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Spillovers in the space sector

A research report for the UK Space Agency

London Economics

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Study overview

The significant challenges of space as an operating environment mean that investments in research and innovation are essential for success. As well as benefiting the space industry, these investments result in new knowledge, expertise and technologies that benefit the wider economy. These impacts are termed 'spillovers' and underpin the case for public investments in the space industry. This report details these impacts in the context of space; presents the evidence on what determines the generation and size of these impacts and presents case studies on the spillovers associated with specific UK Space Agency investments in the space research and technology.

To this end, this study was conducted in three phases:

- **Phase 1 – Framework:** review of the theoretical literature on spillovers to define what we mean by spillovers and detail the key characteristics of spillovers.
- **Phase 2 – Review of evidence:** review of space-specific literature to quantify the main spillover parameters in the space sector, and to identify the key drivers of spillovers.
- **Phase 3 – Case studies:** desk-based research and consultations with space industry stakeholders to develop six case studies that detail the spillovers associated with the following six UK Space Agency investments: Space for Smarter Government Programme (SSGP), National Space Technology Programme (NSTP), Synergistic Air-Breathing Rocket Engine (SABRE), Herschel Spire, ExoMars and Rosetta.

Together, these outputs serve as a critical input in the evidence base on the impact of UK public investments in space sector and will allow the UK Space Agency to make stronger impact assessments and justifications for future activities in the sector.

Key findings

- The harsh characteristics of space place specific design and operational constraints on space technologies. To address these challenges, space programmes develop, refine and/or integrate different terrestrial technologies. These technologies often spin-out of the space sector and add value to terrestrial applications. Satellites also provide services that enable a wide range of applications for government, commercial and citizen users. In these ways, space generates significant additional benefits for society.
- These wider benefits are termed spillovers. The existence of these wider benefits justifies public funding of space activities.
- These spillovers can be categorised into three types: knowledge, market, and network.
- The benefits of space investments are transmitted by the movement of labour between organisations; knowledge exchange between workers; international exchanges, such as through trade, FDIs, and direct learning, and via the commercialisation of innovation.
- Most reviewed studies adopt definitions of economic impact that are inconsistent and narrower than the definition of spillovers used in this study. For this reason, it is difficult to synthesise common findings.
- Even so, the private benefit of R&D to innovators (i.e. ripple effects) appear to be approximately £3-4 in impact for each £1 of public expenditure, with the spillover impacts to the broader public being significantly larger.

- The lag between investments and spillovers impacts for space projects are in the order of 3-5 years, with impacts realised sooner for companies providing downstream services or contract manufacturing services, and longer for companies developing their own products.
- The key drivers of spillovers fall in four areas: funding characteristics; technological characteristics; sectoral characteristics, and environmental characteristics.
- Environmental factors have a dominant influence on spillover impacts. On the technology side, important factors seem to be: i) the diversity of the technologies, ii) their degree of maturity, and iii) the extent to which they are generic or specific. These rank alongside factors related to the relationship between innovators and recipients (degree of trust, existence of absorptive capacities), and the internal structure of innovators and recipients (degree of decentralisation and vertical integration).
- A lack of quantitative studies has limited the extent to which conclusions on the causal link between different drivers of spillovers and key spillover parameters can be made. To make this possible, UK space and research programmes need to be systematically designed to collect quantitative data on programme outcomes from the outset.
- Across the six case studies reviewed for this report, there is strong evidence of high public returns from the UK's space programmes. Several common themes have been identified which underscore the uniqueness of space as an environment for generating spillovers. These include:
  - The critical role of UK grant funding in supporting the realisation of spillover impacts from space programmes is strongly identified;
  - To address the difficult design challenges of the space environment, space programmes have an important role as an integrator and enhancer of terrestrial technologies;
  - Space R&D programmes typically involve large network of multi-disciplinary teams with significant resources over very long periods of time. This environment provides a unique opportunity for long-term knowledge accumulation that can 'spill over' into other areas;
  - Supporting programmes and investment are often required to support the commercialisation of the outputs of space R&D outputs, and
  - The long-term and early-stage nature of space programmes mean that spillovers may not be observed for many years after specific mission milestones have been reached.

1 Introduction

The harsh space environment places stringent design requirements on space technologies. To address these requirements, the space sector has a unique role as an integrator and enhancer of terrestrial technologies for space applications. This results in innovations in knowledge or products that can 'spin-out' of the space sector to address terrestrial challenges.

In this way, the benefits of investments in space-related research or programmes can extend beyond the returns made by those immediately involved. Since these societal benefits cannot be exploited by those directly tasked with delivering the space activities, there is a justification for public funding of space programmes and research activities to serve the broader public interest. These wider benefits are termed 'spillovers', as they 'spill-over' to groups outside of the initial space activity.

The existence and extent of these spillovers in the space sector has already been evidence in previous research, including London Economics' *Case for Space*[1] and *Returns from Public Space Investments*[2] studies for the UK Space Agency.

However, these studies identified limited evidence on the mechanisms that generated these spillovers, and how this varies by different types of investments. Thus, while the UK Space Agency – an executive agency of the UK government responsible for all strategic decisions on civil space programme – strives to estimate economic spillovers using space-specific information, the absence of such specific information means that generic assumptions are often used.

This makes it difficult to assess the relative merit of different public investment proposals within the sector and make a convincing case for limited public funds with competing priorities more broadly.

This study attempts to address this gap. It does so by using desk-based research and a number of consultations with space industry practitioners and experts to: i) provide a framework for space-specific spillovers – including definitions, typologies, and properties; ii) detail the variables that influence spillovers as evidenced in both the general and space-specific literature, and iii) present case studies of the spillovers associated with UK Space Agency investments in space research and technology. Details of the methodology are provided in Annex 1.

To this end, this report is arranged as follows:

- **Chapter 2** presents a framework to define spillovers, differentiate between sources of spillovers, and identify the parameters that influence spillovers;
- **Chapter 3** presents the quantitative evidence on the magnitude of spillovers in the space sector;
- **Chapter 4** identifies the key determinants of spillovers, based on the general and space-specific literature, and
- **Chapter 5** presents six case studies of the spillovers associated with selected UK Space Agency investments in space research and technology, and identifies common themes across these six case studies.

