non-market impacts of research and development

This chapter provides a description and analysis of the typologies we developed as an output of our literature review. Here, as described in our methodology (see Annex B), our process was to (i) develop a 'long-list' of typologies; and then (ii) to use our scoring criteria to reduce these down to a shorter list of specific non-market impacts most relevant to the technology areas of interest.

Long-list of typologies and key categories

As set out previously, we define non-market impacts as: *"an outcome, good or service, that is not directly exchanged or transacted within a market. Consequently, no market prices for the outcome / good / service can typically be observed."*

Using this definition, our starting point was to log every instance of non-market impacts referenced in the literature, so as to ensure we had a comprehensive record. In doing this, we identified both: (i) a range of high-level **categories** of non-market impacts, which tended to reoccur across the literature; and (ii) more **specific types** of non-market impacts, within these categories.

So, for example, one key non-market impact category we identified was 'health', which refers to the overall physical and mental health of citizens. However, within this, we also found various more specific types of impact – for example, including: increased life expectancy, or increased quality of life – and so on. In the following table, we present the comprehensive list of non-market impacts that we identified in the literature.

Table 2: Long-list of non-market impacts

High level non-market impact categories	Specific, more detailed non-market impacts
Health. Refers broadly to the physical and mental health of citizens. Clearly some health outcomes, goods and services are 'market' in nature, as demonstrated by the existence of private healthcare provision. However, equally there are many examples of non-market related health goods and services – such as the spillover benefits of vaccinations, for example.[10]	- Life expectancy rates. - Quality of life. - Mental health (e.g. reduced stress level and lower suicidal rates). - New treatments (e.g. for neglected diseases). - Access to healthcare (e.g. for the elderly). - Quality of healthcare.

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[10] See 'An Integrated Epidemiological and Economic Analysis of Vaccination against Highly Pathogenic Porcine Reproductive and Respiratory Syndrome (PRRS) in Thua Thien Hue Province, Vietnam.' Zhang, Kono and Kubota (2014).

High level non-market impact categories	Specific, more detailed non-market impacts
Environment. Refers broadly to the physical and natural world in which we live, the 'intrinsic' value of which is non-market in nature.	• Climate change mitigation. • Air quality. • Water quality. • Protection of natural resources. • Sustainability. • Sea pollution. • Land, forestry and physical environment.
Safety and security. We define this in terms of safeguarding people, property and freedoms. In economics, the provision of services and goods relating to this are typically classified as 'public goods' and so are non-market in nature. By this we mean: (a) the good is non-rivalrous, so that the 'consumption' or use of it by one individual does not lessen the amount available to another; and (b) the good is non-excludable (i.e. one cannot make it available to one individual without making it available to all). The provision of national defence is a frequently cited example to demonstrate the non-market nature of safety and security.[11]	• Crime (safety of citizens and communities). • Worker safety. • Travel safety. • National security. • Food security. • Energy security.
Society. This typically refers to measures of the overall functioning of society, which consist of both how engaged and informed citizens are (say, allowing them to partake in a democratic process, for example); but also measures of inclusiveness and cohesion.	• Informed citizens. • Engaged / empowered citizens. • Social inclusion and cohesion. • Social capital, which refers to the shared knowledge and understandings in a society. • Social participation.
Equity. Refers to the 'fairness' of the distribution of outcomes (e.g. income, health etc) among individuals. Here, in principle, competitive markets result in an efficient allocation of society's resources, reflecting the underling preferences of consumers and costs of production. However, markets do not value other concepts of equality, which might also be considered beneficial. Consequently, these are inherently 'non-market'.	• Income / wealth equality. • Poverty. • Gender equality. • Health equality. • Equality of access to services.

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[11] For example, see 'Why Does Government Produce National Defense?' Holcombe; Pubic Choice (2008).

High level non-market impact categories	Specific, more detailed non-market impacts
Subjective Wellbeing. Refers to the subjective wellbeing, including happiness of individuals. Wellbeing might be 'indirectly' captured in market prices for goods and services, if it is closely correlated with consumer preferences (which, in turn, determine demand). However, any *intrinsic* happiness or wellbeing of citizens or society unrelated to consumption is non-market. In fact, it is for this reasons that the 'measurement' of wellbeing has itself become a tool *for* attempting to assess the overall value of non-market goods, services and outcomes.[12]	• Consumer wellbeing. • Worker wellbeing, which refers to the wellbeing and safety of the individual while at work / performing their jobs. • Social wellbeing, which refers to the enhancement of social connections and networks between citizens of a society. • Happiness.
Economy. This refers to non-market outcomes, goods or services that affect broader economic performance. Most frequent examples cited in the literature relate to how investment in innovation / R&D can: (i) create spillovers that increase the efficiency of producing goods and services in other markets; (ii) affect the allocation of time and resource (e.g. between household and work production)[13]; and (iii) impact market power of firms, so impacting the distribution of welfare across society.	• Market power and distribution of welfare. • Efficiency of public service provision. • Time spent in household production.

Source: Economic Insight

Prevalence of non-market impacts in the literature

Overall prevalence of non-market impacts

We examined the overall 'prevalence' of the identified non-market impacts across the literature. To do this, we applied a threshold to ensure we only analysed non-market impacts based on papers we considered robust. In particular, we excluded papers with a score below 3 out of 6 on our robustness measure.[14] This cut the number of papers from

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[12] For example, see: 'Valuing non-market goods: Does subjective well-being offer a viable alternative to contingent valuation?' Dolan and Peasgood; Imperial College London (2006).

[13] For example, the creation of the internet is often cited as the most significant innovation driven non-market impact to affect economy – as it has led to efficiency and productivity gains across multiple industries. Similarly, the literature relating to autonomous cars discusses the broader efficiency spillover gains from their development.

[14] We recognise that the choice of any quality threshold is somewhat arbitrary. We therefore tested a number of alternative cut-off points and considered a score of 3 out of 6 struck an appropriate balance between 'filtering out' lower quality papers; whilst still preserving a sufficiently sized evidence base for analysis.

94 to 78. Within these papers, we identified 71 references to our non-market impact categories (some papers were more general and did not reference one of our specific non-market impacts, and some papers referenced more than one). The following figure shows the breakdown of the 71 references by category.

Key points to note regarding prevalence are as follows:

- Health is the non-market impact category that features most often in the literature, accounting for 24% of references.

- The environment and economy are next most prevalent categories, each with 17% - followed by safety and security (15%).

- Equity and subjective wellbeing have the lowest levels of prevalence at 4% and 8% respectively.

Annex D provides further information on prevalence by 'non-market impact type' at a more disaggregated level.

Figure 3: Overall prevalence of non-market impacts at the category level
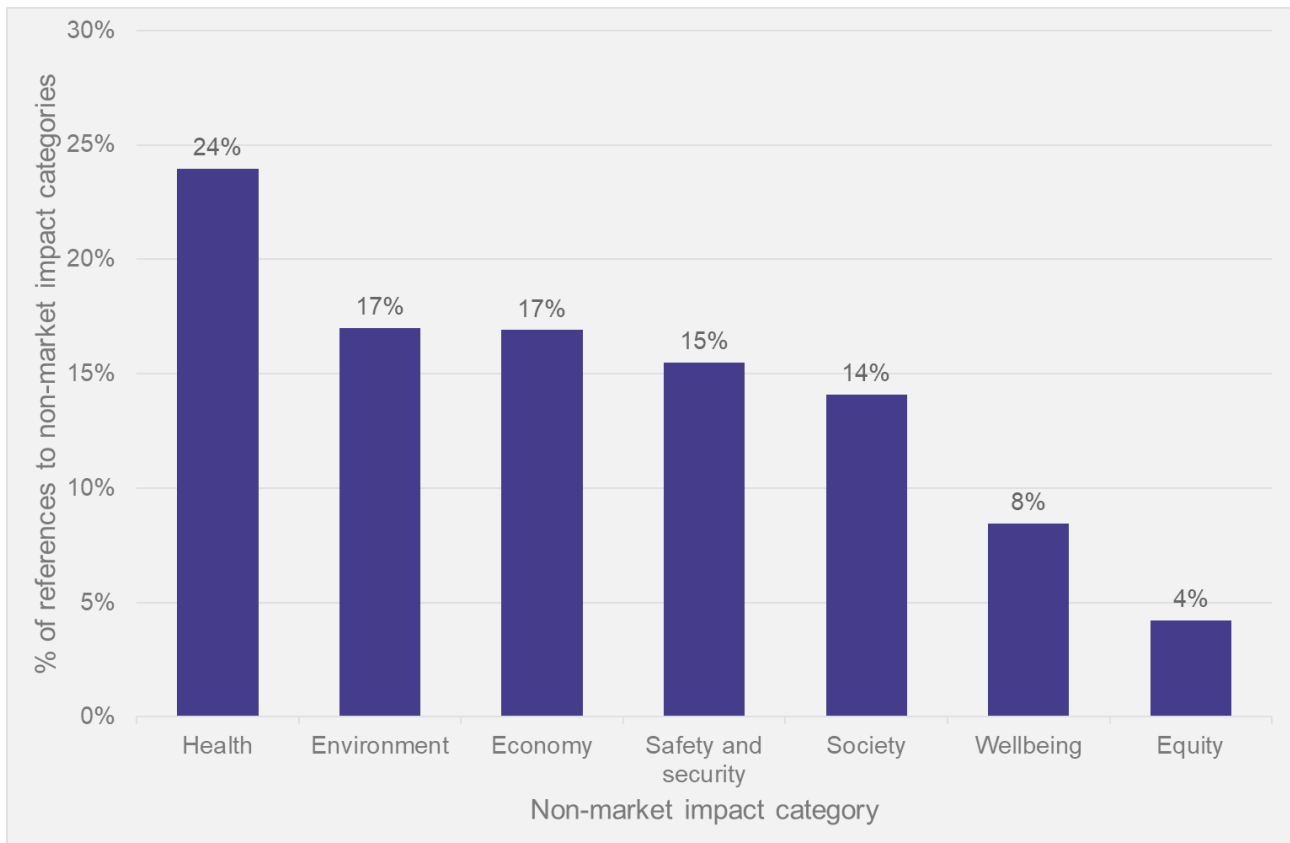
Source: Economic Insight

Prevalence by technology and science area

We have also analysed how the prevalence of non-market impacts varies within the literature by technology area, as is illustrated in the following figure. This analysis is based on the 59 references that could be assigned directly to a technology area (the robustness threshold has also been applied).

Figure 4: Overall prevalence of non-market impacts by technology / science area
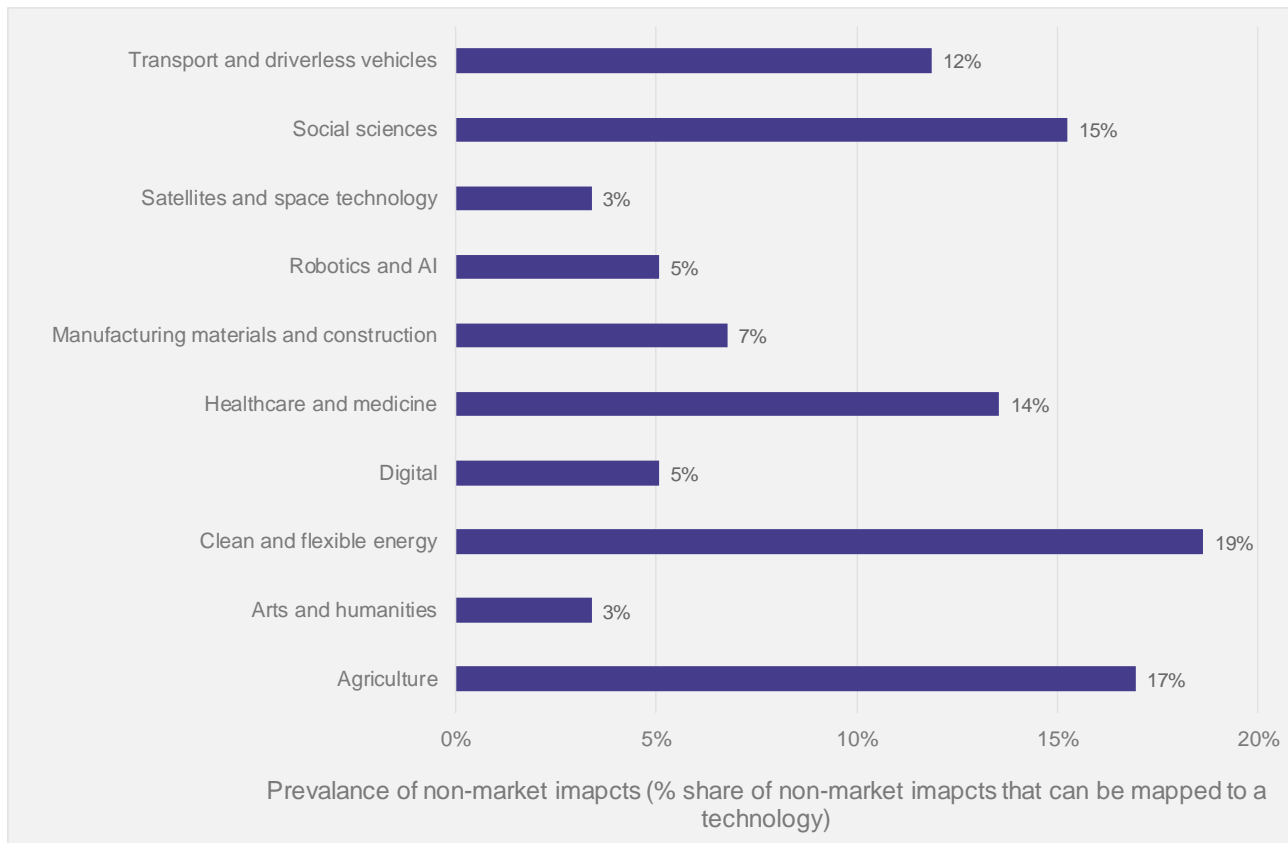
Source: Economic Insight

Interestingly, the above analysis shows that there is considerable variation in the prevalence of references to non-market impacts by technology area within the literature. Key points to note are as follows:

- **Agriculture; and clean and flexible energy, are the technology areas where non-market impacts are most prevalent in the literature.** Collectively they account for 36% of all identified references

- **Healthcare; social sciences; and transport and driverless cars, have a similar level of prevalence, between 12% and 15%.**

- **There are a number of technology areas with a low prevalence of non-market impact references in the literature. These include: satellites and space technology; digital; and arts and humanities.**

This lower prevalence does not *necessarily* imply that non-market impacts are less likely to arise in these technology areas as, we generally found 'fewer papers' in these areas relative to others. The lack or lower prevalence of published evidence in a particular area of research could also be an indication that the non-market impact is harder to observe or measure within the specific technology context. However, in general, it can be argued that, all else being equal, there tends to be a correlation between the amount of published research on any given topic and its relevance or importance. Accordingly, we do think that the above analysis provides useful guidance as to where non-market impacts are most likely to arise.

5. How non-market typologies vary by technology area

In this chapter, we analyse the results of our literature review in more detail, in order to understand how non-market impacts might vary by technology area. In turn we address: (i) overall prevalence by technology area and impact type; (ii) prevalence within technology areas; and resulting from this (iii) develop **more detailed typologies** for the impacts most relevant to each technology area.

Analysis of prevalence by technology area and non-market impact types

It is particularly interesting to examine how prevalence of non-market impacts references vary **by technology area and non-market impact type, combined.** Accordingly, the figure below highlights this, where prevalence is measured as the % share of the 59 non-market references identified above (i.e. those that can be connected to technologies). For example, the table shows that 3% of the 59 references discussed the non-market impact category 'Health' in the context of agriculture. The 'Overall' column in the table presents the percentage of the 59 references that discussed the high-level non-market impacts in the context of the technology identified by the corresponding row.

Figure 5: Prevalence by technology area and non-market impact type combined

		Non-market impact category							
		Health	Environment	Safety and security	Society	Equity	Wellbeing	Economy	Overall
Technology area	**Agriculture**	3%	5%	2%	2%	2%	0%	3%	17%
	Arts and humanities	0%	0%	0%	2%	2%	0%	0%	3%
	Clean and flexible energy	2%	8%	8%	0%	0%	0%	0%	19%
	Digital	2%	0%	0%	2%	0%	0%	2%	5%
	Healthcare and medicine	7%	0%	2%	2%	0%	0%	3%	14%
	Manufacturing materials and construction	3%	3%	0%	0%	0%	0%	0%	7%
	Robotics and AI	2%	0%	0%	2%	0%	2%	0%	5%
	Satellites and space technology	0%	0%	2%	2%	0%	0%	0%	3%
	Social sciences	2%	0%	0%	3%	0%	5%	5%	15%
	Transport and driverless vehicles	5%	2%	5%	0%	0%	0%	0%	12%

Source: Economic Insight

The above suggests that specific combinations of technology area / non-market impact that may arise most frequently include:

- the impact of clean and flexible energy on the environment and on safety and security;

- the impact of healthcare and medicine on health outcomes;

- the impact of agriculture on environmental outcomes; and

- the outcome of transport on health and safety and security.

It is also worth highlighting the fact that the results of the above analysis seem generally logical and accord with sensible expectations. For example, it is intuitively clear that one would expect clean and flexible energy to have impacts associated with the environment and / or safety and security.

Analysis of prevalence within technology areas

Another way to look at the prevalence is by looking at how categories of non-market impacts are split across the different non-market impacts that we identified *within* each technology area. Accordingly, the next table shows how each technology area's non-market impact references are split by non-market impact type (i.e. the split for each technology area is shown out of 100%). Each row of the table below shows the breakdown of non-market impacts as percentages of the total papers that discuss the non-market impacts within that technology area.

Table 3: Prevalence within each technology area (share of non-market impacts)

Tech area / non-market impact	Health	Environ-ment	Safety and security	Society	Equity	Subjective Wellbeing	Economy
Agriculture	20.0%	30.0%	10.0%	10.0%	10.0%	0.0%	20.0%
Arts and humanities	0.0%	0.0%	0.0%	50.0%	50.0%	0.0%	0.0%
Clean and flexible energy	9.1%	45.5%	45.5%	0.0%	0.0%	0.0%	0.0%
Digital	33.3%	0.0%	0.0%	33.3%	0.0%	0.0%	33.3%
Healthcare and medicine	50.0%	0.0%	12.5%	12.5%	0.0%	0.0%	25.0%
Manufacturing materials and construction	50.0%	50.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Robotics and AI	33.3%	0.0%	0.0%	33.3%	0.0%	33.3%	0.0%
Satellites and space technology	0.0%	0.0%	50.0%	50.0%	0.0%	0.0%	0.0%
Social sciences	11.1%	0.0%	0.0%	22.2%	0.0%	33.3%	33.3%
Transport and driverless vehicles	42.9%	14.3%	42.9%	0.0%	0.0%	0.0%	0.0%

Source: Economic Insight

The above shows that, for many technology areas, only a limited number of non-market impacts appear in the literature. For example, for the arts and humanities, only 'society' and 'equity' non-market impacts occur. Similarly, for manufacturing and construction, non-market impacts are limited to health and environment.

This is, in fact, helpful for those engaged in: policy design; policy or investment decision-making; and policy or financial evaluation. Specifically, this evidence can be used to help identify the 'priority' non-market impacts to pay particular attention to, when considering issues in relation to a specific technology area.

To help make it easier to draw these inferences, the following table simply summarises the 'key' (i.e. most prevalent) non-market impacts by technology area, drawing on the analysis shown in the above chart.

Table 4: Summary of key non-market impact types by technology area

Technology areas (Investing in these gives rise to non-market impacts shown in the adjacent column)	Key non-market impacts (The types of non-market impacts that are most supportable by evidence)
Agriculture	The Environment
Arts and humanities	Society Equity
Clean and flexible energy	The environment Safety and security
Digital	Health (but generally low prevalence)
Healthcare and medicine	Health
Manufacturing materials and construction	The environment
Robotics and AI	Health (but generally low prevalence)
Satellites and space technology	Safety and security Society
Social sciences	Wellbeing Economy
Transport and driverless vehicles	Health Safety and security

Analysis of robustness across typologies

Whilst all of the papers used to inform our typologies met a minimum robustness threshold, there is still some variation in robustness across those typologies. Accordingly, the figure below shows the average robustness score (out of 6) for each typology described above.

Figure 6: Comparison of robustness across typologies
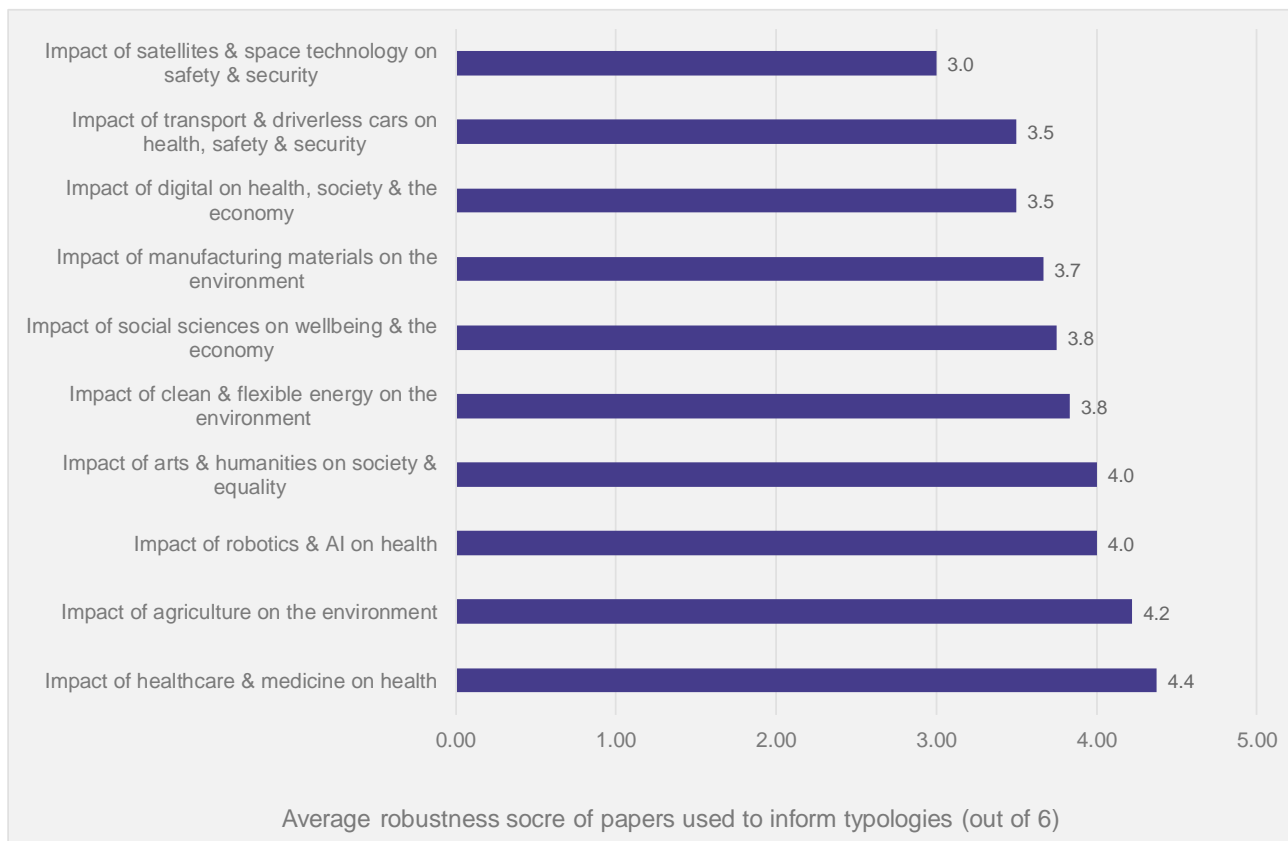
Source: Economic Insight

Key points to note are as follows:

- **The impact of healthcare and medicine on 'health' is the typology for which the supporting evidence is strongest,** with an average score of 4.4.

- Other typologies for which the evidence base is particularly strong include:

- the impact of agriculture on the environment;

- the impact of robotics and AI on health; and

- the impact of arts and humanities on society and equality.

- The impact of satellites and space technology on safety and security has a somewhat weaker evidence base, with an average robustness score of 3.0.

Regarding the above, it is important to be mindful of the subjectivity in the scoring system we applied. As a consequence, whilst we think it is meaningful to use the criteria we identified to distinguish between papers that are, broadly, 'robust' or 'not robust', **one should not over-interpret relatively small differences in average scores across papers or typologies.**

Developing detailed examples of key typologies

Above we examined how non-market impacts vary by technology area and identified 'priority' non-market impacts for each. Following from this, we have developed more specific examples (including more detailed explanations) of how the non-market impacts might arise in these priority areas.

Accordingly, in the subsequent subsections, we provide: (i) flow diagrams showing the causality of non-market impacts by technology area; and (ii) associated explanatory information for each of the following:

- The non-market impact of **clean and flexible energy on the environment** (in particular, sustainability).

- The non-market impact of **agriculture on the environment.**

- The non-market impact of **social sciences on subjective wellbeing and the economy.**

- The non-market impact of **investment in healthcare on health.**

- The non-market impact of **transport and driverless vehicles on health, safety and security.**

- The non-market impact of **manufacturing materials and construction on the environment.**

- The non-market impact of **robotics and AI on health.**

- The non-market impact of **digital on health, society and the economy.**

- The non-market impact of **satellite and space technology on safety and security.**

- The non-market impact of **arts and humanities on society and equality.**

Non-market impact of *clean and flexible energy* on the *environment (sustainability)*

Figure 7: non-market impact typology for clean and flexible energy

R&D (additional investments in the technology)

Innovation (new or enhanced products / services)

Outputs (what changes as a result of the innovation)

Non-market impact

Investments in **clean and flexible energy.**

- Clean and sustainable energy technologies: solar, hydro, wind and biomass.
- Advances in waste management techniques.
- Energy efficient technologies.
- Carbon capture technologies.

- Continued improvements in renewals generation directly lowers emissions.
- As waste management becomes more effective, overall energy demand is reduced.
- Capture technologies directly reduce pollutants in the air.

Environmental non-market impacts:

Climate change mitigation and improved sustainability.

Investment leading to innovation, leading to non-market impacts

The literature suggests that investments in 'clean and flexible' technology are likely to support technological innovation and investment relating to:

- The continued development and deployment of renewable generation. For example, Ellabban et al (2014) discuss how investment in smart grid technologies can promote a greater use of renewable energy sources.[15] In turn, greater use of renewables can lead to a direct reduction in emissions (because they lower reliance on fossil fuels). For example, photovoltaic modules of electricity generation reduced CO2 emission by around 6.8 million tons over a period of 30 years in the USA. Ultimately, therefore, investment in this technology can help mitigate climate change – which is an inherently non-market impact (i.e. because the benefit of reducing climate change is not 'priced' into the generation of energy).

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[15] Ellabban, O., Abu-Rub, H. and Blaabjerg, F., 2014. Renewable energy resources: Current status, future prospects and their enabling technology. Renewable and Sustainable Energy Reviews, 39, pp.748-764.

- Advances in waste management (i.e. both recycling, but also harnessing waste as energy – as is increasingly occurring in the water sector). Here, for example, Brunner and Rechberger (2015) discuss the growth in waste-to-energy (WTE) plants – which not only result in more efficient and environmentally friendly energy generation, but also have wider spillover benefits associated with providing better data and information regarding waste composition.[16] In turn, improved energy recovery reduces the overall need for energy. As above, this ultimately mitigates climate change over time (because less CO2 is produced), which is non-market.

- Faster adoption of energy efficiency technologies. Here, the literature discusses how it may take time for certain energy efficiency technologies to be adopted – say, due to uncertainty as to their effectiveness and / or high up-front costs. For example, Mulder et al (2014) explain this in terms of technological 'diffusion' rates, comparing the adoption of energy efficiency technology to technology adoption profiles in other industries.[17] Here, it is found that increased investment (and in some cases, state support) can increase the adoption profile. Faster adoption of energy efficiency technology has implications beyond the generation of energy itself (for example, it has direct implications for transport). This can further mitigate emissions (and therefore, climate change, which is - as explained above - non-market). For example, investment in a range of power unit / efficiency technologies related to diesel engines[18] are estimated to have reduced CO2 emissions in the USA by 177.3 metric tonnes between 1995 and 2007.[19]

- Improvements in carbon capture technology. Carbon capture and storage is a technology that can capture the carbon dioxide (CO2) emissions produced from the use of fossil fuels in electricity generation and industrial processes, preventing the carbon dioxide from entering the atmosphere. As explained above, any reduction in CO2 can mitigate climate-change over time, which is, therefore, a non-market impact. In addition, carbon capture technology also results in there being less air pollutants, which is also a non-market impact (because the wider environmental sustainability and health 'costs' of air pollution are not explicitly priced).

In summary, the literature is most supportive of the primary non-market impacts arising from investing in green and flexible energy to be: greater climate change mitigation; and improved environmental sustainability.

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[16] Brunner, P.H. and Rechberger, H., 2015. Waste to energy–key element for sustainable waste management. Waste Management, 37, pp.3-12.

[17] Mulder, P., de Groot, H.L. and Hofkes, M.W., 2003. Explaining slow diffusion of energy-saving technologies; a vintage model with returns to diversity and learning-by-using. Resource and Energy Economics, 25(1), pp.105-126.

[18] Technologies include: laser diagnostics and optical engine technologies; combustion modelling; emsmissions control; and solid state energy conversion.

[19] Link, A.N., 2010. Retrospective Benefit-Cost Evaluation of US DOE Vehicle Combustion Engine R&D Investments: Impacts of a Cluster of Energy Technologies (No. DOE/EE-1529). University of North Carolina at Greensboro.

A note on sustainability

A key aspect of the environmental non-market impacts of 'clean and flexible energy' is the promotion of **'sustainability'.** This concept is widely discussed in the literature – and definitions vary. However, in broad terms it refers to: *meeting needs in the present, without compromising the ability of future generations to meet their own needs* (see Brundtland Report, 1987). This is sometimes discussed more specifically in terms of 'environmental sustainability' or 'sustainable development'.

It is worth highlighting that the literature also identifies how energy efficiency (and its related sustainability impacts) can interact with other non-market impacts. For example, in relation to the former, Cambridge Econometrics (2015) set out a number of 'knock-on' impacts that can arise from energy efficiency, including social impacts, such as increased employment and reduced energy poverty.[20] Perhaps even more pertinently to this study, a Harvard Business Review paper[21] argues that sustainability is, itself, a fundamental driver of increased innovation. This, therefore, suggests that there may be a 'virtuous circle' arising from investing in technologies that promote sustainability.

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[20] Cambridge Econometrics, 2015. Assessing the Employment and Social Impact of Energy Efficiency.
[21] Nidumolu, R., Prahalad, C.K. and Rangaswami, M.R., 2009. Why sustainability is now the key driver of innovation. Harvard business review, 87(9), pp.56-64., Ram et al., Harvard Business Review.

Non-market impact of *agriculture* on the *environment*

Figure 8: non-market impact typology for agriculture

R&D (additional investments in the technology) → Innovation (new or enhanced products / services) → Outputs (what changes as a result of the innovation) → Non-market impact

Investments in **agriculture.**

- Crop sensors, which monitor crop health.
- Real-time equipment telematics.
- Enhancements to livestock biometrics and tags.
- Livestock feed efficiency tech.

- Adoption of agri-tech allows for precision farming. Results in resources being used more efficiently e.g. less fertiliser etc.
- Feed efficiency tech can materially reduce amount of energy required in farming.

Environmental non-market impacts:

Improved environmental sustainability.

Investment leading to innovation, leading to non-market impacts

In relation to investment in agriculture, the main types of 'innovation' identified in the literature relate to what is known, collectively, as 'agri-tech'. In broad terms, agri-tech refers to technological innovations that will promote greater yield and efficiency in the agricultural sector. Specific examples of innovations identified in the literature, and their non-market impacts, include:

- Crop sensors: for example, Lamb and Brown (2001)[22] discuss how airborne remote-sensing can be used as a technique for identifying and mapping weeds in crops – which in turn should help generate timely and accurate weed maps. Based on a review of previous studies they find that, more generally, crop sensors are able to provide real-time information on crop health data.

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[22] Lamb, D.W. and Brown, R.B., 2001. Pa—precision agriculture: Remote-sensing and mapping of weeds in crops. Journal of Agricultural Engineering Research, 78(2), pp.117-125.

- Equipment telematics: this refers to the collection and analysis of telematics data from agricultural equipment, providing detailed information on key operating parameters, which in turn can help:

    – optimise equipment use;

    – inform maintenance schedules; and

    – identify potential equipment failures before they arise.

    Mark and Griffin (2016)[23] set out how the use of this technology is already rising rapidly, with only 7% of agriculture service providers offering office-to-field telematics in 2011, up to 20% in 2015.

- Livestock biometrics: refers primarily to ways of utilising digitised bio-data to identify livestock. This can include, for example, radio frequency identification (RFID); iris identifiers; and so on – as discussed by Barron et al (2009).[24]

- Feed efficiency technology: refers to technology that allows feed intake (and provision) for livestock to be monitored and adjusted 'live'. For example, feeding machines collect data in on feed consumption by cattle, and can transmit this remotely (using cloud based systems). In turn, nutritionists can then analyse the data and make adjustments to feed intake and composition, to improve animal health (as we set out in the following, this particular technology has a very direct non-market impact, relating to the spillover benefit of lower energy consumption).

The adoption of agri-tech (which in turn delivers precision farming) will primarily be motivated by commercial considerations. That is to say, collectively this technology allows farmers to produce more output, more efficiently. However, the literature also identifies that these technologies will have significant non-market impacts, because they have the potential to create wider environmental benefits (which, of course, are not reflected in the 'price' adopters pay for the technology – i.e. this is why they are non-market).

Examples identified in the literature include:

- Reduced fertiliser use (which can be facilitated by crop sensor and equipment telematics in particular) will directly reduce water pollution and energy consumption. For example, Brookes et al (2008) showed that bio-crops and agri-tech innovation led to a 22.9% reduction in the use of insecticide, leading to significant positive impacts on the environment of the crop area over a 10-year period.[25]

- Reduced feed (enabled by feed efficiency technology) will similarly directly reduce energy consumption. For example, in the UK, it is estimated that the animal feed

[23] Mark, T. and Griffin, T., 2016. Defining the Barriers to Telematics for Precision Agriculture: Connectivity Supply and Demand. In 2016 Annual Meeting, February 6-9, 2016, San Antonio, Texas (No. 230090). Southern Agricultural Economics Association.

[24] Gonzales Barron, U., Butler, F., McDonnell, K. and Ward, S., 2009. The end of the identity crisis? Advances in biometric markers for animal identification. Irish Veterinary Journal, 62(3), pp.204-208.

[25] Brookes, G. and Barfoot, P., 2008. Global impact of biotech crops: socio-economic and environmental effects, 1996-2006.

industry accounts for around 620,000 (tCO2)[26]. Key innovations that can help reduce feed (or increase its energy efficiency) include: active energy management; process optimisation; product scheduling; moisture control; and the use of more innovative equipment (including energy efficient presses, multicrackers[27] and biomass heating).

- More 'indirectly,' the more efficient use of resources should generally improve environmental sustainability over the longer term (and this seems to be the most supportable / significant non-market impact in the literature).

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[26] The Carbon Trust., 2008 'Industrial Energy Efficiency Accelerator: guide to the animal feed milling sector.'
[27] Multicrackers are a particle size reduction technology used to tear or crack open the substrate instead of grinding it. The cracking action is achieved by two contra-revolving rows of discs. Multicrackers use significantly less energy than conventional systems and the technology is thought to be suitable for many types of substrate including cereals and seeds.

Non-market impact of *social sciences* on *subjective wellbeing and economy*

Figure 9: non-market impacts for social sciences

R&D (additional investments in the technology) → **Innovation** (new or enhanced products / services) → **Outputs** (what changes as a result of the innovation) → **Non-market impact**

Investments in **social sciences.**

- Studies examining what drives societal wellbeing and happiness.
- Studies to improve measurement of wellbeing.
- Studies examining linkages between wellbeing and broader economic performance.

- Public and private decision-making becomes more reflective of wellbeing.
- Public policy decisions are more likely to be welfare enhancing.

Non-market impacts on wellbeing:

Enhanced social wellbeing.

Non-market impacts on the economy:

Greater efficiency of (public) goods and services provision.

Investment leading to innovation, leading to non-market impacts

Social science refers to a broad range of academic disciplines, aimed at understanding 'how' societies work. As a science / academic area, investment here will, in the immediacy, tend to result in additional / new research. From a non-market impact perspective, the literature tends to focus on studies relating to understanding the concept of 'wellbeing' and how it is measured – but also, interlinkages between wellbeing and the economy.

The literature argues that the main *outputs* of such studies are:

- that decision-making in both the public and private sector becomes more reflective of 'wellbeing' (because wellbeing is both better understood and more robustly measured as a result of investing in this research area); and

- that consequently, public-policy decisions are more likely to be 'welfare-enhancing' for society than would otherwise be the case.