[1] London Economics (2015). *The Case for Space 2015.* The impact of space on the UK economy.

[2] London Economics (2015). *Return from Public Space Investments.* An initial analysis of evidence on the returns from public space investments.

2 Spillover framework

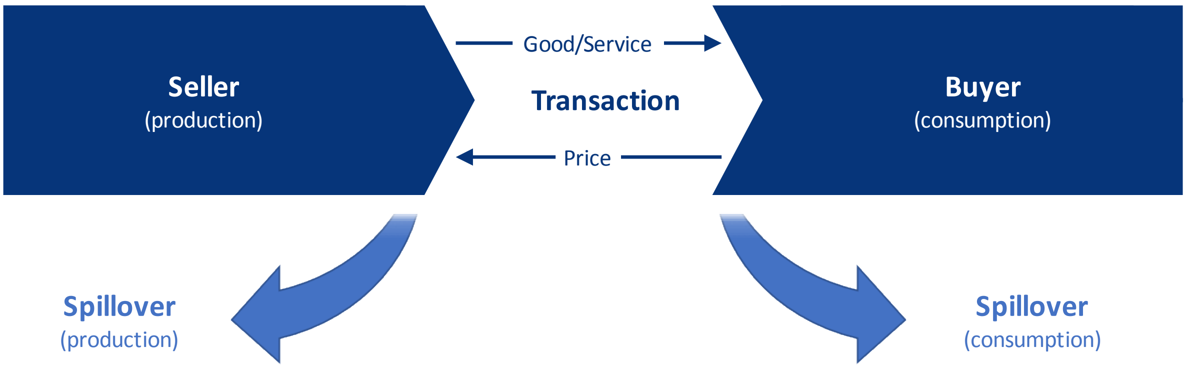
The spillover literature is characterised by an inconsistency in terminology, definitions, typologies, and measurement methodologies. To overcome this, this section proposes a standardised framework for understanding spillovers, including: a definition, a typology, and an overview of the key characteristics of spillovers. This framework also identifies and defines the channels through which spillover impacts occur (i.e. the linkages between inputs, activities and impacts).

2.1 What is a ‘spillover’?

In economics, the term ‘spillover’ is used to describe any effect arising from an activity that is not reflected in the cost paid (or payoff received) by the parties directly involved in the activity, particularly on external third parties. For this reason, a spillover is also referred to as an ‘externality’.

Consider a simple market transaction: a **seller** provides a good/service to a **buyer** in exchange for an agreed sum of money (price). The commercial value is captured in the **price**. However, there is usually additional value that is not captured in the price. For example, the seller’s production may generate environmental pollution (e.g. space debris), or the buyer’s consumption of the good/service may enhance the well-being of others (e.g. satellite communications and navigation for emergency services benefits citizens). This **additional value ‘spills over’** beyond the transaction. ‘Spillover’ effects can be positive or negative, and intended or unintended.

Figure 1 Potential for value to ‘spill over’ from a market transaction



Source: London Economics

The potential for spillovers is particularly high where new knowledge, goods and services are being generated through **investments in research and development (R&D)**, and few industries are more highly R&D intensive than the space industry[3].

Investments in R&D can generate impacts that accrue to those making the investment (**internal effects**), such as the additional profit a company earns from its own investment, or to third parties (**external effects**)[4]. Together, these effects represent the total return of an innovation to society, referred to as the **social return of an innovation**.

[3] London Economics (2016). *The Size & Health of the UK Space Industry.*
[4] London Economics (2012). *The impact of investment in intangible assets on productivity spillovers*, May 2012. BIS Research Paper number 74.

Internal effects include: i) **first order effects** that *directly* result from an investment, such as the intended cost savings from research into more efficient manufacturing processes, and ii) **ripple effects** (i.e. second order effects) which refer to the follow-on benefits of an investment within the investing organisation (the innovator). Ripple effects include leveraging knowledge gained and capability demonstrated in one R&D project to another project, client, or product/service. Internal effects represent the **private return to an innovation**, and therefore the innovator's incentive to innovate.

External effects are referred to as **spillovers**, and describe the difference between the total social return of an innovation and the private return to an innovation. The effects can be either positive – benefitting the wellbeing of others, or negative – detrimental to the wellbeing of others. For example, if an R&D project in one organisation raises the productivity of employees in that organisation, and these employees then move to other organisations, the increased productivity such employees bring to these other organisations are referred to as spillovers.

Linking back to the definition above, it is important to note that any benefits from a company's R&D activities that are accounted for by price mechanisms are not spillovers. For example, employees that are compensated with higher wages when they move between organisations may have *fully* internalised the knowledge gains that they may bring from their previous employers through the higher wages. The higher productivity that they bring to the new organisation, therefore, does not represent a spillover.

2.2 Why should governments invest in activities with positive spillovers?

Without government support, private companies are likely to under-invest in activities with positive spillovers because they cannot fully capture all the benefits of these activities. Conversely, in the absence of government intervention, private actors are likely to over-invest in activities generating negative spillovers because they do not fully bear the costs. Both these cases of market failure present justifications for government intervention.

However, increased globalisation and international labour and capital mobility suggest that countries can benefit from knowledge spillovers without investments in domestic R&D[5]. Nevertheless, public investment in R&D remains important as it increases the absorptive capacity of domestic organisations. The absorptive capacity represents an organisation's ability to capture and transform knowledge, so any increase would enable greater spillovers into the domestic economy. Thus, public investment in R&D remains a key driver for generating innovation and spillovers even as knowledge becomes more internationally mobile[6,7].

2.3 Spillovers in the context of the space sector

Spillovers from the space sector are most often the product of **technology transfers**. This describes the transfer of knowledge – often embodied in a patent or product – from one organisation (the innovator) to another (the recipient). Successful transfer sometimes requires modifications and

[5] Haskel, J., Pereira, S. and Slaughter, M. (2002). *Does Inward Foreign Direct Investment boost the Productivity of Domestic Firms?* SSRN Electronic Journal.
[6] Sveikauskas L. (2007). *R&D and productivity growth: A review of the literature*. BLS Working Papers 406.
[7] Hall B, et al. (2010). Chapter 24: Measuring the returns to R&D. In: Hall BH, Rosenberg N (eds.). Handbook of the Economics of Innovation, Volume 2.

adaptations of the technology itself, or of other aspects that can support is utilisation (e.g. changes in organisation structure, adoption of new procedures, etc.).