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As a result of this, non-market impacts arise in relation to:

- 'wellbeing' itself, (because the overall 'happiness' of society is higher – and this end result would not be reflected in the original 'cost' / 'price' of the social science research in the first place); and

- 'economy', because state provided services in particular are delivered / allocated more efficiently (where, again, this benefit would not have been reflected in the cost of the original social science research). For example, of relevance to the former, research at the London School of Economics (Happiness in Economic Policy) encouraged the introduction of an index of 'wellbeing' to be developed by the Office for National Statistics in the UK.[28]

The literature further identifies that, in relation to 'wellbeing', social science research can assist in understanding and enhancing **the wellbeing of specific groups**, such as ethnic minorities or women in work – etc. For example, Professor Ram's work on ethnic minority entrepreneurship and finance, backed by the ESRC, has influenced the banking industry in the UK; and the way in which leading banks interact with their customers and key stakeholders.[29]

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[28] Russell Pioneering Research Group, 2012. The social impact of research conducted in Russell Group universities. Russell Group Papers, 3, pp.1-60.
[29] Economic and Social Research Council, 2017. Network boosts ethnic minority business. http://www.esrc.ac.uk/news-events-and-publications/impact-case-studies/network-boosts-ethnic-minority-business/

Non-market impact of investment in *healthcare and medicine* on *health*

Figure 10: non-market impacts for healthcare and medicine
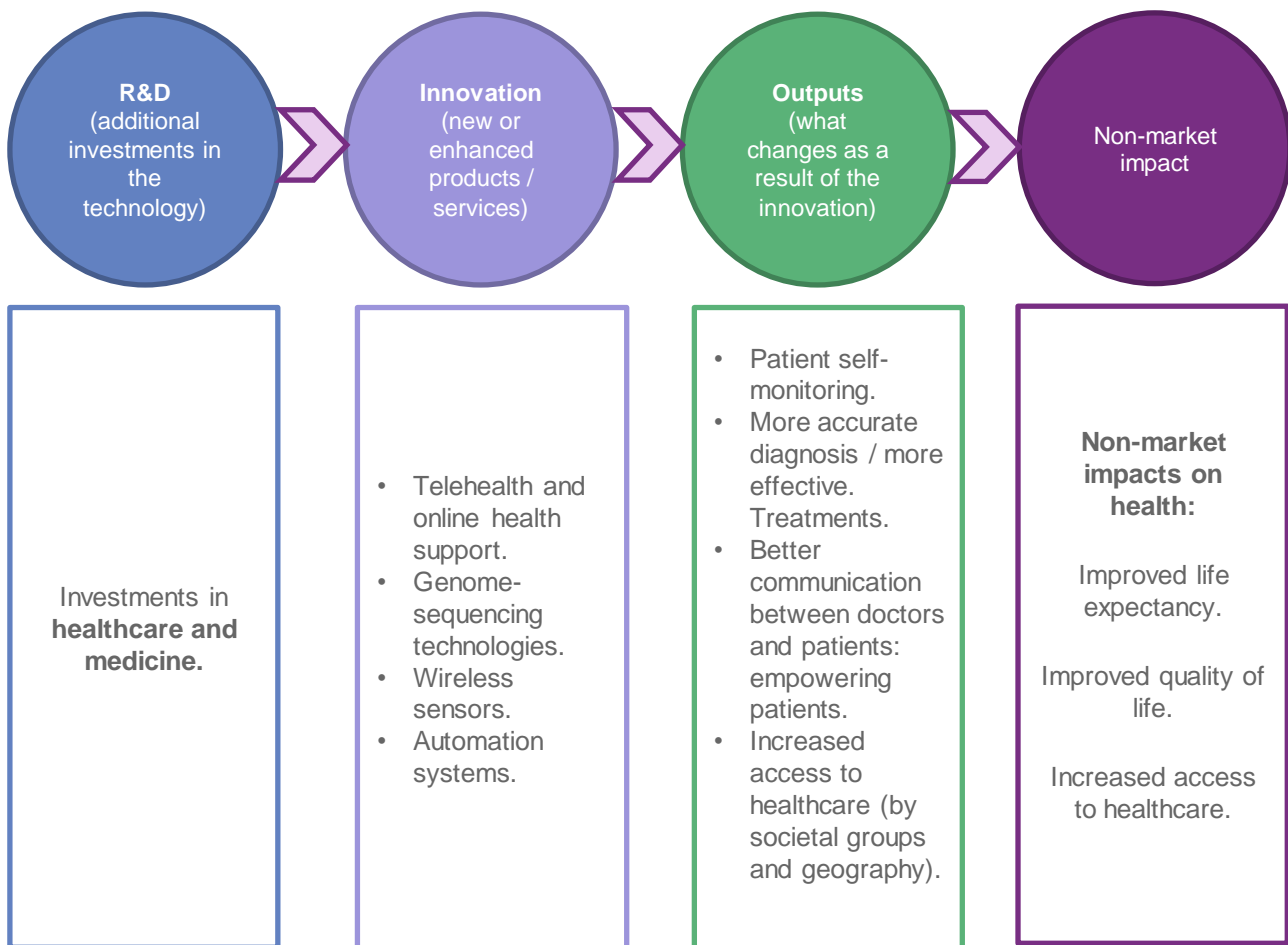
Investment leading to innovation, leading to non-market impacts

The main technological innovations in healthcare and medicine discussed in the literature, for which there are identifiable non-market impacts, include the following:

- *Telehealth* enables medical professionals to reach patients who are: (i) in distinct 'vulnerable' societal groups; and / or (ii) rural geographic areas, which expands accessibility to healthcare (especially to individuals with long-term conditions). A systematic review of the literature discussing the socio-economic impact of telehealth concludes that telehealth had 'significant socio-economic benefit' in terms of improved quality of care, quality of life, and enhanced social support.[30] These socio-economic benefits are 'non-market', because elements of them are unlikely to be reflected in the cost or price of the systems and software necessary to deliver telehealth in practice. For example, whilst the purchasers / users of any telehealth (or online) system for providing healthcare services would fund the 'direct' cost of

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[30] Jennett, P.A., Hall, L.A., Hailey, D., Ohinmaa, A., Anderson, C., Thomas, R., Young, B., Lorenzetti, D. and Scott, R.E., 2003. The socio-economic impact of telehealth: a systematic review. Journal of telemedicine and telecare, 9(6), pp.311-320.

the service provision itself, if this, in turn, had knock-on impacts on overall quality of life or societal health outcomes (e.g. because by increasing access to health services, people received earlier diagnosis and had more access to treatment) then these would all constitute 'non-market impacts'.

- Genome-sequencing technologies contribute to the development of advanced / effective drugs and personalised treatments. This will lead to improvements in the quality and efficiency of healthcare provided to individuals. The technologies also contribute to addressing medical issues, or disease, based on the genetic code that would have otherwise not been possible, which improves overall access to healthcare. Again, access to healthcare would be a non-market impact because this positive spillover arising from genome-sequencing would not be expected to be reflected in the cost of the research in the first place. Chadwick and Wilson (2004)[31] also discuss this in relation to the potential to create genomic databases, which provide a repository of information that increases access to, and quality of, healthcare (thus, being inherently 'non-market').

- Wireless sensor technology enables timely self-monitoring by patients, which in turn allows for more effective diagnosis and treatment. This empowers patients and allows for the timely detection and treatment of medical issues as they arise. This contributes in providing patients with a 'sense of relief', where they know their health is being monitored, which improves their overall quality of health and life. This issue is explored by Alemdar and Ersoy (2010)[32], who discuss how sensory technology can be used to provide 'alerting mechanisms', which in turn reduce the need for caregivers. As currently, a material proportion of 'care' is provided voluntarily and for no remuneration (e.g. by family and friends), again this impact is non-market.

- 'Automated systems' primarily relate to digital platforms that help exchange information across medical professionals; and between medical professionals and patients. These, collectively, reduce time allocated to 'paperwork' and other administrative tasks, so that more resource is focused on care-giving. This also has the impact of empowering patients, helping to facilitate patient-centred healthcare services.

  – A review of 302 empirical studies, concludes that, besides the impact of technologies on the time spent by health professionals on care-giving duties, the introduction of digital technologies also allows patients to become *"an integral part of their own care team"*, where they have *"more responsibility for monitoring their symptoms and outcomes."*[33]

  – Clearly, the value that patients themselves derive from feeling 'part of their own care team' is highly likely to be non-market, because it is a spillover

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[31] Chadwick, R. and Wilson, S., 2004. Genomic databases as global public goods?. Res Publica, 10(2), pp.123-134.

[32] Alemdar, H. and Ersoy, C., 2010. Wireless sensor networks for healthcare: A survey. Computer networks, 54(15), pp.2688-2710.

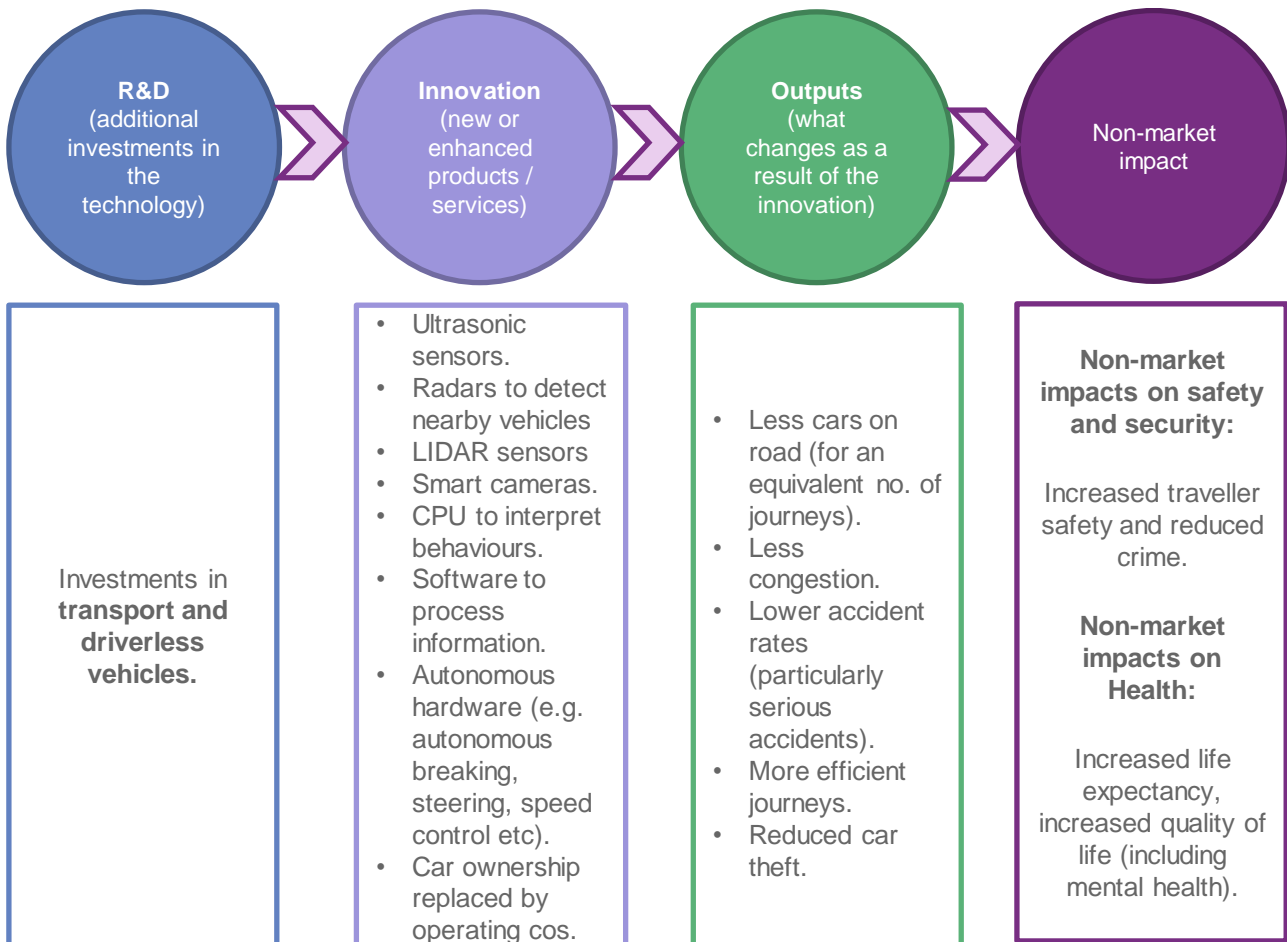[33] Skills for Health, 2011. How do new technologies impact on workforce organisation. The Evidence Centre for Skills for Health.
www.skillsforhealth.org.uk/index.php?option=com_mtree&task=att_download&link_id=101&cf_id=24

benefit arising from 'automated systems', rather than being something that is explicitly part of the 'cost' of developing such systems, or the prices charged for them in the market.

Non-market impact of *transport and driverless vehicles* on *health, safety and security*

Figure 11: Non-market impacts of transport and driverless cars

R&D (additional investments in the technology)	Innovation (new or enhanced products / services)	Outputs (what changes as a result of the innovation)	Non-market impact
Investments in **transport and driverless vehicles.**	• Ultrasonic sensors. • Radars to detect nearby vehicles • LIDAR sensors • Smart cameras. • CPU to interpret behaviours. • Software to process information. • Autonomous hardware (e.g. autonomous breaking, steering, speed control etc). • Car ownership replaced by operating cos.	• Less cars on road (for an equivalent no. of journeys). • Less congestion. • Lower accident rates (particularly serious accidents). • More efficient journeys. • Reduced car theft.	**Non-market impacts on safety and security:** Increased traveller safety and reduced crime. **Non-market impacts on Health:** Increased life expectancy, increased quality of life (including mental health).

Investment leading to innovation, leading to non-market impacts

In the figure above, we focus on specific non-market impacts arising from driverless vehicles associated with 'safety and security' and 'health', as these were most prevalent in our review.[34] However, the adoption of autonomous vehicles is also expected to have positive impact on the environment, due to the likely increase in transport efficiency and reductions in emissions.

Key 'health' and 'safety and security' non-market impacts, that are likely to arise from investment in this area, include the following:

- In relation to 'safety and security', car related crime is expected to reduce for a variety of reasons. For example, potential forms of crime reduction identified in the literature include:

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[34] For example, see: Litman, T., 2014. Autonomous vehicle implementation predictions. Victoria Transport Policy Institute, 28.

- reduction in vehicle (and vehicle related) theft, because car ownership is expected to be displaced by 'pay per use' models); and

- reduction in motoring offences (e.g. autonomous vehicles would not infringe traffic laws).

These impacts are 'non-market' because they are benefits associated with the adoption of autonomous vehicles which are not intrinsically priced into the development of autonomy technology itself.

- More significantly, the technology should eliminate the main cause of serious road accidents and fatalities (human error) - resulting in gains to life expectancy and quality. For example, Carstena and Tateb explored elements of these impacts as far back as 2005.[35] Here, their paper focused on 'intelligent speed systems' specifically (rather than full autonomy per se). However, even focusing just on this one dimension of the technology, the authors found that fatal accident rates could be reduced by up to 37%. These health impacts are non-market in nature, because they would not be expected to be reflected (at least not in full) in the 'price' of autonomous cars. For example, even if the users of autonomous cars were willing to 'pay' for these health benefits, because the of benefits 'spillover' to non-car drivers (e.g. pedestrians that might have otherwise been involved in accidents), at least some element of the impact must be non-market.

- Other forms of non-market impact that are identified in (or can be inferred from) the literature) include: reduced congestion; lower stress; and providing mental health benefits. For example, in relation to congestion, Talebpoura and Mahmassan (2016)[36] explain how autonomous cars can improve traffic flow, due to their ability to run 'in close proximity' and their ability to intelligently 're-route' their journeys. This impact would be 'non-market' because, again, it is a 'spillover gain' associated with the adoption of autonomous technology.
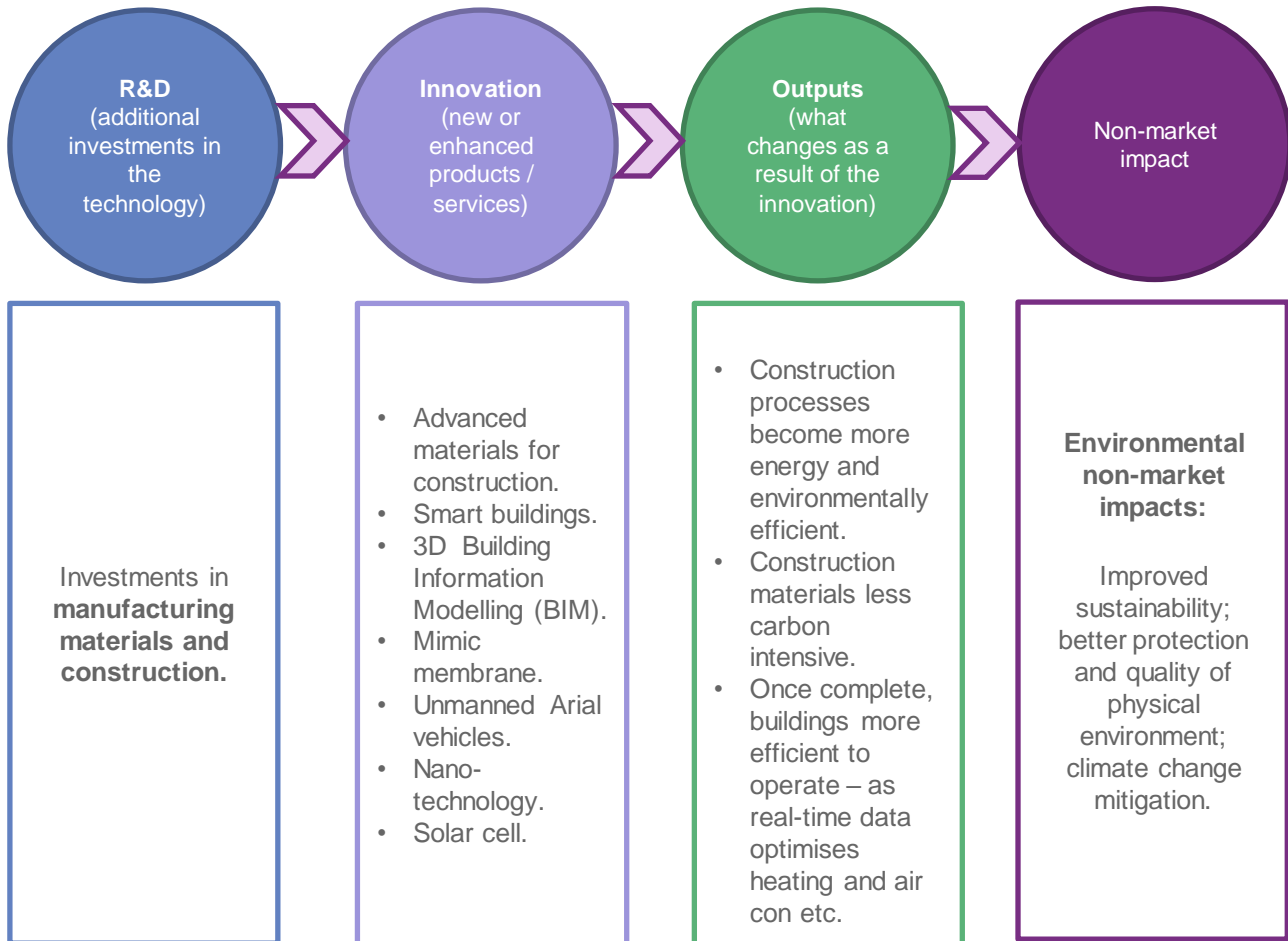
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[35] Carsten, O.M. and Tate, F.N., 2005. Intelligent speed adaptation: accident savings and cost–benefit analysis. Accident Analysis & Prevention, 37(3), pp.407-416.
[36] Talebpour, A. and Mahmassani, H.S., 2016. Influence of connected and autonomous vehicles on traffic flow stability and throughput. Transportation Research Part C: Emerging Technologies, 71, pp.143-163.

Non-market impact of *manufacturing materials and construction* on the environment

Figure 12: Non-market impacts of manufacturing and construction on the environment

R&D (additional investments in the technology)	Innovation (new or enhanced products / services)	Outputs (what changes as a result of the innovation)	Non-market impact
Investments in **manufacturing materials and construction.**	• Advanced materials for construction. • Smart buildings. • 3D Building Information Modelling (BIM). • Mimic membrane. • Unmanned Arial vehicles. • Nano-technology. • Solar cell.	• Construction processes become more energy and environmentally efficient. • Construction materials less carbon intensive. • Once complete, buildings more efficient to operate – as real-time data optimises heating and air con etc.	**Environmental non-market impacts:** Improved sustainability; better protection and quality of physical environment; climate change mitigation.

Investment leading to innovation, leading to non-market impacts

Advances in technology relating to manufacturing materials and construction are likely to have spillover / non-market benefits relating to:

- the 'processes' involved in manufacture and construction (i.e. better information allows resource and time to be better optimised);

- the efficiency, both energy and cost, of construction materials themselves; and

- post-construction, where buildings will be inherently more efficient to operate – resulting in improved sustainability.

Specific examples of technologies and the non-market impacts they give rise to (as identified in the literature) include the following:

- The Building Information Model (BIM) is a model-based process for creating and managing project information. It provides a digital description of every aspect of the build, which in turn allows all relevant stakeholders (e.g. architects, builders,

designers) to visually 'see' the build and interact with each element of it, so that they can better optimise their own activities. The potential for non-market impacts arises because BIM should allow professionals to create better, more efficient, plans - and thus more efficient buildings.[37] For example:

- – more efficient buildings could also include efficiency from an environmental sustainability perspective;

- – this would be a non-market impact because it is, in effect, a 'knock-on' outcome of implementing the BIM, which would not be reflected in the market price for utilising BIM itself.

- The construction industry is the largest consumer of raw materials in the UK (as reported by various sources, including the ONS).[38] Relatedly, the UK Government has identified 'Advanced Materials' as being one of eight 'great technologies' that are vital to the UK's future economic growth.[39] Here, 'advanced materials' broadly refers to any 'new' materials that have fundamental properties (e.g. in terms of their strength, durability, weight, production costs and so on) that are significantly 'better' than existing materials. In relation to non-market impacts that can arise from investments in advanced materials, the literature discusses a number of aspects, notably including environmental sustainability. For example, advanced materials will primarily be adopted for commercial reasons (i.e. a combination of their cost and the 'value' they add to a construction process). However, in many instances, those same materials might be more 'environmentally sustainable'; say, because:

- – they have a lower carbon footprint;

- – are more recyclable; and / or

- – result in buildings being more 'energy efficient' over time.

None of these effects would necessarily be fully reflected in the 'price' of such materials, and so are 'non-market' in nature. Furthermore, it is important to note that there could be sustainability benefits associated with both the construction process itself; but also, the resultant buildings (i.e. if the 'materials' used result in those buildings being more environmentally efficient to operate).

- Nanotechnology is also identified as an idea in which substantial technological gains can be realised in relation to materials. In a construction context, this is sometimes referred to as 'nanostructuring'. It generally refers to the 'assembly' of construction materials at a 'nano' level, which enables manufacturers to both:

- o influence the physical qualities of the materials themselves; and

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[37] World Economic Forum, 2016. Shaping the Future of Construction: A Breakthrough in Mindset and Technology. http://www3.weforum.org/docs/WEF_Shaping_the_Future_of_Construction_full_report__.pdf
[38] https://www.ons.gov.uk/economy/environmentalaccounts/articles/ukenvironmentalaccountshowmuchmaterial istheukconsuming/ukenvironmentalaccountshowmuchmaterialistheukconsuming
[39] https://www.gov.uk/government/speeches/eight-great-technologies

o in some cases, make the materials 'programmable', embedding technology within them that allows for the collection and transmission of information, such that the properties of materials can be physically adapted over time.

Bainbridge (2001) summarises that such nanostructuring will bring: *"lighter, stronger, and programmable materials; reductions in life-cycle costs through lower failure rates; and use of molecular/cluster manufacturing, which takes advantage of assembly at the nanoscale level for a given purpose."*[40]

In turn, nanostructuring may give rise to non-market impacts because the increased adaptability of the resultant materials is also likely to enhance their environmental sustainability.
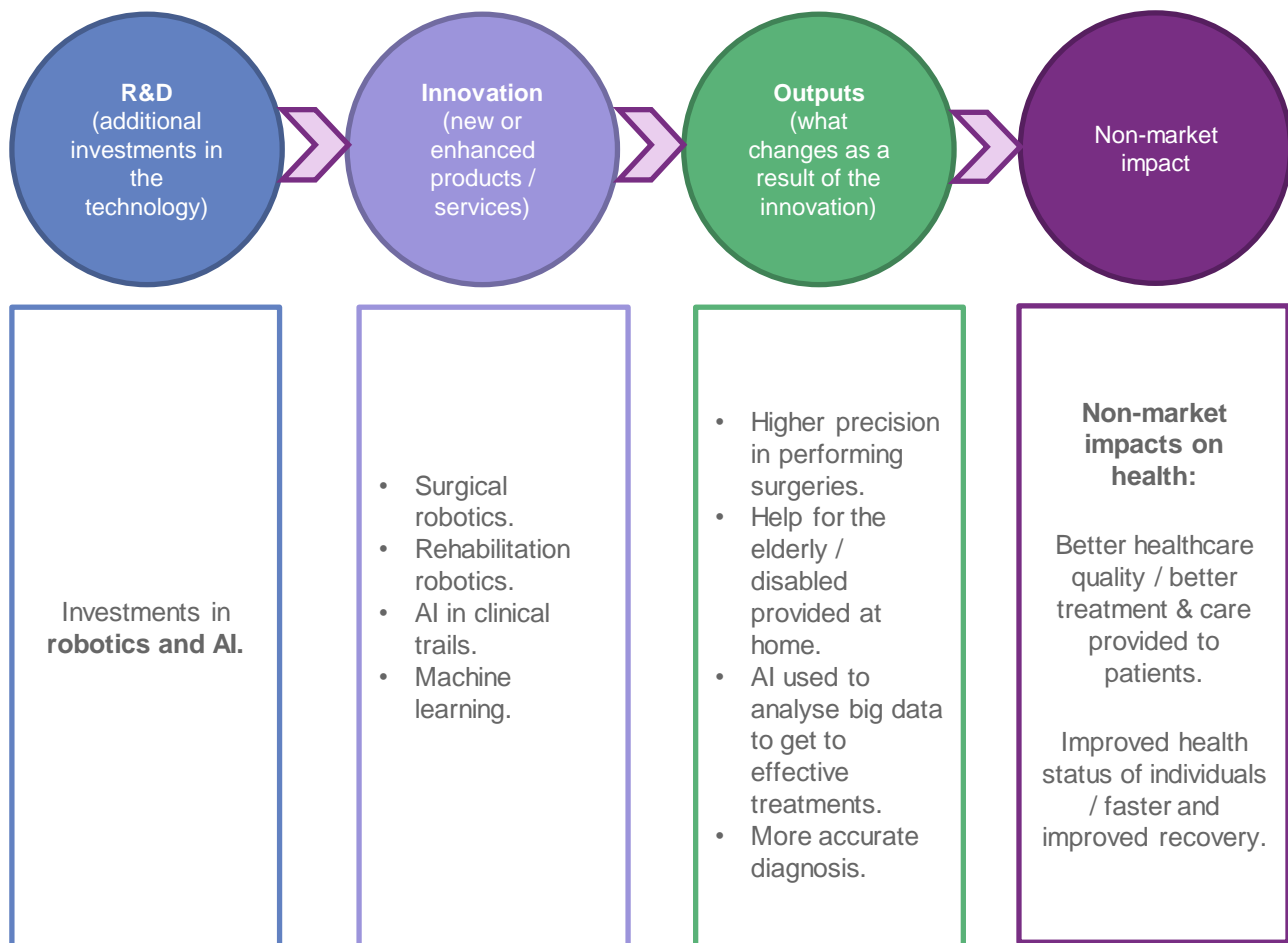
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[40] Bainbridge, W.S. ed., 2001. Societal implications of nanoscience and nanotechnology. Springer.

The non-market impact of *robotics and AI* on *health*

Figure 13: Non-market impacts of robotics and AI

R&D (additional investments in the technology)	Innovation (new or enhanced products / services)	Outputs (what changes as a result of the innovation)	Non-market impact
Investments in **robotics and AI.**	• Surgical robotics. • Rehabilitation robotics. • AI in clinical trails. • Machine learning.	• Higher precision in performing surgeries. • Help for the elderly / disabled provided at home. • AI used to analyse big data to get to effective treatments. • More accurate diagnosis.	**Non-market impacts on health:** Better healthcare quality / better treatment & care provided to patients. Improved health status of individuals / faster and improved recovery.

Investment leading to innovation, leading to non-market impacts

The literature identifies various ways in which investments in robotics and AI can lead to non-market impacts, relating to healthcare. Examples of this include the following:

- One type of robotics that is used in medicine is *surgical robotics,* which allow certain medical surgeries to be performed to a very high degree of precision (decreasing the level of risk on patients). Surgical robotics also allow for surgeries that medical professionals would not be able to otherwise perform (i.e. the total 'provision' of healthcare is thus increased). Examples of using robotics in healthcare show that robotically assisted surgeries to the head and neck led to higher patient satisfaction, due to the avoidance of cervical incision, and minimal other complications[41]. Whilst elements of the impact of robotics would be 'market' (i.e. direct improvements in the health of a privately paying patient), others are likely to be 'non-market'. For example, the uplift in the overall 'provision' of healthcare is clearly a spillover benefit that would not be reflected in the price paid by an individual patient for (robotics)

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[41] Lobe, T.E., Wright, S.K. and Irish, M.S., 2005. Novel uses of surgical robotics in head and neck surgery. Journal of Laparoendoscopic & advanced Surgical techniques, 15(6), pp.647-652.

treatment. Similarly, broader positive impacts on patient satisfaction are also likely to be non-market.

- Another type of robotics is *rehabilitation robotics* – these are increasingly used to assist the elderly in taking care of themselves and perform various tasks more independently. This notion is discussed in detail by Yakub et al (2014)[42], who explore recent trends in rehabilitation robotics, but also identify challenges associated with its future adoption, including ethical concerns around the level of 'intrusion' and issues of 'patient control'. Rehabilitation robotics has the potential to give rise to non-market impacts in a number of ways – but most obviously, by increasing 'access to healthcare' (because it allows rehabilitation to be conducted without the physical presence of a medical professional, or voluntary carer).

- Artificial intelligence is widely used to analyse big data to develop drugs that are more effective in treating illness, and potentially cause less side-effects to patients. Specifically, artificial intelligence is expected to contribute to the value chain by contributing to the *'project, produce, promote, and provide'* stages. In the case of healthcare, this includes the prediction of disease, reducing patients' risk, optimising hospital operations, and adapting therapies to patients.[43]
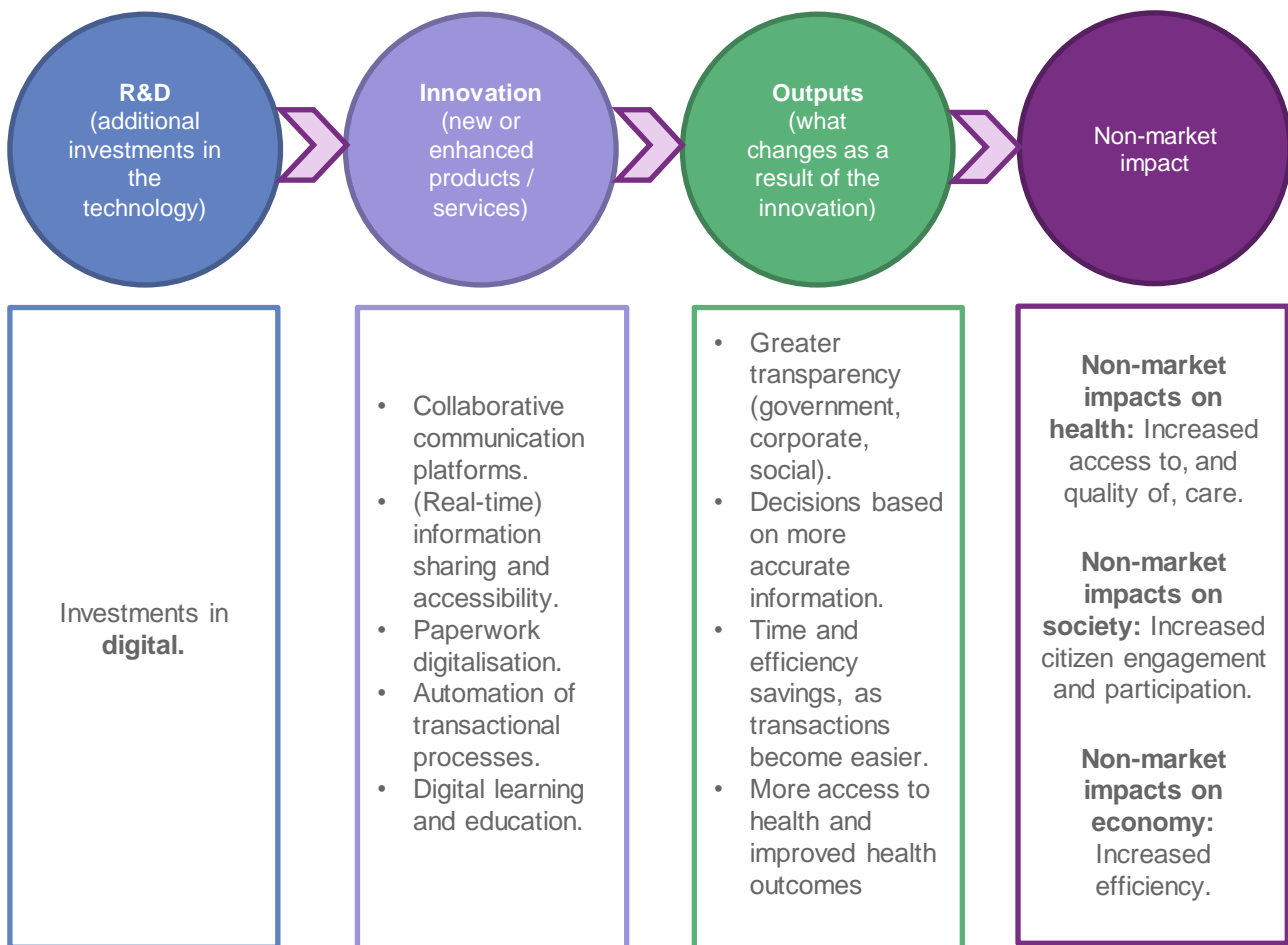
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[42] Yakub, F., Khudzari, A.Z.M. and Mori, Y., 2014. Recent trends for practical rehabilitation robotics, current challenges and the future. International Journal of Rehabilitation Research, 37(1), pp.9-21.
[43] Chui, M., 2017. Artificial intelligence the next digital frontier? McKinsey and Company Global Institute.

Non-market impact of *digital* on *health, society and economy*

Figure 14: Non-market impacts of digital

R&D (additional investments in the technology)	Innovation (new or enhanced products / services)	Outputs (what changes as a result of the innovation)	Non-market impact
Investments in **digital.**	• Collaborative communication platforms. • (Real-time) information sharing and accessibility. • Paperwork digitalisation. • Automation of transactional processes. • Digital learning and education.	• Greater transparency (government, corporate, social). • Decisions based on more accurate information. • Time and efficiency savings, as transactions become easier. • More access to health and improved health outcomes	**Non-market impacts on health:** Increased access to, and quality of, care. **Non-market impacts on society:** Increased citizen engagement and participation. **Non-market impacts on economy:** Increased efficiency.

Investment leading to innovation, leading to non-market impacts

'Digital' is an extremely broad concept and, as such, innovations relating to this technology area can affect almost every aspect of society. From our literature review, however, non-market related impact references were most prevalent in relation to: health; society; and economy. Here, ways in which investment in digital can give rise to non-market impacts include the following:

- Collaborative communication, and increased information sharing, invariably improves transparency across society. In the literature, it is suggested that this, in turn, will promote citizen engagement and participation. Specifically, the OECD (2016) reports that the adoption of ICT and data analytics by government (and the use of open data by citizens) will *"increase the openness, transparency and accountability of government activities and thus boost public trust in governments."*[44] As described previously in this report, 'public trust'; 'transparency' and other measures relating to 'society' are inherently non-market in nature,

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[44] OECD, 2016. Stimulating Digital Innovation for Growth and Inclusiveness: The Role of Policies for the Successful Diffusion of ICT.

because there are no 'ownership rights' associated with them and, therefore, they do not have any market prices associated with them. Similarly, Kshetri (2014)[45] discussed how 'big data' may additionally lead to 'negative' non-market impacts, associated with consumer privacy and security.

- Related to 'big data' is the concept of 'open data' (data with open standards and access). As is much discussed in the literature, the impact of open data is inherently 'non-market', because the benefits it gives rise to relate to facilitating cooperation, better systems integration and the cross-pollination of ideas and analysis – none of which can be captured in the 'price' one could charge a private user for access to, or use of, said data. As such, open data is typically 'free' to access.

- The continuation of current trends towards the automation and digitisation of transactions and document production and handling lead directly to a material reduction in 'paperwork'. This, in turn, can result in significant time and efficiency savings. Some of these savings might be 'market' in nature (i.e. a company directly benefits financially from a time saving as a result of implementing digital transaction handling, for example). However, equally they can be non-market, where the time / efficiency saving spills over beyond the agent who has paid for the digitisation. For example, research indicates that there are often spillover efficiency gains for the economy as a whole. Here, a 2016 comparative study of digitalisation of public services across OECD countries shows that the digitalisation of 'labour cost-intensive' services, such as social care and education, lead to considerable efficiency and productivity gains, as well as quality improvements.[46]

- Finally, the digitisation of healthcare can act as a powerful tool to both increase access to health and, also, the quality of healthcare provision.   For example, Nelson (2016)[47] describes how the creation of 'digital registries' (such as patient records) have already had far-reaching effects. These include:

    - facilitating public reporting;

    - enabling retrospective and prospective research;

    - promoting professional development; and

    - driving service improvements.