The term '**spin-off**' is often used interchangeably with technology transfers in the literature. However, it refers to a specific case where the technology transfer is achieved through the creation of a new organisation in charge of the transfer and exploitation of the new technology[8].

In the space domain, spillovers are typically generated through technology transfers via the **Earth-Space-Earth technology transfer pathway**. This means that technologies 'spin-in' from terrestrial industries to the space sector, before undergoing development to improve their performance and feasibility to address the high design requirements of space (e.g. environmental robustness, low power, low weight, miniaturisation, cost minimisation). This process results in an innovation that can then be used in terrestrial applications[9], although only after the innovation has been 'downgraded' for use in the non-space domain. For this reason, **the space sector has a special role as an integrator and enhancer of terrestrial technologies**[10].

2.4 What are the types of spillovers?

Several studies have suggested various typologies for R&D spillovers. One of most prominent suggests four categories: technological, commercial, managerial, and work-factor effects[11]. However, these categories can effectively be reduced to just three types of spillovers[12]:

- **Knowledge spillovers** are the primary focus of spillover-related literature and refer to knowledge generated by an organisation (innovator) and used by another who does not fully compensate the innovator for the full value of the knowledge[13]. This is possible because knowledge is often 'non-rivalrous'. This means that its use by one agent does not prevent others from using it[14]. Knowledge spillovers occur through various channels, including the mobility of labour, the publication of papers, and international trade, but they are also embodied in the commercialisation of the innovation. This is because commercialisation signals the success of an innovation and results in products or processes that directly embody the new knowledge and can be copied.
- **Market spillovers** refer to spillovers that occur through the market mechanism, and not the flow of knowledge itself. In other words, market spillovers only flow to other market participants and only once the innovation has been successfully commercialised. This happens when an innovating organisation is not able to charge a price that fully captures all the benefits of their innovation, with producers (further down the supply-chain), and consumers capturing the difference. This difference is referred to as **producer surplus** and **consumer surplus**, respectively. For example, the extent to which an innovation in an

[8] Bach, L., Cohendet, P., and Schenk, E. (2002). Technological Transfers from the European Space Programs: A Dynamic View and Comparison with Other R&D Projects. The Journal of Technology Transfer. p.323.

[9] Venturini, K., and Verbano, C. (2014). A systematic review of the Space technology transfer literature: Research synthesis and emerging gaps. Space Policy. p.104

[10] Bach, L., Cohendet, P., and Schenk, E. (2002). *Technological Transfers from the European Space Programs: A Dynamic View and Comparison with Other R&D Projects*. The Journal of Technology Transfer. p.325.

[11] Cohendet, P. (1998). Evaluating the industrial indirect effects of technology programmes: the case of the European Space Agency programmes.

[12] Jaffe, A. (1998). The importance of "spillovers" in the policy mission of the advanced technology program. *The Journal of Technology Transfer*, 23(2), pp.11-19.

[13] Jaffe, A. (1998). The importance of "spillovers" in the policy mission of the advanced technology program. *The Journal of Technology Transfer*, 23(2), pp.11-19.

[14] Graziola, G., Cristini, A., and Di Ciaccio, S. (2015). *The Importance of the Technological Spillovers for the Returns to Space Investments, with an Empirical Application to the Italian High-Tech and Space Sectors.* New Space.

upstream organisation represents either: i) profit for the innovating upstream organisation (i.e. internal benefits); ii) profit for the downstream companies, which can provide better applications as a result of the upstream innovation (producer surplus), or iii) increased consumer surplus because of the use of the improved application, depends on the level of market competition in the upstream and downstream markets[15]. High levels of competition in either market favour the immediate purchaser of the good or service as they prevent the price from rising to fully reflect the value of the innovation. In this way, competition has the effect of raising market spillovers, even as they reduce the private returns to innovation[16].

- **Network spillovers** occur when an innovation increases the value of other innovations, such as when the value of a technology is dependent on the development of related technologies[17]. For example, consumers will only purchase applications on a particular operating system if other providers develop other applications that make the operating system itself sufficiently attractive and widely used[18]. In other words, a **'critical mass'** of users is required for the system to function properly. Thus, a company that develops an application generates a positive spillover for other companies by increasing the likelihood of reaching this critical mass. The existence of network spillovers does, however, create a **coordination problem.** For example, individual organisations may postpone innovations until they are sure that complementary innovations are being undertaken by others[19].

2.5 How are spillovers transmitted?

Spillovers are transmitted via several mechanisms. At a high-level, these channels include: the movement of labour between organisations; knowledge exchange between workers; international exchanges, such as through trade, FDIs, and direct learning, and via the commercialisation of innovation. These channels are explained in more detail below.

- **Labour mobility**: knowledge can be transmitted through the mobility of skilled workers who may acquire knowledge in one organisation and then share it with their new employers when they change job[20]. This knowledge exchange only constitutes a spillover if the value of the employee's knowledge is not fully compensated for by a higher wage at the new organisation.
- **Worker interaction:** worker interaction refers to knowledge that is shared between organisations via formal knowledge exchanges between workers e.g. at conferences, and through publications, and informal exchanges at meetings or networking events[21]. The benefits of this type of interaction are often acknowledged by organisations who may

[15] Graziola, G., Cristini, A., and Di Ciaccio, S. (2015). *The Importance of the Technological Spillovers for the Returns to Space Investments, with an Empirical Application to the Italian High-Tech and Space Sectors.* New Space.
[16] Bakhtiari, S. and Breunig, R. (2017). The role of spillovers in research and development expenditure in Australian industries. *Economics of Innovation and New Technology*, 27(1), pp.14-38.
[17] Bakhtiari, S. and Breunig, R. (2017). The role of spillovers in research and development expenditure in Australian industries. *Economics of Innovation and New Technology*, 27(1), pp.14-38.
[18] Jaffe, A. (1998). The importance of "spillovers" in the policy mission of the advanced technology program. The Journal of Technology Transfer, 23(2), pp.11-19.
[19] Jaffe, A. (1998). The importance of "spillovers" in the policy mission of the advanced technology program. The Journal of Technology Transfer, 23(2), pp.11-19.
[20] London Economics (2012). *The Impact of Investment in Intangible Assets on Productivity Spillovers.* BIS Research Paper Number 75, May 2012.
[21] Bloom, N., Schankerman, M., Van Reenen, J. (2013). Identifying Technology Spillovers and Product Market Rivalry.

engage in multi-organisation research collaborations to internalise other organisation's research efforts in this way[22,23].

- **International exchange:** a wide variety of literature examines the effects of foreign R&D on domestic productivity[24,25,26]. There are three mechanisms that explain how international knowledge spillovers occur[27]:
  - **International trade:** knowledge may be transmitted through international trade as domestic producers may benefit from the purchase of foreign-produced intermediate inputs that embody new innovations.
  - **Foreign direct investment (FDI):** knowledge spillovers may come from FDIs through one of two mechanisms. Firstly, local organisations may acquire knowledge by purchasing technologies from foreign multinational subsidiaries. Secondly, domestic organisations may enter new countries to acquire the local knowledge in their host countries.
  - **Direct learning:** international knowledge spillovers may occur through directly learning from foreign technologies at a reduced cost relative to the cost of innovation through, for example, the exchange of blueprints or licensing.
- **Commercialisation:** the commercialisation of knowledge, as embodied in products or processes, can reveal some aspects of the new knowledge to buyers and users of those new products or processes. This is because successful commercialisation can signal that the research was productive (or conversely, that the failure to commercialise is a signal that a line of research is not worth pursuing)[28], and secondly because the use of a product or service is a direct means of understanding the new knowledge that is embodies. For example, competitor organisations can acquire the knowledge underpinning innovative products through **reverse engineering** or **technology licensing**.

The effectiveness of these channels is influenced by geography. For example, close **geographical proximity** between organisations allows more interaction between workers and organisations, fosters more competition, and increases both the size and diffusion rate of knowledge spillovers[29] via the mechanisms outlined in Box 1 below.

The close concentration of organisations (e.g. industrial clusters) can also result in **agglomeration benefits**, increasing both innovative potential and ability to absorb, generate, and diffuse knowledge. For example, Silicon Valley is widely recognised to be a tech cluster whose geographical concentration of tech industries is key to its status as one of the world's frontier technological

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[22] London Economics (2012). *The Impact of Investment in Intangible Assets on Productivity Spillovers.* BIS Research Paper Number 75, May 2012.

[23] Moretti, E. and Thulin, P. (2013). *Local multipliers and human capital in the United States and Sweden*. Industrial and Corporate Change, 22(1), pp.339-362.

[24] Coe T., Helpman E. and Hoffmaister W. (2008) *International R&D spillovers and institutions*, National Bureau of Economic research, NBER Working Papers 14069.

[25] Belitz, H. and Mölders, F. (2016). International knowledge spillovers through high-tech imports and R&D of foreign-owned firms. The Journal of International Trade & Economic Development, 25(4), pp.590-613.

[26] Verspagen, B. (1997). 'Estimating international technology spillovers using technology flow matrices', Review of World Economics (Weltwirtschaftliches Archiv), 133(2), p.226-248

[27] London Economics (2012). *The Impact of Investment in Intangible Assets on Productivity Spillovers.* BIS Research Paper Number 75, May 2012.

[28] Jaffe, A. (1998). The importance of "spillovers" in the policy mission of the advanced technology program. The Journal of Technology Transfer, 23(2), pp.11-19.

[29] Numerous studies evidence this including: Bakhtiari, S. and Breunig, R. (2017). The role of spillovers in research and development expenditure in Australian industries. Jaffe, A. (1988). *Demand and Supply Influences in R&D Intensity and Productivity Growth*. Lychagin, S., Pinkse, J., Slade, M., Van Reenen, J. (2016) *Spillovers in Space: Does Geography Matter?* Bottazzi, L. and Peri, P. (2003). *Innovation and spillovers in regions: Evidence from European patent data.*

hubs[30]. The space cluster in Harwell aims to achieve similar benefits. Likewise, the UK's Catapult centres are often seen to provide central hubs of concentrated knowledge. The importance of agglomeration benefits is frequently cited in the literature as being a key determinant for spillover generation[31].

However, agglomeration spillovers may also produce negative effects because organisations may under-invest in training since geographical proximity increases the likelihood of labour mobility. For this reason, the net effect of agglomeration in some cities has been found to be negative in some cases[32]. In general, however, geographical proximity is similar to network spillovers in that concentrations of activity generally benefit the wider system as a whole.

Box 1 Why geography matters: codified vs tacit knowledge

To understand why **where** an innovation takes place matters, it is important to distinguish between two types of knowledge: (1) codified knowledge and (2) tacit knowledge.

Codified knowledge refers to knowledge that can be transmitted between actors formally and is easily understood. For example, the discovery of a new mathematical formula can be written down and transferred to another person. Codified knowledge is ***not* geographically bounded**: physical distance does not affect the ability or inability of this type of knowledge to spread. In recent years, the increasing sophistication of information and communications technology, means that codified knowledge transmission faces fewer physical barriers (for instance, a formula can be transferred across the globe in a matter of seconds via the internet).

Tacit knowledge, however, ***is* geographically bounded.** Tacit knowledge refers to knowledge that is hard to formally teach, and is knowledge that contains components that may not be known even to expert practitioners. For example, a type of tacit knowledge includes recognising the market potential of a new invention. Tacit knowledge is geographically bounded because many types of knowledge transmission must occur face-to-face, the individual actors capable of recognising an innovation opportunity only exist in certain geographical spaces, or the agglomeration of many actors pursuing the same goal in a geographical area leads to positive externalities that are difficult to replicate remotely (for example, one key to Silicon Valley's dominance in the tech-sector is its concentration of high-tech organisations in the local area).

Codified and tacit knowledge have very different transmission mechanisms. Codified knowledge can be transmitted through automatic diffusion, including voluntary and involuntary imitation of a competitor's technology. Likewise, codified knowledge can be transmitted through market transactions involving intellectual property rights (e.g. patents).