    However, the author also identifies significant further potential for the technology. This includes, for example, (i) a lack of 'data feedback' between key healthcare stakeholders; (ii) a lag in the delivery of data and care provision; (iii) examples of restricted use of data for limited purposes, reducing its overall value; and (iv) limited patient engagement and involvement in the collection, analysis and use of, data. Related to this, the author identifies a key non-market impact that (at

[45] Kshetri, N., 2014. Big data's impact on privacy, security and consumer welfare. Telecommunications Policy, 38(11), pp.1134-1145.
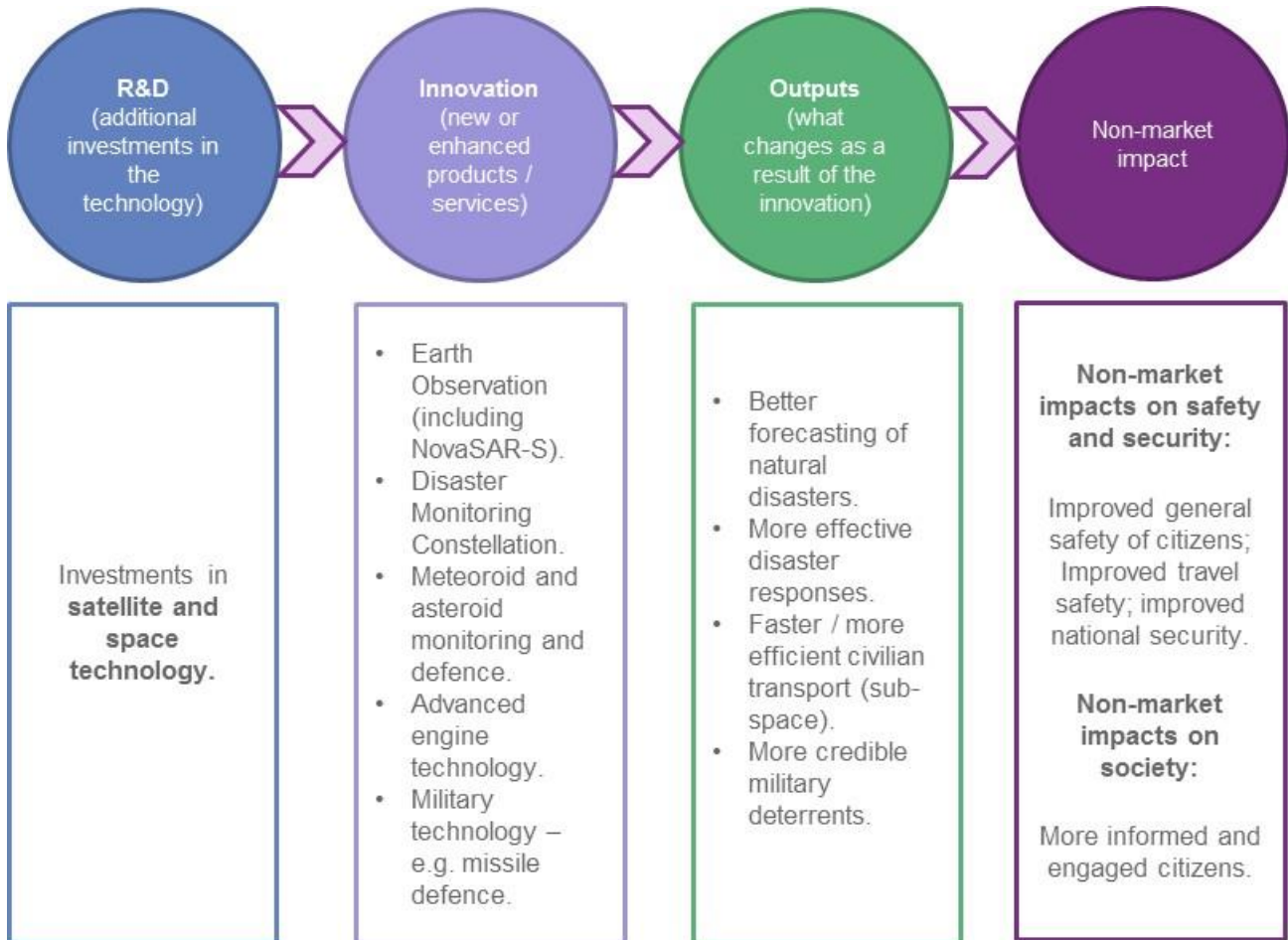[46] OECD, 2016. Digital Government Strategies for Transforming Public Services in the Welfare Areas.
[47] Nelson, E.C., Dixon-Woods, M., Batalden, P.B., Homa, K., Van Citters, A.D., Morgan, T.S., Eftimovska, E., Fisher, E.S., Ovretveit, J., Harrison, W. and Lind, C., 2016. Patient focused registries can improve health, care, and science. BMJ, 354, p.i3319.

present) is likely being utilised to only a limited degree. Namely, if data is democratised more to patients, this in turn enables patients to better 'self-manage' their case – whilst also improving their phycological wellbeing (i.e. because with access to data they can feel more assured).

Non-market impacts of *satellite and space technology* on *society, safety and security*

Figure 15: Non-market impacts of satellite and space technology

R&D (additional investments in the technology) → Innovation (new or enhanced products / services) → Outputs (what changes as a result of the innovation) → Non-market impact

| Investments in **satellite and space technology**. | • Earth Observation (including NovaSAR-S).
• Disaster Monitoring Constellation.
• Meteoroid and asteroid monitoring and defence.
• Advanced engine technology.
• Military technology – e.g. missile defence. | • Better forecasting of natural disasters.
• More effective disaster responses.
• Faster / more efficient civilian transport (sub-space).
• More credible military deterrents. | **Non-market impacts on safety and security:**

Improved general safety of citizens; Improved travel safety; improved national security.

Non-market impacts on society:

More informed and engaged citizens. |

Investment leading to innovation, leading to non-market impacts

The literature identifies a number of ways in which satellite and space technology may give rise to non-market impacts. Key ways in which such impacts can arise include the following:

- **Earth observation** refers to the use of satellite technology to provide detailed observational data on the planet. In a civilian context, this technology was originally used to support meteorology, but its application is now much broader – encompassing all aspects of the natural environment. As such, the literature identifies a number of way in which it can give rise to non-market impacts. These include:

  - Improvements in this technology increasingly allow for better monitoring, forecasting and management of natural disasters (such as floods, hurricanes, and tsunamis). In turn, these can deliver non-market impacts relating to (human) safety and security.

- Relatedly, observation technology has a role in monitoring borders, monitoring illegal traffic, and damage assessment. Collectively, these are essential inputs to a number of policy areas, including: immigration; counter-terrorism; and defence.[48] As explained previously, it is widely recognised that defence is an intrinsically 'public good' (i.e. national defence cannot be funded by a market) and so these impacts are, by definition, non-market.

- Onoda and Young (2017)[49] further highlight the (unexpected) positive spillover benefit that earth observation has delivered relating to the environmental sustainability of space. Here, the authors discuss how, over time, problems have developed relating to the debris generated by space exploration, which orbits the earth, creating both environmental and human safety risks. The authors explain that facilities installed, for the purpose of earth observation, have inadvertently helped mitigate these risks, by:

  - allowing for up-to-date information capture regarding the status of space debris; and
  - helping to raise the profile of 'space debris' and pollution more broadly.

- **Investment in satellite and space technology can have broader non-market impacts on society.** In broad terms, the literature explains this in two main ways:

  - Firstly, the 'multinational' nature of space programmes is thought to help reinforce positive societal values – as well as encouraging a constructive environment for international relations. For example, Bignami and Sommariva (2016)[50] provide a detailed assessment of how space exploration has helped foster improved diplomatic relations over time. They also suggest that, greater cooperation in space exploration itself is inherently 'valuable' and that, the more countries that cooperate, the greater the utility from diplomatic prestige. Clearly such impacts are non-market in nature, because the 'price' of space exploration does not reflect any tangential knock-on effects on diplomacy or citizens' attitudes.

  - Secondly, space exploration democratises information (space agencies typically make considerable data available to citizens on an 'open' basis) – this is said to make citizens feel 'more engaged' in society generally.

Relating to the above, it is worth highlighting that the way in which space agencies behave is typically consistent with the presence of society related non-market impacts. For example, NASA has a programme around societal engagement, called '*Participatory Exploration.*'[51]

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[48] Booz & co., 2014. Evaluation of Socio-Economic Impacts from Space Activities in the EU.
[49] Onoda, M. and Young, O.R. eds., 2017. Satellite Earth Observations and Their Impact on Society and Policy. Springer Singapore.
[50] Bignami, G. and Sommariva, A., 2016. The Future of Human Space Exploration. Palgrave Macmillan.
[51] https://open.nasa.gov/blog/citizen-engagement/

Key features of this include:

– Opportunities for citizens to actively engage, and share ideas with, NASA engineers;

– Open sharing of data and information with citizens (part of NASA's broader open data agenda); and

– Workshops on NASA's values and goals.

Non-market impact of *arts and humanities* on *society and equality*

Figure 16: Non-market impacts of arts and humanities
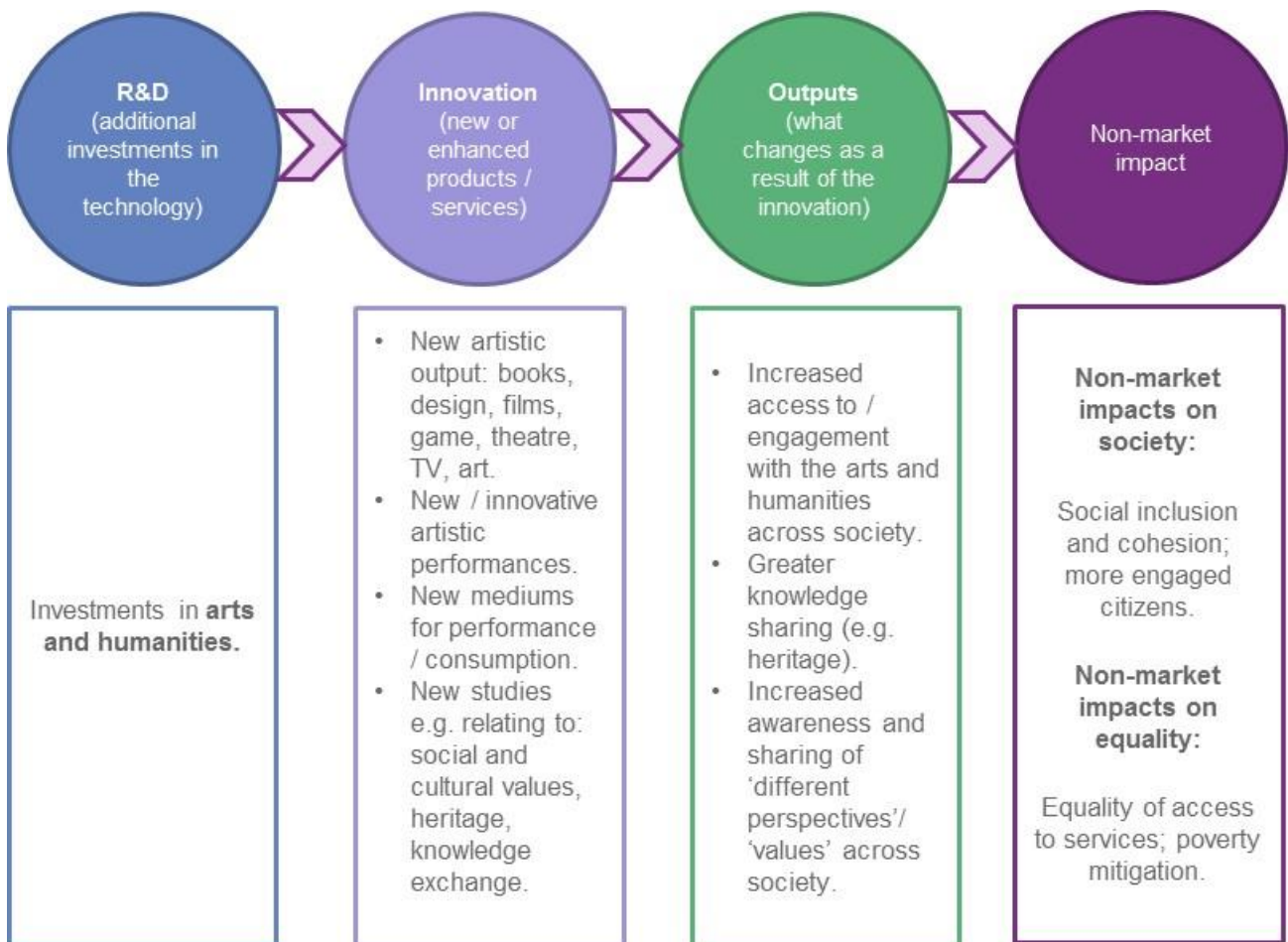
Investment leading to innovation, leading to non-market impacts

The 'arts and humanities' is an extremely broad area, encompassing subjects as diverse as fine art and geography. The literature tends to focus on non-market impacts arising in relation to 'society' and 'equality'. In relation to both, the transmission mechanism is essentially the same: namely, that arts and humanities innovation results in greater sharing of information and views, allowing people to:

• engage with issues they might not otherwise have been aware of; and / or

• seeing issues from the perspective of diverse societal groups with whom they might not otherwise engage.

As a result, it is argued that:

- **Societal non-market impacts can arise.** In particular, the literature refers to the arts and humanities promoting social cohesion (where the OECD defines a cohesive society as one that: *"works towards the well-being of all its members, fights exclusion and marginalisation, creates a sense of belonging, promotes trust, and offers its members the opportunity of upward social mobility."*)[52] The argument here is that attending performances, or watching cultural productions, enhances the sense of community belonging and social participation - which has a direct impact on the disadvantaged and leads to improved social cohesion. An example of a project that has contributed to social cohesion in the UK includes the *'Be Creative, Be Well'* initiative that supports art projects in disadvantaged areas in London. The initiative has led to 85% of participants reporting feeling 'more positive' after participating in the projects.[53] With reference to our previous definition of non-market impacts, 'social cohesion' is inherently non-market, because it is not 'priced' within a market.

- **Equality non-market impacts can also arise.** Here, the principal is that the arts and humanities both raises awareness regarding inequality (and, in particular, poverty) but also encourages debate as to how best to mitigate it. In addition, both qualitative and statistical studies suggest links between consumption of the arts and humanities and poverty mitigation.

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[52] OECD, 2012. Perspectives on Global Development 2012.
[53] Farrell, B., 2016. Understanding the value of arts & culture: the AHRC cultural value project (2016) by Geoffrey Crossick and Patrycja Kaszynska. Cultural Trends, 25(4), pp.273-276.

6. Conclusions and findings

Drawing together the various analyses contained in the preceding chapters of this report, our findings are as follows:

- Non-market impacts are generally found to be highly relevant to the technology areas considered within the scope of our work. Consequently, this reinforces the need for relevant stakeholders to consider (and where possible evaluate) them within decision-making.

- The relevant literature base identifies a very broad spread of potential non-market impact types (some 35 types, split across 7 higher-level non-market impact categories).

- The literature base from which we have identified the non-market impacts is of good quality. For example, we evaluated each paper we reviewed in terms of its robustness and relevance. In relation to the former, the average score of the papers reviewed was 3.7 out of 6. In relation to the latter, the average score was 4.1 out of 6. We further applied a 'quality threshold' to all papers included within our analysis. As such, we are confident that the non-market impacts identified in our work are credible.

- The relevance (prevalence) of specific types of non-market impact varies considerably across specific technology areas. This is an important piece of evidence for stakeholders, as it can be used to help inform: (i) where and when they should consider non-market impacts; and (ii) what those non-market impacts are likely to be. Relating to this, we find that non-market impact references are most prevalent in relation to:

  - clean and flexible energy;
  - agriculture;
  - social sciences; and
  - healthcare and medicines.

- Consequently, it is in the above areas where we would generally advise policy makers and evaluators to pay most attention to the possibility of non-market impacts, which might need to be factored into their analysis.

- Conversely, references to non-market impacts are less prevalent in relation to: satellite and space technology; and arts and humanities. Here, therefore, we might tentatively suggest that, on average, policymakers might need to pay less attention to the possibility of non-market impacts on these areas. However, here we must add a note of caution: namely, that as the scope of our work was limited to a literature review, a lack of prevalence in said literature does not necessarily indicate that non-market impacts are unimportant in every circumstance.

Following from the above, our literature review gives rise to the following recommendations regarding potential future research and work in this area:

- It would be beneficial to test the key non-market impact types identified here with wider stakeholders, particularly individuals working within these technology areas. For example, a mini-stakeholder survey might be one way of further verifying and refining the conclusions we have reached, based on the literature.

- It would be helpful to develop materials that can be used to 'disseminate' the priority non-market areas across wider stakeholders. This will help increase the awareness of non-market impacts more generally; but also, should help people focus on the issues that are likely to matter most.

Annex A. Background context information

Key context to our work

In the following sub-sections, we set out the key context to our work, which focuses on the UK's Industrial Strategy and the historically low levels of innovation related investment observed relative to other, comparable, countries.

The UK Government's Industrial Strategy

In November 2017, the UK Government published a White Paper on Industrial Strategy. Here, the overarching objective is to: *"create an economy that boosts productivity and earning power throughout the UK."*[54]

Within the White Paper, five foundations of productivity were identified as being essential to achieving this aim. Additionally, the White Paper specifies the industries that the UK want to be at the forefront at: (a) AI & Data Economy; (b) Clean Growth; (c) Future of Mobility; and (d) Ageing Society. The discussion and evidence contained in the White Paper provide vital context to our work for BEIS.

Following from the above, the UK government has committed to reaching 2.4% of its GDP on investments in research and development.

Historical under-investment in research and innovation in the UK

Following from the above, evidence in the Green Paper, highlighted the fact that **the UK is, at present, under-investing in research and innovation relative to peers.** Specifically, the Paper states: *"The UK invests in total 1.7 per cent of GDP in private and public R&D funding. This is below the OECD average of 2.4 per cent and far behind the leading backers of innovation – South Korea, Israel, Japan, Sweden, Finland and Denmark – which contribute over 3 per cent of their GDP to this area."*[55] The following figure, which shows directly **publicly** funded investment in R&D by country, as a % of GDP, illustrates the extent of the challenge.

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[54] 'Building our Industrial Strategy.' Green Paper – HM Government (January 2017); page 10.
[55] 'Building our Industrial Strategy.' Green Paper – HM Government (January 2017); page 26.

Figure 17: UK R&D investment challenge (publicly funded R&D by country)
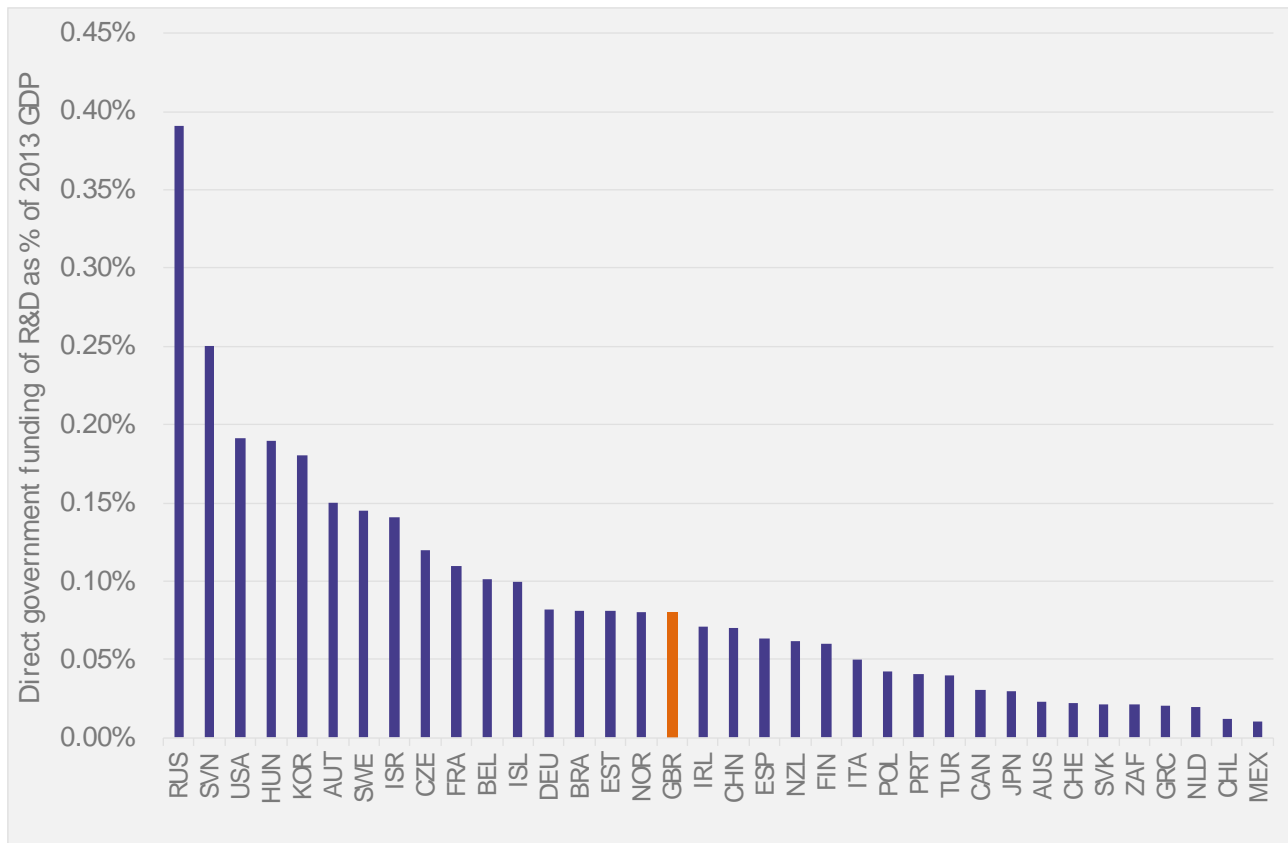
Source: OECD

The Industrial Strategy Challenge Fund

Following from the concern regarding the UK's current funding position relating to R&D investment (and productivity), various policy initiatives are now being rolled out. These include:

- an increase in direct public funding of investment in R&D (£4.7bn by 2020/21);

- the strengthening of the UK's strategic capability through the creation of UK Research and Innovation (UKRI), which will bring together the Research Councils, Innovate UK, HEFCE and Research England;

- supporting further Science and Innovation Audits in eight locations across the UK;

- a review of the tax environment for R&D, to examine whether more can be done to stimulate private sector investment and make the UK an even more competitive place to do R&D; and – of particular relevance to this project;

- the creation of the Industrial Strategy Challenge Fund (ISCF), which is designed to help the UK capitalise on its strengths in research and innovation.

Within the ISCF, six key 'challenge areas' (all relating to areas of technology) have been identified as priorities to receive funding. These are: (i) healthcare and medicine; (ii)

robotics and Artificial Intelligence; (iii) clean and flexible energy; (iv) driverless vehicles; (v) manufacturing and materials of the future; and (vi) satellites and space technology.[56]

Potential linkages between under-investment and non-market impacts

In order to help ensure that any future investment (both public and private) is properly targeted, it is vital to ensure policymakers have a robust evidence base to explain why there may have been under-investment (or misdirected investment) historically. Here, one potentially important factor could be the presence of non-market impacts. That is to say, either negative or, (more likely), positive impacts arising from investment in R&D in the UK that are not explicitly "priced" – and so will not be taken into account in private investor decision-making (see our previous definition of non-market impacts).

Consequently, if these 'non-market impacts' have not been well-understood or evidenced to date – the case for public investment will not have been as strong as it might have been. Nor, to the extent that these impacts vary by technology area, will any investment have been targeted as effectively as might have otherwise been the case.

Limitations to the existing evidence base concerning non-market impacts

There is, of course, a range of evidence that directly, or indirectly, addresses non-market impacts of investment in R&D or innovation and technology more broadly. However, to date this evidence has not been systematically brought together in a way that allows policymakers to understand its respective strength or implications.

In essence – this 'gap' underpins the objectives and scope of this work. Put simply, our aim here is to develop a resource that provides a comprehensive summary of potential non-market impacts arising from R&D related investment. In turn, this should help motivate greater consideration of such impacts when contemplating investment and policy decisions.

[56] www.gov.uk/government/collections/industrial-strategy-challenge-fund-joint-research-and-innovation

Annex B. Methodology and approach

This annex contains a detailed description of the methodology used to develop our report for BEIS. Here, we firstly set out a high-level overview of our approach, before subsequently providing further detail regarding each of the key stages in our work.

Overview of our approach

Our approach consisted of four main elements, as summarised in the figure below; and described further in the following sub-sections.

Figure 18: Four key stages of our approach
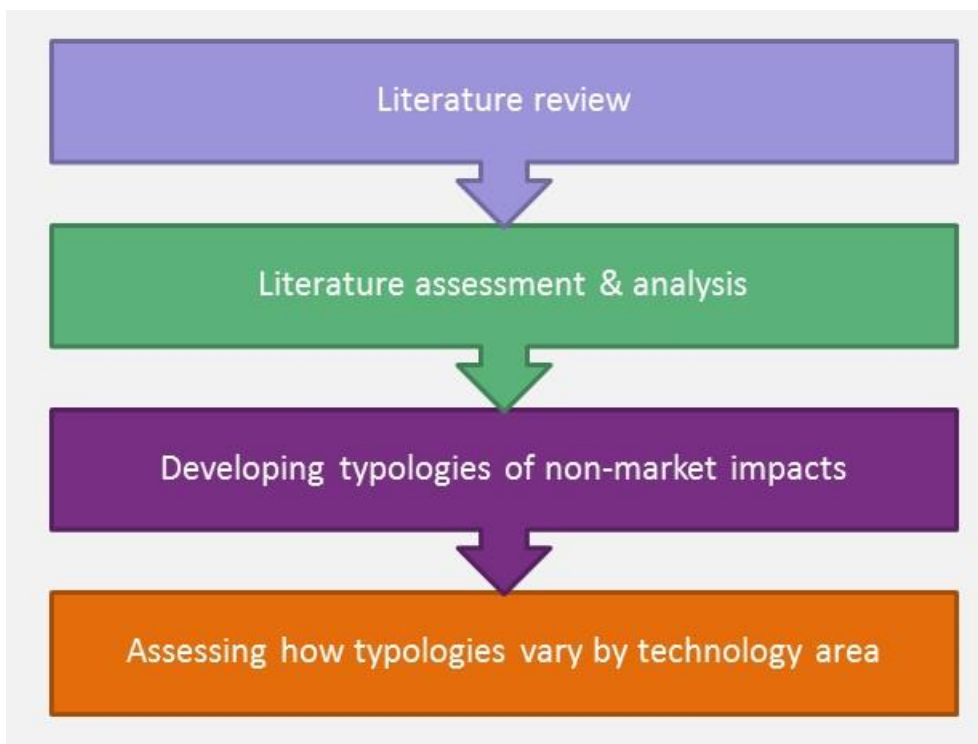
Source: Economic Insight

Literature review

The core element of our work was **an extensive literature review,** which involved applying six complementary search strategies to identify relevant papers. Once classified, the papers were subject to a detailed analysis in order to appraise their robustness and, accordingly, inform the development of our typologies. In the following sub-sections, we provide further details of the specific search strategies we employed.

Search strategy 1: research by keyword

Research process. The first strategy in identifying literature on non-market impacts of R&D involved searching for relevant keywords through a range of search platforms, including: *Google Scholar;* JSTOR; Econlit; CORE; Emerald; NBER; and American Economic Review. Through discussions with BEIS, we agreed on a list of keywords for the literature review. The list of keywords is presented in the table below.[57]

Table 5: Keywords used

Non-market	Non-monetary	Non-economic
Social impacts	Social goods	Wellbeing
Market failures	Externalities	Underinvestment
Barriers to investment	Socio-economic	Innovation
Patents	Spillovers	Distributional impacts

Source: Economic Insight

In searching for literature by keywords, each of the terms were combined with other relevant search fields as appropriate. For example, the keyword 'socio-economic' was searched for, not only in isolation, but also by prefixing and suffixing it to other relevant terms (e.g. 'socio-economic impacts of R&D investments').

As we undertook our search, we systematically recoded our progress using a colour coding system (green, yellow, and grey). Here, the colours signified the following:

- **Green** indicated that the keyword yielded: (i) literature covering a wide scope of papers, encapsulating theoretical and empirical work, literature reviews and case studies; (ii) a good spread of both academic (peer reviewed) papers, and grey literature, including consultancy papers, research council papers and papers by other research institutes; and (iii) that additional searching using the keyword was now yielding very similar / overlapping returns to those already reviewed.

- **Yellow** indicated that some further search was still required, either because: (i) the scope of coverage (topics) was not deemed adequate; (ii) that the scope of 'types' of papers covered was narrow (e.g. that, in particular, there was a lack of academic papers); and / or (iii) that additional searching was continuing to yield new, and useful, returns.

- **Grey** was used to indicate keywords where only preliminary searching had begun.

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[57] Note, additional key words were identified within our subsequent search strategies (see following subsections).

Search strategy 2: research by technology area

Research process. The second search strategy involved looking at non-market impacts of R&D investments arising *within specific technology areas.* Through discussions with BEIS it was determined that we should focus on the following technology and science areas. Note that for some technologies, we further agreed on additional specific search words *within* that technology area. These are shown as bullet points within the relevant categories below.

Table 6: Technology /science areas

Keywords

Agriculture • Agritech	Manufacturing materials and construction
Arts and humanities	Robotics and Artificial Intelligence
Clean and flexible energy	Satellites and space technology • Earth Observation • Spin-offs
Digital • Mobile communications	Social sciences
Healthcare and medicine • Biotech • Social care (through technology)	Transport and driverless vehicles

Source: Economic Insight

In line with the approach taken for the first strategy, we combined the technology areas with relevant keywords and searched for papers through a variety of search platforms, including Google Scholar and other academic tools.

Notably here, when searching by technology area, we again used suffixes and prefixes to allow us to combine technologies with key search word terms (as set out in our description of search strategy 1). For example, when searching for literature relating to 'agriculture', our terms will have included: *'socio-economic impacts of agricultural innovations';* or *'non-economic impacts of agriculture R&D'* – and so on.

Search strategy 3: research by academics

Research process. The third search strategy involved looking at work by specific experts in the field of R&D economics. These were identified through recommendations from BEIS and, in particular, Peter Swann (Emeritus Professor at the University of Nottingham) – whose input and advice was highly valuable. Specific academic authors we searched for are shown below.

Table 7: Academics included in search scope

Keywords

Eric von Hippel	Dominique Foray	Dietmar Harhoff
Jason Potts	Hans- Jürgen Engelbrecht	Henry Chesborough
Sinclair Davidson	Stephen Roper	Mark Taylor

Source: Economic Insight

The search strategy involved accessing the publication page of each of the academics, and undertaking an initial 'scoping' review of their published papers, in order to identify the literature most closely related to the scope of our work. Having done this, we then undertook a more detailed review of the most relevant papers, again tracking our progress as described previously.

Search strategy 4: research by research council/department

Research process. The fourth search strategy involved looking at work undertaken by research departments and institutes around the UK. The list of departments was provided to us by BEIS – and is as follows.

- Administrative Data Research Network;
- AHRC;
- Centre for the Understanding of Sustainable Prosperity;
- Centre on Dynamics of Ethnicity;
- DRUID Conferences;
- Economic and Social Research Council;
- Research Excellence Framework;
- Schumpeter Conferences;
- The Nexus Network;
- What Works Crime Reduction;
- What Works Scotland; and
- What Works Wellbeing.

The process involved accessing the webpage of each of the departments; and looking for published work under the tabs 'case studies', 'publications', or 'research'. In many instances, the focus of the work was on: (i) demonstrating impacts on public policy; or (ii) seeking to substantiate certain non-market impacts as a means of supporting arguments for investment in particular academic disciplines. As such, there was considerable overlap across the papers reviewed. Consequently, in order to maximise the usefulness of this material, we tended to focus on papers that were most closely aligned to influencing policy **relating to the technology areas included within the scope of our work for BEIS.**

Search strategy 5: typology-driven research

Research process.   The fifth search strategy was developed after we identified an initial list of high-level typologies of non-market impacts from our literature review (discussed subsequently). Examples of high-level typologies that we identified include: environment; safety and security; and equity. Within each high-level impact, we further identified more specific types of non-market impacts. For example, in the case of the 'environment' typology, the list includes dimensions of: air quality; water quality; climate change mitigation; and sustainability.

The non-market impacts - both high-level and detailed types – were themselves then used as keywords. Again, these were searched for both in isolation; and combined with our other keywords. For example, we searched for literature relating to: *'the impacts of space technologies on climate change'* - and so on.

Search strategy 6: follow through reference/citation

Research process.   As a general approach for all the above-mentioned search strategies, we followed through the references in papers that we identified relevant to our purpose in classifying non-market impacts of R&D.

Summary of search strategy results

Using the search strategies, in total we identified and reviewed, in detail, some **94** papers. The following pie chart shows how these were split across the six strategies we deployed. Key points to note are that:

- There is a relatively even split across the search strategies, indicating that each was valuable in its own right as a means of identifying literature relating to non-market impacts.

- **Searching by technology area proved to be the most effective strategy,** followed by: searching by research council / department; typology driven searches; and follow-through reference checking.

- General key-word searching yielded the lowest share of papers we reviewed. However, this nonetheless accounted for 10% of the papers, indicating that it was a useful approach.

Figure 19: Split of papers reviewed by search strategy used to identify them
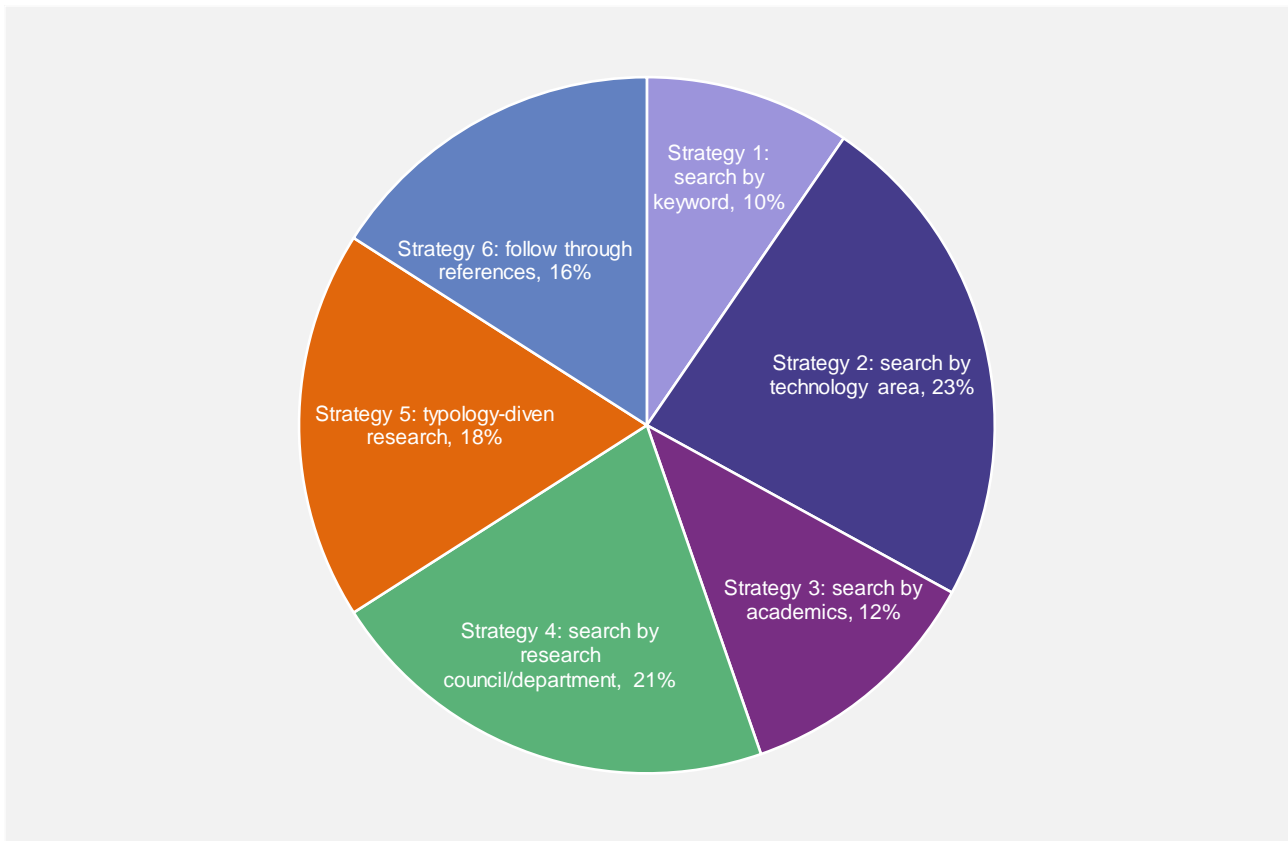
Source: Economic Insight

Methodology for literature analysis

Our analysis of the literature had three main components: (1) a systematic classification of the literature in various dimensions; (2) an evaluation of the 'robustness' of the evidence base against a set of criteria; and (3) drawing out a 'long-list' of initial typographies.

Approach to literature classification

Each of the papers found from our research was classified per the following:

- title;
- author;
- paper methodology (theoretical / conceptual, literature review, case study, or empirical analysis);
- journal of publication;
- publication details (consultancy paper, peer-reviewed academic journal, research council, research / other type of institution paper, other academic paper);
- technology / science area;
- subject country; and
- year of publication.

In terms of classifying the 'methodology' of the paper, in practice papers can, of course, combine multiple methodologies. Accordingly, our classification reflects our judgment regarding the 'primary' method deployed within each paper we reviewed. Recognising that this exercise is somewhat subjective, this classification was: (i) firstly undertaken by a single person to ensure consistency; and (ii) in cases that were identified as being 'marginal', a second project team member reviewed the proposed classification and suggested amendments where appropriate. In most cases, however, the 'primary' methodology of papers was sufficiently clear that no ambiguity arose.