Tacit knowledge is more complex, and its transmission often relies on face-to-face contacts, which is **geographically bounded**, and the interaction of important agents in the market (e.g. key scientists and entrepreneurs making a new discovery through collaboration). In other words, networks are very important.

[30] Chatterji, A., Glaeser, E. and Kerr, W. (2014). Clusters of Entrepreneurship and Innovation. *Innovation Policy and the Economy*, 14, pp.129-166.
[31] For example, see: Cincera, M. (2005). Firms' productivity growth and R&D spillovers: An analysis of alternative technological proximity measures. *Economics of Innovation and New Technology*, 14(8), pp.657-682.
[32] Brunello, G. and Gambarotto, F. (2007). *Do spatial agglomeration and local market competition affect employer-provided training?* Evidence from the UK. Regional Science and Urban Economics, 37(1), pp.1-21.

In summary, there is academic consensus that many types of knowledge spillovers are localised, and often its transmission relies on tacit knowledge, meaning that **where** an investment is made within a country can greatly change the resulting spillovers.

2.6 How are spillovers measured?

The spillover impact of a public space investment can be measured (or modelled) with reference to a range of parameters, as defined below:

- **Spin-off technologies** refer to commercial goods or services (or the creation of a company) resulting from technological developments in another organisation or sector.
- **Technology transfer** is the process of transferring a technology from an innovator to a wider distribution of actors.
- **Innovators** are the organisations that originally developed a technology or knowledge through receiving R&D funding.
- **Recipients/beneficiaries** are the organisations to which the technology or knowledge is transferred.
- **Magnitude:** quantifies the net spillover impact from the investment of public funds. Magnitude is measured as the quantified impact on the output or productivity of other organisations and wider benefits (knowledge spillovers, consumer surplus, environment, health, safety, etc.). One way to measure the magnitude of spillovers is the multiplier approach. The division of total benefits by the total cost of the R&D investment (both in Net Present Value terms) results in a multiplier which can be interpreted as the average additional economic benefits to the economy after an initial public investment of £1, or the return per pound of public investment. However, different studies adopt different definitions of value, which are often narrower than the definition of spillovers used in this study. Examples include the following:
  - **Ripple effects ratio:** this looks at the ratio of indirect benefits earned by the organisations in receipt of R&D contracts (i.e. follow-on revenues) to the aggregate value of these contracts. This ratio is focused only on those R&D benefits that are accrued by organisations that undertook the R&D activity.
  - **Internal effects ratio:** includes both direct and follow-on revenues from R&D contracts that are earned by the organisations that undertook the R&D activity. It is the ratio of total benefits from a contract to the aggregate value of these contracts. In this sense, it measures an impact that is much broader than that captured by the ripple effects ratio.
  - **Spillover rate of return:** measures the impact of an investment on the output (producer surplus) of other organisations not involved in the R&D activity and wider benefits (knowledge spillovers, consumer surplus, environmental benefits, etc.) net of deadweight and displacement effects. It is expressed as the ratio of total spillover impacts to the size of the investment (Net Present Value / Departmental Expenditure Limit). This is equivalent to the spillover return per £1 of public investment.
- **Lag:** time in years before the spillover impact begins to be realised.
- **Benefit duration:** time in years (from the end of the lag) that the spillover impact endures.
- **Depreciation:** refers to the rate at which spillover benefits diminish over a period of time.
- **Deadweight:** the spillover impact that would have occurred without the public investment. This estimation of what would have happened in the absence of the investment is known as the ‘counterfactual’ scenario.

- **Displacement or 'crowding out':** the decrease in private, third sector, and foreign public investment as a result of the investment of public funds.
- **Leakage:** spillover benefits that arise outside of the domestic economy.

3 Quantitative evidence on spillovers

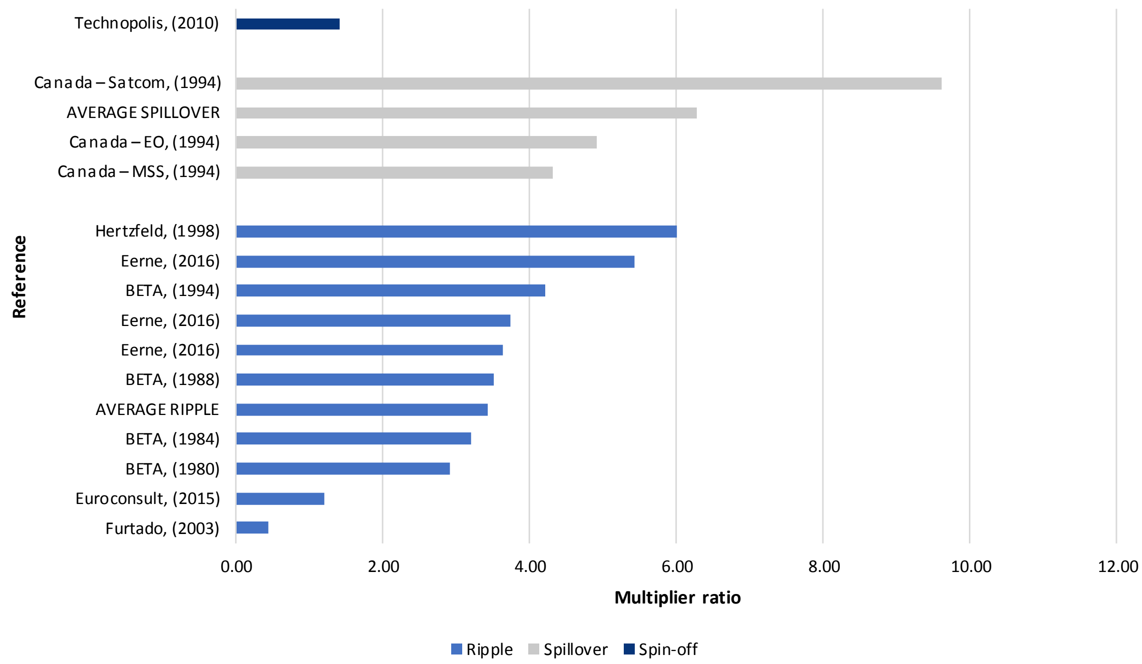
Economic impact can be expressed as either a multiple of the investment costs required to realise them – usually termed the **multiplier ratio** or are amortised over a period of time and expressed as a proportion, usually a percentage, of the investment cost that is realised on an annual basis. This is known as the **rate of return**. The following chapter presents a summary of the quantitative evidence on the magnitude and lag of spillovers. Within the literature reviewed for this study, the return is almost exclusively expressed in terms of the multiplier ratio. The majority of reviewed studies also adopt definitions of economic impact that are narrower than the definition of spillovers used in this study. **These differences in terminology, definitions, estimation methodologies, data sources, and typology of impact makes it difficult to synthesise any common themes across the literature.**