Approach to assessing the robustness of the literature

The second stage in the literature analysis was to assess the 'quality' of the literature. This is because, ultimately, we want to ensure that the final set of non-market typologies we propose is itself robust. To do this, we agreed a set of evaluation criteria with BEIS, grouped by 'robustness' and 'relevance'. Each paper was scored a: 0; 1; or 2 against each individual criterion. The criteria and scoring benchmarks are shown in the table below.

Table 8: Evaluation criteria

	Characteristic / score	0	1	2
Robustness	Research method.	Purely conceptual.	Simple empirics / case studies.	Detailed empirics / case studies.
	Type of author/paper.	Working paper / consultancy.	Research / other type of institution.	Peer-reviewed academic journal article.
	Objectivity.	Direct influence on public policy / funding.	Indirect influence on public policy / funding.	No observed intended influence.
Relevance	Relevance to technology areas.	Tangentially relevant to technology areas.	Somewhat relevant to technology areas.	Very relevant to technology areas.
	Relevance to UK research.	Tangentially relevant to UK research.	Somewhat relevant to UK research.	Highly relevant to UK research.
	Recency.	Before 2000.	2000-2009.	2010 onwards.

Source: Economic Insight

The rationale and approach to each criterion was as follows:

- **Research method.** The research methods considered under this criterion were: literature review; conceptual / theoretical; case study; and empirical papers. Empirical methods provide an assurance that an impact is realised, rather than just being a theoretical possibility (or evidenced anecdotally). Accordingly, empirical papers that estimate econometric models were given a score of 2, case studies and literature reviews a score of 1; and theoretical / conceptual papers a score of 0. In the case that a paper draws conclusions from the output of *multiple case studies,* it was given a score 2 (if quantitative evidence was also a feature of the case study work). Here, it is important to emphasise the fact that non-market impacts are typically difficult to quantify. Consequently, whilst it is appropriate to place more weight on quantitative papers, clearly qualitative work is also of value.

- **Type of author/paper.** Papers under this criterion were scored based on whether they were written/published by or in: peer-reviewed academic journals; research councils; other research / industry institutions; private consultancies; or some other non-peer reviewed academic setting (e.g. a working paper). The rationale behind this criterion is that it indirectly informs the likely robustness of the evidence. For example, papers published in peer-reviewed academic journals are likely to have a more robust methodology / research approach (and so are scored '2'). Papers by private consultancies score a '0', with other categories taking a score of '1'.

- **Objectivity.** Papers are considered to be 'objective' if they are intended to address a research question (as is typically the case with academic, peer-reviewed, papers). Such papers are scored a '2'. In contrast, if a paper *explicitly* identifies an objective other than addressing a research question (e.g. it is to influence policy and / or funding and / or to support marketing) a score of '0' is awarded. If the paper does not explicitly fulfil an objective other than research, but where such an intention can be reasonably inferred, a score of '1' is awarded.

- **Relevance to technology area.** Given that the objective of the study is to assess non-market impacts by technology area, we added this characteristic to help us identify papers that analyse impacts *in specific technology contexts.* Accordingly, papers that thoroughly and directly discuss the socio-economic impacts of different applications of a technology were given a higher score than papers that discuss the non-market impacts or spillovers of R&D more generally.

- **Relevance to UK research.** Papers that discuss the application of R&D in the UK were given a higher score than papers that discuss technologies' implications within other countries / contexts. This is to reflect the fact that the application of our literature review is primarily to inform policy design and evaluation in a UK setting.

- **Recency.** This characteristic was included to reflect the probability that papers discussing recent technological innovations are more likely to identify non-market impacts that will arise in the future (and so will be more relevant to future policy-making and evaluation – and thus be useful to BEIS). When scoring papers on this dimension, we also took into account the fact that more conceptual/theoretical papers can remain relevant over relatively long periods of time. Accordingly, and as

agreed in discussions with BEIS, scoring was based on 10-year-intervals, as shown in the previous table.

How we identified the initial 'long list' of typographies from the literature

The final step in our literature analysis was to develop our 'long-list' of typologies. As we explain later, this was subsequently 'refined' based on 'filtering out' certain evidence based on a threshold. Our process for developing the initial long-list, however, was as follows:

- We undertook an initial 'skim review' of each paper and, for each, recorded any specific non-market impacts that were explicitly identified – or could reasonably be inferred.

- In recording the above entries, we also noted whether the reference was "clear and unambiguous" (i.e. there was no doubt as to whether the paper did support the non-market impact referenced) or was "uncertain" (e.g. the impact is more implicit).

- For papers where the record was marked as "uncertain", a second-round review was undertaken. This consisted of a more detailed read-through of the paper by 2 project team members. The non-market impact was only recorded where both reviewers concurred that the paper supported its presence.

- Finally, as part of this review, we undertook an initial assessment of 'how' the non-market impacts arise (to the extent that this was contained in the literature). The output of this was brief bullet-points / sentences setting out the *causality* that gives rise to the non-market impact.

Annex C. Literature analysis

This annex sets out our analysis of the literature we reviewed – which, in turn, provided the basis for the typologies we subsequently developed. In the following we: (i) firstly, summarise the results of our 'classification' of the papers; and then (ii) secondly, provide an assessment of the 'robustness' of the papers.

Summary of our classification of the papers

In total, we identified some 94 papers. Our analysis included systematically classifying the papers in various dimensions, so as to help us both: (i) identify common themes in terms of non-market impacts; and (ii) subsequently, evaluate their robustness.

Literature classified by type

By 'type' of paper, we are referring to the publication details of the papers included in the study. The 'types' of papers were as follows.

Research / other type of institution papers – examples include:

- European Commission;
- International Federation of Robotics;
- National Bureau of Economic Research (NBER);
- Nesta;
- OECD;
- Russell Group;
- UK Space Agency; and
- World Bank.

Peer-reviewed journal articles – examples include papers published in:

- European Economic Review;
- Journal of Nanoparticle Research;
- Journal of Urban Economics;
- Research Policy;
- Science and Public Policy; and
- The British Journal of Sociology.

Research Council papers include studies by the Economic and Social Research Council (ESRC); and the Arts and Humanities Research Council (AHRC). **Consultancy reports** include, for example, those written by Deloitte, Cambridge Econometrics, Euroconsult, and

Mckinsey & co. **Other academic papers** consist of academic work not published in peer-reviewed journals.

Following from the above, the figure below shows a breakdown of the total papers we reviewed, split by publication type.

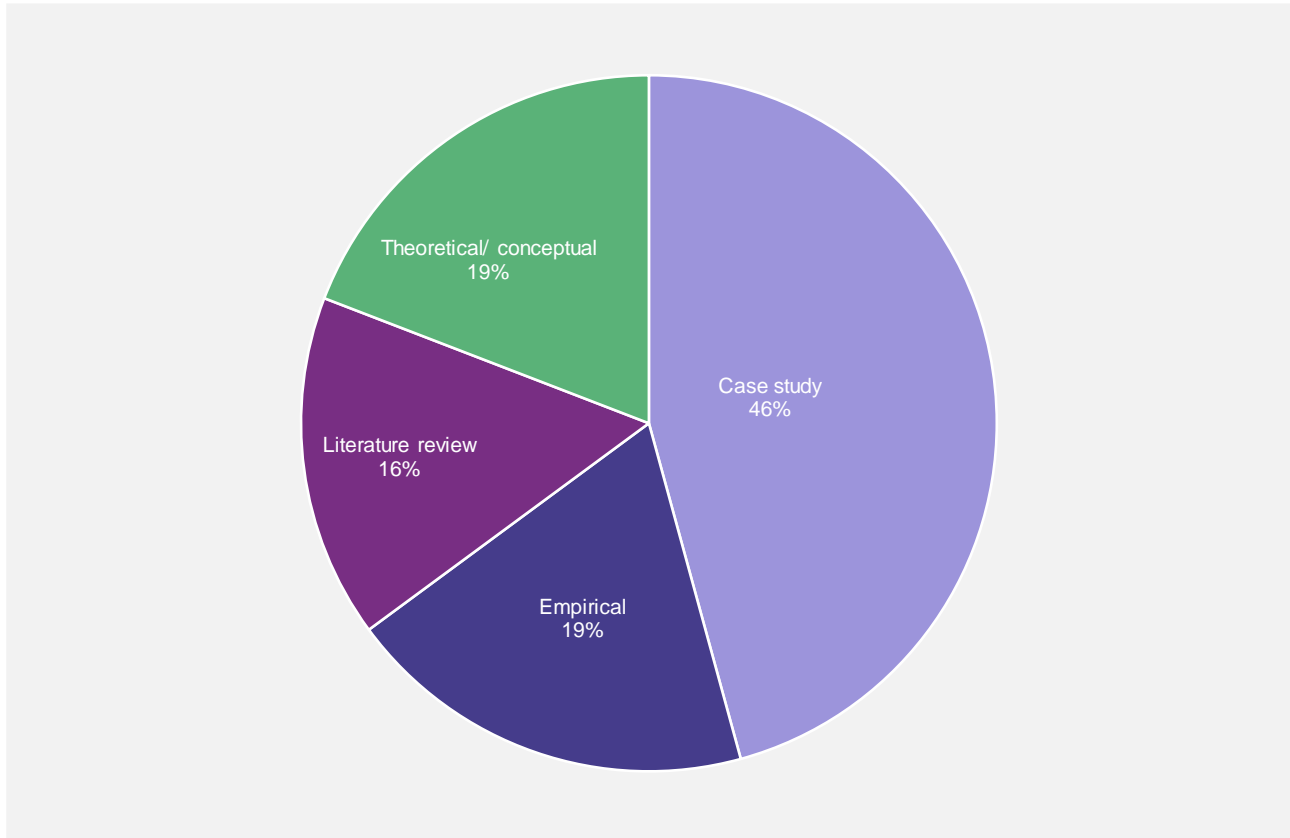**Figure 20: Breakdown of papers by type**
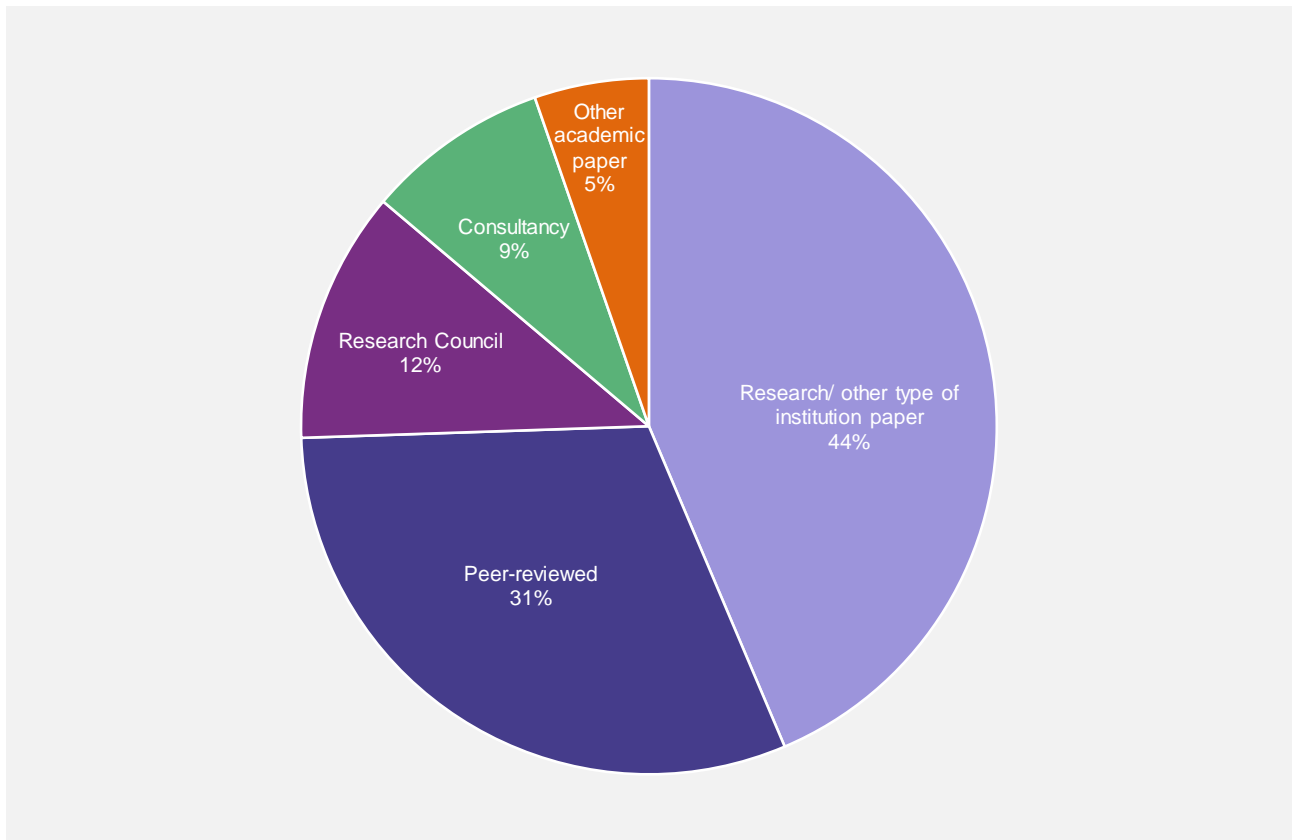
Source: Economic Insight

The key points to note from the above chart are as follows:

- The largest category of papers we reviewed was 'research / other type of institution paper' – which accounted for 44% of the literature base.

- The second largest proportion of papers we reviewed related to 'peer-reviewed academic papers', which accounted for 31% of the papers.

- The smallest category was 'other academic papers', accounting for 5% of the literature.

Literature classified by methodology

The following chart shows the breakdown of papers we reviewed by methodology.

Figure 51: Breakdown of papers by methodology

Source: Economic Insight

The key points to note from the above chart are as follows:

- 'Case studies' were the most frequent methodology used, accounting for 46% of the papers we reviewed.

- The other categories (empirical; literature review and conceptual) were all of a similar size, accounting for: 19%, 16% and 19% respectively.

Literature classified by technology / science area

Papers were also categorised by technology area, as per the following figure.

Figure 22: Breakdown of papers by technology / science area
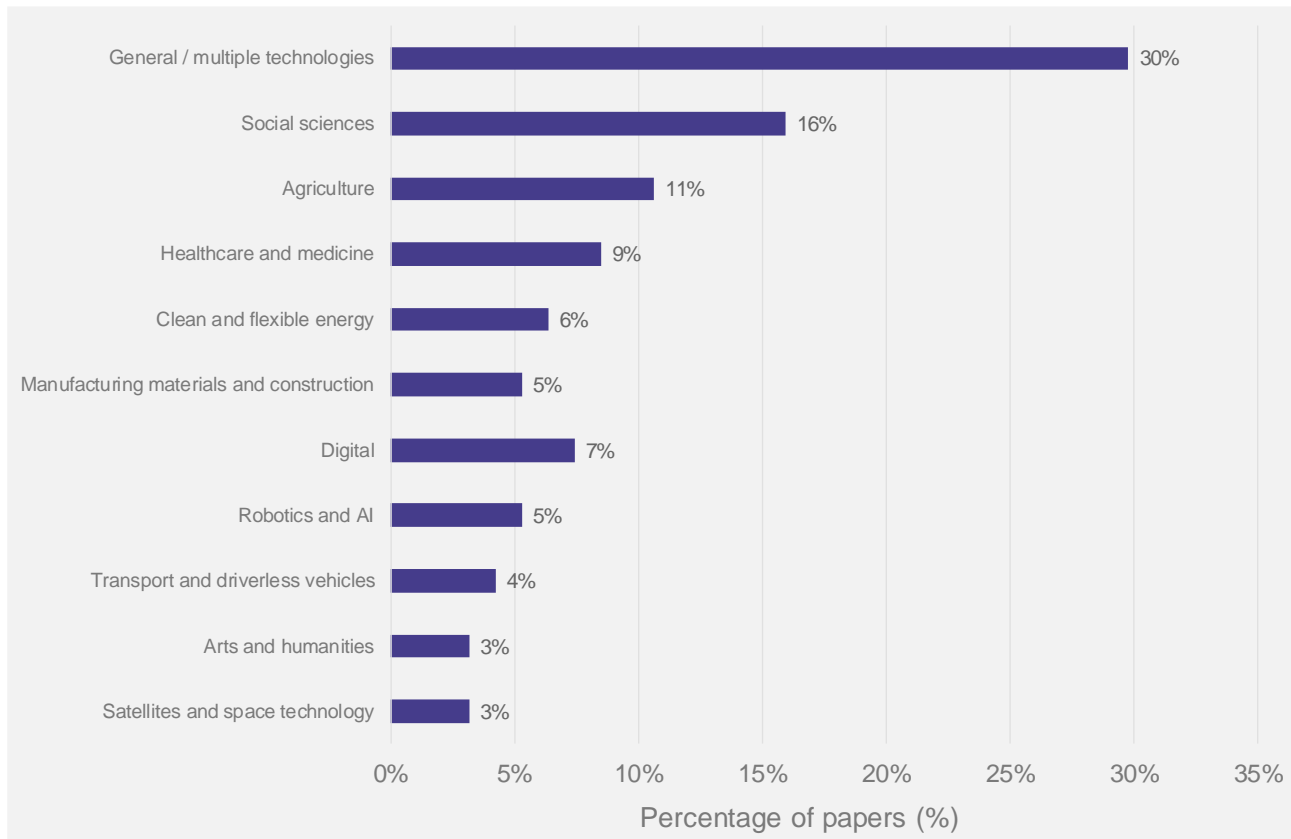
Source: Economic Insight

The main observations we draw from the above include:

- Whilst there is a relatively high number of papers in the 'general' category – this does not imply that they do not relate to technology areas. Rather, we found that many of these papers actually 'cut-across' multiple technologies – and so are helpful sources of evidence for developing typologies.

- Examples of papers that discuss general or multiple technologies include: conceptual papers on the non-market impacts of R&D; papers that estimate the spillovers from R&D investments in general; and papers that assess the non-market impacts of multiple technologies simultaneously.

- Whilst there are relatively 'few' papers relating specifically / solely to certain technology areas (e.g. satellites and space technology) this does not mean that valid typologies cannot be developed for those areas. Indeed, this depends also on the quality of the papers – but also the extent of overlap from the 'general' category above.

Literature classified by publication year

The chart below shows the split of papers by year of publication.