3.1 Magnitude: multiplier effects

Despite the diversity of indicators, the narrowly defined **ripple-effects ratio** – reflecting only the additional return to innovating organisations in receipt of R&D funding, and not the wider gains to other organisations – is the most frequently estimated in the literature. Evidence suggest that every **£1** of expenditure on R&D has been associated with a further **£0.43** to **£6.00** in impact (see Figure 2 and Table 2) that accrue solely to the organisation undertaking the research. These estimates therefore capture the ripple effects – i.e. all the technological, commercial, network, reputational and management knowledge gained from the R&D project, which are leveraged to support innovation and increased sales in other areas of the organisation. Despite most of these estimates being underpinned by a common methodology derived by the Bureau d'Economie Théorique et Appliquée (BETA)[33], they vary over a significant range. For example, one study finds estimates a low ripple effects ratio of 0.43. However, this unusual finding is explained by the fact that the outputs of the project were available to organisations that "did not know how to capitalize on the knowledge" generated by the programme. Thus, while a simple **averaging from the literature suggests a more 'typical' ripple effects ratio of 3.4**.

[33] BETA's concept of spin-off ratio corresponds to this study's definition of ripple effect ratio.

Figure 2 Multiplier ratios in the literature



Source: London Economics

Table 1 Space-specific literature: multiplier effects

Paper	Value	Type of ratio	Level of estimate
Canada – EO, (1994)[34]	4.9	**Spillover:** broad framework considers space programmes are investments in physical and non-physical assets. Exploitation of these assets creates both public and private benefits. Corresponds to spillovers and ripple effects.	Programme
Canada – MSS, (1994)[35]	4.3		
Canada – Satcom, (1994)[36]	9.6		
BETA, (1980)[37]	2.9	**Ripple I:** Indirect benefits to organisations involved in the contract, e.g. from sales of products, and market, organisation, method and critical mass effects (BETA).	ESA
BETA, (1984)[38]	3.2		
BETA, (1988)[39]	3.5		
BETA, (1994)[40]	4.2		
Eerme, (2016)[41]	3.63	**Ripple II:** Includes all benefits in terms of technology, know-how, corporate image or contracts that accrue to the contract participants as a result of participation in the contract (BETA).	Country (Ireland)
Eerme, (2016)	3.73		Country (Denmark)
Eerme, (2016)	5.43		Country (Norway)
Euroconsult, (2015)[42]	1.2	**Ripple III:** Reputational or networking benefits of working on space projects, the sale of products based on contracts, or organisational/production improvements at organisation level due to contract involvement (BETA).	Country Canada)

[34] Bureau d'Economie Théorique et Appliquée, BETA (1994). Indirect economic effects of ESA contracts on the Canadian economy.
[35] Bureau d'Economie Théorique et Appliquée, BETA (1994). Indirect economic effects of ESA contracts on the Canadian economy.
[36] Bureau d'Economie Théorique et Appliquée, BETA (1994). Indirect economic effects of ESA contracts on the Canadian economy.
[37] Bureau d'Economie Théorique et Appliquée, BETA (1980). Economic Benefits from ESA Contracts.
[38] Bureau d'Economie Théorique et Appliquée, BETA (1988). Study of the Economic Effects of European Space Expenditure.
[39] Bureau d'Economie Théorique et Appliquée, BETA (1988). Study of the Economic Effects of European Space Expenditure.
[40] Bureau d'Economie Théorique et Appliquée (1994). Indirect economic effects of ESA contracts on the Canadian economy.
[41] Eerne., T. (2016). Indirect industrial effects from space investments.
[42] Euroconsult (2015). Comprehensive Socio-Economic Impact Assessment of the Canadian Space Sector. Reference is made to a HEC Montreral study.

Hertzfeld, (1998)[43]	6	**Ripple IV:** Value-added in a company's product function as a result of involvement in R&D – including sales, reputation, management, and staff benefits (BETA).	Programme (life sciences)
Technopolis, (2010)[44]	1.4	**Spin-off:** Unclear, but it is implied that is excludes benefits within the space sector and wider effects (and uses a narrower definition than BETA's).	Programme (space exploration)
Furtado, (2003)[45]	0.43	**Ripple V:** The added-value to involved participants (BETA).	Programme (China-Brazil)

Source: London Economics based on quoted sources

Another study has estimated a 'spin-off' return ratio to public investments in space exploration of 1.4. In line with the smaller estimate, this ratio reflects an impact that is narrower than the BETA definition and excludes space sector and wider benefits.

One study has gone further and estimated broader impact/cost ratios which also include estimates of the broad value of technology diffusion and spin-offs that were associated with the Canadian space programme in the 1990s. Results range from **4.3** and **9.6**, depending on the part of the space programme considered. Compared to the smaller ripple-effect and 'spin-off' ratios discussed previously, these higher ratios seem logical – the difference is accounted for by the wider benefits to other organisations not directly involved in either R&D or space programme delivery.

These figures also align with previous London Economics range estimates of the spillover rate of return[46]. With research suggesting that the spillover returns are typically 2 to 3 times larger than the private return of an investment, the spillover ratio of various programmes have been estimated as follows:

- **ESA membership:** given direct benefits of £3-4, spillover benefits are estimated at £6-12 per £1 invested;
- **Space science and innovation:**
  - **Earth Observation:** given direct benefits of £2-4, spillover benefits are estimated at £4-12 per £1 invested;
  - **Telecoms:** given direct benefits of £6-7, spillover benefits are estimated at £6-14 per £1 invested;
  - **Navigation:** given direct benefits of £4-5, spillover benefits are estimated at £4-10 per £1 invested.

3.2 Lag

There are very few studies that estimate the lags between a programme and the realisation of spillover effects.

One prominent study by the Bureau d'Economie Théorique et Appliquée (BETA) in France identifies a **lag of about five years** between ESA programmes and the marketing of a products that derive

[43] Hertzfeld, H. (1998). Measuring the Returns to NASA Life Sciences Research and Development. Space Policy Institute, George Washington University
[44] Technopolis (2010). Space Exploration and Innovation
[45] Furtado, T., Filho, E. (2003). Assessing the economic impacts of the China- Brazil resources satellite program
[46] London Economics. (2015). *Return from Public Space Investments An initial analysis of evidence on the returns from public space investments FINAL REPORT*.

from the programmes[47]. This period is described as the 'incubation' phase where know-how is applied to the development of new products. This finding is supported by other studies that report lags of "several years" (between 3 and 5 years) before R&D becomes operative[48].

This same paper also finds that lags appear to be shorter for companies that develop downstream services or are providing contract manufacturing services, and longer for companies that are developing their own products[49]. These findings are not dissimilar from London Economics' previous *Returns from Public Space Investments* study, which also finds that lags vary by type of programme (e.g. pure science and exploration tend to a longer lag than infrastructure formation, which in turn has a longer lag than near-market innovations of existing technologies)[50].

4 What variables influence spillovers?

This section presents the evidence on the key variables that influence spillovers. These variables can be categorised into the following four areas:

- **Funding characteristics:** how the size, source, and channel of funding influence the size, duration, and lag of spillovers;
- **Technological characteristics:** how the type of R&D being funded – as characterised by the technology level, radicalism, objective, commercial potential, etc. – influence the size, duration, and lag of spillovers;
- **Sectoral characteristics:** how the type of sector, the sector's level of competition, and the age of the sector influence the size, duration, and lag of spillovers; and
- **Environmental characteristics:** how the environmental factors in which an investment is taking place – including the area's laws and regulations, the relationships between actors in the area, the sector's absorptive capacity, and the possible existence of agglomeration effects – influence the size, duration and, lag of spillovers.

However, one important point to note is that all these variables are extremely interactive, and often linked to one another. This means that isolating the causal effect of each variable on the key spillover parameters (magnitude, lag, and duration) is difficult. For example, the literature highlights the dominating influence of environmental factors on spillover impacts, which are often correlated with some of the non-environmental variables.

4.1 Funding characteristics

4.1.1 Amount of R&D investment

The evidence on the degree to which the amount of investment affects the spillover rate of return is **inconclusive**.

However, one study suggests that the level of spillovers is linked to the size of the space project. Mega-science projects – defined as those that involve a large amount of investment, a lot of

[47] Cohendet, P. (1997). Evaluating the industrial indirect effects of technology programmes: the case of the European Space Agency (ESA) programmes. Published in Policy evaluation in innovation and technology : towards best practices. - Paris, 1997, p. 189-223.
[48] Eerme, T. (2016). Indirect industrial effects from space investments. Space Policy.
[49] Eerme, T. (2016). Indirect industrial effects from space investments. Space Policy.
[50] London Economics (2015). Return from Public Space Investments. An initial analysis of evidence on the returns from public space investments.

collaborators and stakeholders, and a very long programme duration (e.g. the International Space Station, the Large Hadron Collider, or the Square Kilometre Array) have the highest potential for spillovers. This is because the benefits of the programme will be able to affect different areas of society over time, as innovation will be carried out for the duration of the programme[51].

Anecdotal evidence from interviews with UK space programme grant holders also suggests that large projects may be associated with significant spillovers. This is because large multi-year programmes support long-term retention of research staff, which in turn support a high-degree of cumulative knowledge generation, technological specialisation, and deep networks of collaboration.

Despite these studies, **there is insufficient evidence to draw conclusions on how the spillover rate of return varies by different scales of investment.**

4.1.2 Source of funding

The empirical literature does not differentiate spillovers by the sources of R&D investment (e.g. public vs. private investment). It is therefore not possible to distinguish how the spillovers rate of return varies between public and private sources of R&D investment.

This gap is driven by several methodological issues that make it difficult to establish a causal link between the source of funding and the magnitude of spillovers. For example, isolating the difference between public and private R&D funding is complicated by the fact that both variables influence each other. For example, the evidence suggests that public R&D funding **incentivises** additional private R&D funding[52]. The alternative view – that public R&D funding displaces (or 'crowds out') private R&D funding seems to have little to no empirical backing in the literature. For these reasons, the empirical evidence does not highlight a causal link between public or private funding and the level of spillovers.

Nevertheless, there is theoretical evidence to suggest that private funding may be associated with higher spillover returns only in the sense that private funding is more inclined to fund near-market R&D investments with a high probability of commercial success. This is because commercialisation of R&D is a prerequisite of market spillovers and important contributor to knowledge spillovers[53].

In terms of lags, private R&D investments tend to have **shorter** lags between investments and the occurrence of any economic returns than public R&D investments. Private R&D lags range from around 1 to 3 years, whereas public R&D lags are much longer[54]. This difference may be because privately funded R&D is more likely to be focused on near-market innovations with a higher probability of commercial success, compared to public investments which are typically geared towards basic research without specific commercial applications in mind.

However, the economic returns over this period this again varies greatly on a sectoral level. For example, private investments in R&D-intensive industries like aerospace typically have much longer lags before any economic returns occur.

[51] European Cooperation in Science and Technology. (2010). Benefits of Research Infrastructures beyond Science.
[52] Frontier Economics. (2014). Rates of return to investment in science and innovation. Report for the Department for Business, Innovation and Skills, p.8, 47.
[53] Jaffe, A. (1998). The importance of "spillovers" in the policy mission of the advanced technology program. The Journal of Technology Transfer, 23(2), pp.11-19. p.14.
[54] Frontier Economics. (2014). Rates of return to investment in science and innovation. Report for the Department for Business, Innovation and Skills. p.8, 135.