Figure 23: Breakdown of papers by publication year
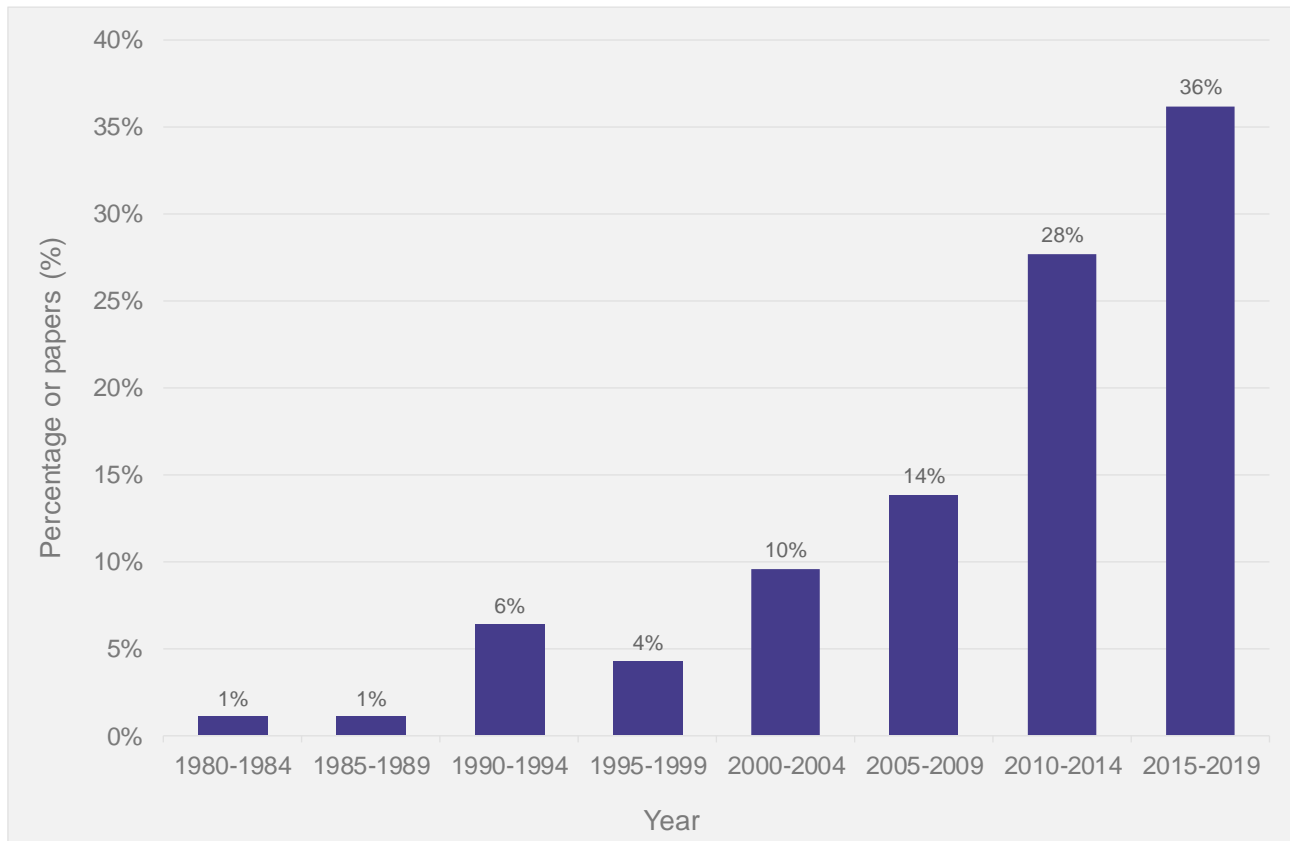
Source: Economic Insight

The above shows that the majority of papers we reviewed were published relatively recently. Specifically, 64% of the papers were published from 2010 onwards; and 78% of papers were published from 2005 onwards. Only 12% of papers were published before 2000.

Assessing the robustness of the literature

Using the method described in the previous annex, the papers were assessed against six criteria (three for robustness / quality and three for relevance) in order to provide information on their overall quality and suitability for developing typologies from.

Overview of quality scores

The following figure provides a summary of the overall **robustness** scores of the papers we reviewed.

Figure 24: Breakdown of papers by robustness score
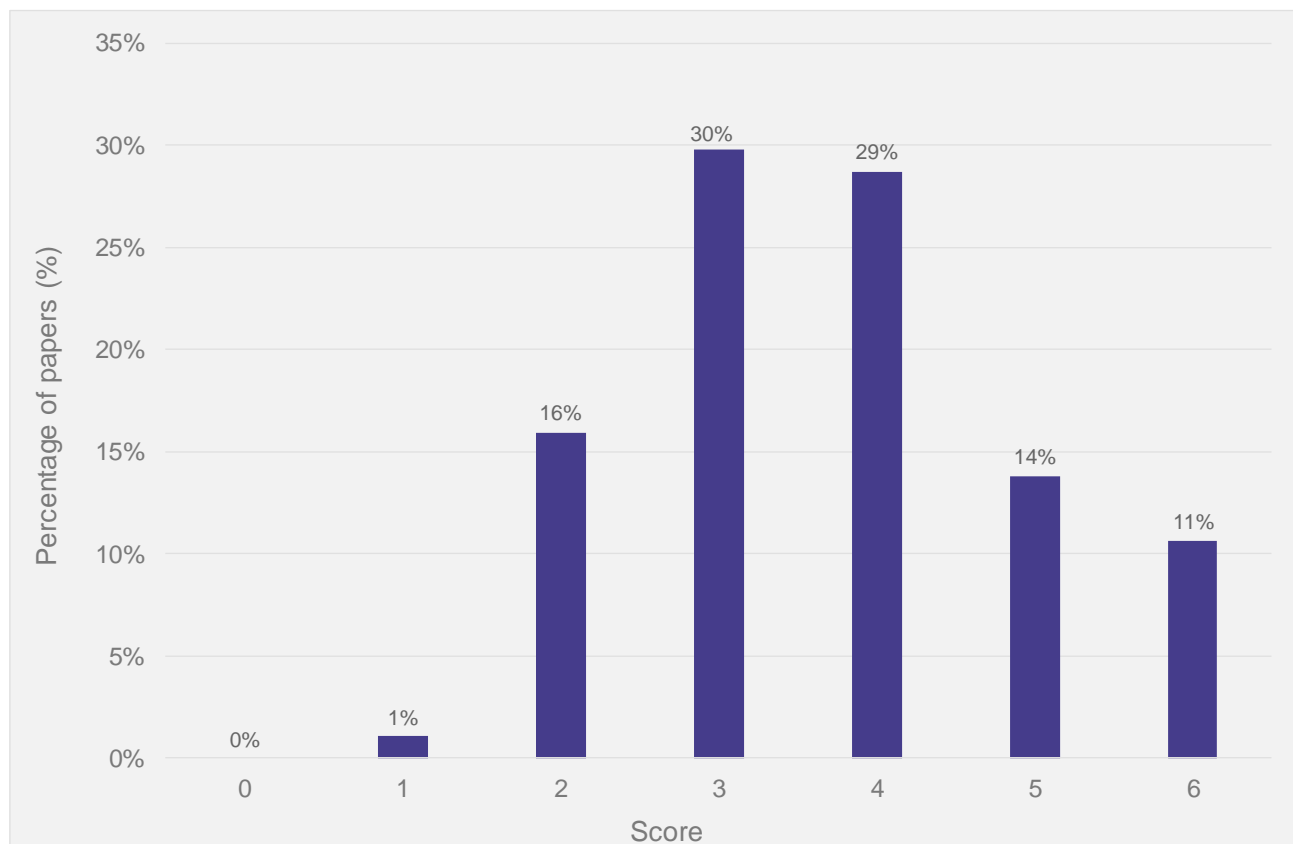
Source: Economic Insight

The key points to note from the above chart are as follows:

- The overall average score of all papers reviewed was **3.7** out of 6.

- The majority of papers (84%) had a score of **3** or more out of 6.

- Furthermore, we find that (54%) had a score of **4** or more out of 6.

- Our overall finding, therefore, is that the 'robustness' of the literature base is generally good.

- Following from the above, the next figure shows our assessment of papers according to 'relevance' (again, out of 6).

Figure 25: Breakdown of papers by relevance score
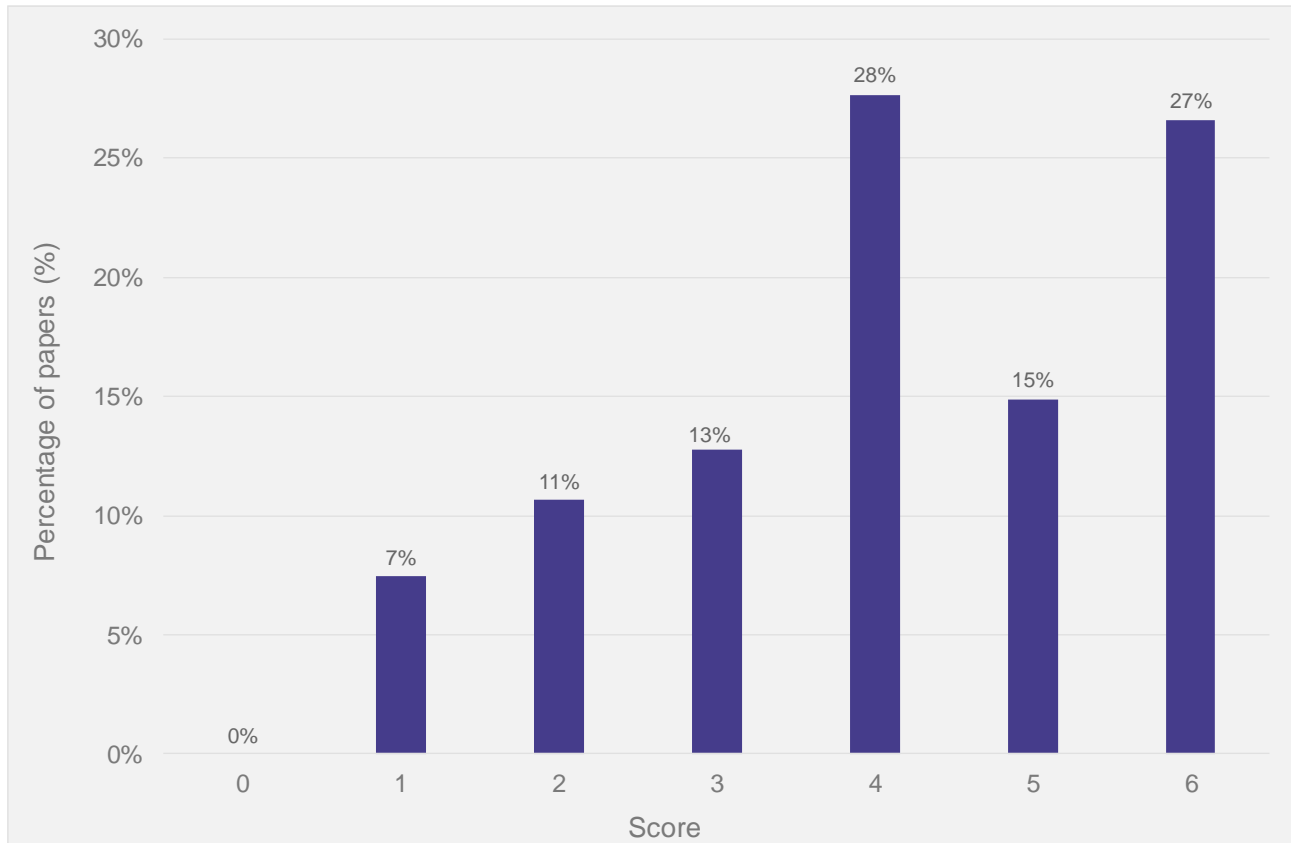
The key points to note from the above chart are as follows:

- The overall average score of all papers according to 'relevance' was **4.1** out of 6.

- **83%** of papers had a score of 3 or more relating to relevance.

- **70%** of papers had a score of 4 or more in relation to relevance.

Again, therefore, we generally find that the literature we reviewed performed well in terms of 'relevance'. As we subsequently explain, we ultimately applied a 'threshold' regarding our assessment of the quality of the literature, in order to filter down to the most credible (and useful) set of typologies to focus on.

Selected examples of high quality papers

To help further illustrate the application of our scoring system in practice, it is worth highlighting some *selected* examples of the papers we found to be useful. These are summarised in the following text boxes.

> **The Social Impact of Research Conducted in Russell Group Universities, Russell Group (2012)**
>
> This paper presents a range of case studies in relation to the contribution of research in improving the quality of life in the broad spheres of society, health, the environment, policymaking and culture. It covers 50 case studies, including, for example: a new musical instrument designed by academics at the University of Edinburgh to help children with profound physical and learning challenges; a collaborative research programme that has contributed to possible new treatments for malaria; and a University of Cambridge study that has helped reduce crop losses from pests and pathogens.

> **Evaluation of Socio-economic Impacts from Space Activities in the EU, Booz & Co (2014)**
>
> This paper catalogues and characterises over 200 studies, past assessments and reports of socio-economic impacts from space activities in the EU. The analysis focuses on applications of space technology in the following domains: Earth Observation (EO), navigation, telecommunications, launchers, space sciences, and space exploration. Within each domain, impacts were classified into: GDP impacts; catalytic impacts; other measurable impacts; and intangible positive externalities. Examples of non-market impacts identified include: increased safety (including national security and improvements to wider travel safety) and broad societal benefits. The paper also presents a framework for assessing the socio-economic impacts of space activities that could be applied in other contexts of space technologies.

How do New Technologies Impact on Workforce Organisation?, The Evidence Centre for Skills for Health (2011)

This paper reviews 302 empirical studies on the impacts that the introduction of new technologies in the healthcare system has on the organisation of staff and teams. An example of an impact identified from the case studies is "empowering patients", where patients have more information, that enables them to be an integral part of their care team, and closely follow through the symptoms and the outcomes. Evidence also exists on the positive impacts of introducing new technologies on the care delivery process, and staff satisfaction.

The Social and Economic Impact of Innovation in the Arts, NESTA (2017)

This paper presents a methodological framework explaining how arts participation and attendance contribute to positive social outcomes, such as reduction in crime, enhancement of social capital, and improved health outcomes. Subsequently, the authors review empirical studies that estimate the relationship between art and wellbeing. Findings from an empirical study by Fuijwara et al (2014) show that there is a statistically significant positive relationship between consumption of arts and an individual's wellbeing.

Research on human vision preventing road accidents, ESRC (2017)

This case study discusses the impacts that research undertaken by Professor John Wann had on public policy in the UK, with regard to speed limits. In particular, the Professor's research facilitated the testing of 20mph speed limits for residential areas across 40 local authorities, including: Liverpool, Portsmouth, Bristol, York, Brighton, Bath, Newcastle, Oxford, Cambridge, and Hackney. These trials ultimately influenced policy, resulting in the 20mph limit being rolled out more widely across residential areas. It is estimated that this policy change results in saving 38 lives and preventing over 450 serious injuries each year.

Annex D. Further evidence on typology prevalence

We next examined prevalence at the more detailed level of specific non-market impact types, as shown in the following figure. Here, by definition, because there is a much larger set of specific 'types' of impacts (relative to the higher-level categories shown above) the prevalence of any one type will be materially lower.

Figure 26: Overall prevalence of non-market impacts at detailed level

Prevalance in literature (% of total non-market imapct references)
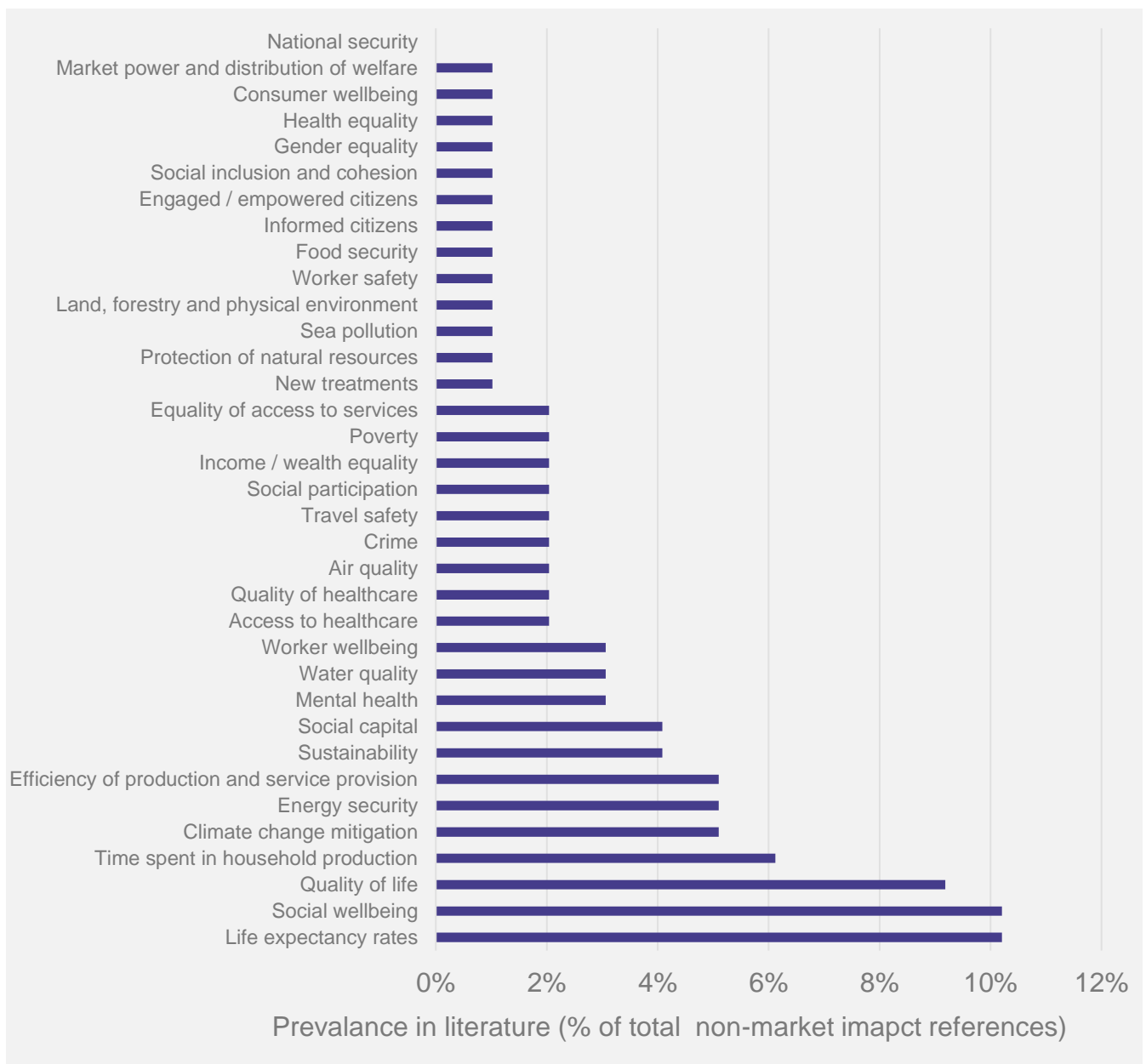
Source: Economic Insight

Here, we find that:

- The non-market impacts most prevalent in the data include: life expectancy; social wellbeing; and quality of life.

- There is a relatively 'long-tail' of non-market impact types, which all have low levels of prevalence (i.e. indicating that they receive one or two mentions across the papers reviewed). These include, for example: market power; consumer wellbeing; health equality; gender equality; social inclusion / cohesion; engaged / empowered citizens; food security; worker safety; land, forestry and physical environment; sea pollution; protection of natural resources; and new (health) treatments.

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