In terms of duration, various studies suggest that the returns from private R&D investments depreciate at approximately 20% per year. **Public investments are assumed to depreciate at much slower rates, if at all**[55]. Again, this is because public research is typically focused on basic research which, once it has generated knowledge, will remain in place in perpetuity. But again, there are important caveats. For example, there is no consensus on whether these depreciation rates are constant over time. Likewise, there are large sectoral variations, and even variations between products within sectors.

More generally, a number of studies suggest a complementary relationship between industry and public sector R&D, as it appears there is a 'crowding-in' effect from public investments in R&D[56].

Unfortunately, the literature does not examine how varying proportions of public and private funding affect spillover parameters. For this reason, **the difference between public and private funding on spillover outcomes is still quite ambiguous**.

4.1.3 Investment channels

Investment channels refer to how public R&D investments are 'funnelled'. For example, R&D can be channelled through research councils, the government (e.g. civil or defence sectors), or higher education. Different types of 'funnels' may have different effects on spillover magnitude.

In general, public **R&D channelled through research councils generate higher social rates of return,** in terms of market sector productivity benefits, than R&D conducted by civil government departments, defence or through higher education where there appears to be no empirical evidence of market sector productivity benefits[57]. Apart from high quality of the UK science base, this is best explained by the fact that research institutions typically fund research that is freely available, certainly relative to defence where the secretive nature of R&D is explicitly designed to limit 'spillovers'. These finding suggests that funding via research councils can maximise the macroeconomic impact of public innovation spending. However, these findings do not mean that these other types of investments are associated with no social returns. Instead, it is likely to mean that the social return to R&D spending by government departments or higher education are felt in other ways not detected in the data (e.g. they may be associated with longer lags and/or more qualitative benefits).

Within research council investments, the highest spillovers seem to occur from science-based applied research, which are close to the kind of R&D investments undertaken by the private sector. However, other publicly funded research may have social returns with longer lags and are therefore not picked up in the literature[58]. **It is therefore difficult to make strong conclusions about the relative merit of different sources of R&D funding.**

[55] Frontier Economics. (2014). Rates of return to investment in science and innovation. Report for the Department for Business, Innovation and Skills. p.8, 135

[56] Haskel, J,. Hughes, A., Bascavusolgu-Moreau, E. (2014). The economic significance of the UK science base. A report for the campaign for science and engineering. p.8, 20, 49

[57] Haskel, J. and Wallis, G. (2010). *Public support for innovation, intangible investment and productivity growth in the UK market sector.* IZA DP No. 4772. p.3, 23

[58] Frontier Economics. (2014). Rates of return to investment in science and innovation. Report for the Department for Business, Innovation and Skills. p.7,31

Finally, there are interactive effects between channels. For example, research council funding is often directed towards academic institutions. This makes it difficult to identify how spillovers vary by the source of funding[59].

4.2 Technological characteristics

Technological characteristics refers to the stage of the technology being funded, as well as the type of innovation conducted.

4.2.1 Stage of innovation

Technologies are characterised by different stages of development. For example, fundamental (or pure) scientific research to understand the intricacies of propulsion engines is at a different 'stage' of development than research into the best way to make a prototype engine marketable.

A possible hypothesis is that technology at its later stages of development – that is, closer to market – generates more spillovers than technology at more fundamental research stages. This is because near-market technologies may attract more third parties seeking to commercialise the technology. Likewise, public funding in these technologies may signal to the private sector that the technology has marketable potential, hence 'crowding in' more private investment[60]. For example, one study found that the US' Small Business Innovation Research (SBIR) program, which funded some organisations with innovations close to a marketable stage, resulted in a significant number of other organisations being established due to this "demonstration effect"[61].

However, there is very limited comparative analysis of how spillovers vary depending on types of technologies at different stages of innovation. This is largely because it is difficult to make clear distinctions between different types of technology empirically[62]. **As a result, there is no conclusive evidence that technologies at a later stage of development (e.g. near-market innovations) are associated with higher spillovers.**

Despite this evidence, the importance of absorptive capacity in supporting the uptake and utilisation of knowledge spillovers suggests a complementarity between 'pure' and applied research. This is because 'pure' (i.e. fundamental science) research can enhance the absorption of the outputs of applied research[63].

Rather than affecting the magnitude of spillovers, **research that is more applied may simply mean that spillovers are realised sooner**. This is because applied projects are likely to reach market much sooner than fundamental science projects, and will therefore be associated with the faster onset of market and knowledge spillovers[64].

[59] Frontier Economics. (2014). Rates of return to investment in science and innovation. Report for the Department for Business, Innovation and Skills. p.7
[60] Medhurst, J., Marsden, J., Jugnauth, A., Peacock, M. and Lonsdale, J. (2014). *An Economic Analysis of Spillovers from Programmes of Technological Innovation Support*. ICF GHK, p.31.
[61] Audretsch et. al (2001): Public/Private Technology Partnerships: Evaluating SBIR-Supported Research. p.9-10
[62] Medhurst, J., Marsden, J., Jugnauth, A., Peacock, M. and Lonsdale, J. (2014). An Economic Analysis of Spillovers from Programmes of Technological Innovation Support. ICF GHK. p.31.
[63] Haskel, J,. Hughes, A., Bascavusolgu-Moreau, E. (2014). The economic significance of the UK science base. A report for the campaign for science and engineering. p.7
[64] Jaffe, A. (1998). The importance of "spillovers" in the policy mission of the advanced technology program. The Journal of Technology Transfer, 23(2), pp.11-19. p.14.

Instead, to understand how technological stages affect spillovers, it may be more fruitful to focus on how technology interacts with and influences the different environmental elements of the innovation system – such as its demographics and educational profile.

Indeed, many examples in the literature back up this view. For instance, one study[65], based on patent diffusion in the United States, finds no evidence that the technological stage of an investment matters in terms of diffusion. However, what the authors do find is that spillovers are heavily characterised by information diffusion mechanisms – that is, the relationships between agents and how knowledge is transferred between them. In this sense, this study suggests that environmental; factors play a key role in the spillover characteristics of research and development.

4.2.2 Technology maturity

The potential for spin-off from the space sector are highest if the innovation is based on a 'mature' technology that has been subject to iterative development and proven its reliability. This is because non-space sectors are often characterised by rapid innovation cycles that cannot accommodate the slow process where technologies from Earth 'spin-in' to the space sector, before spinning-out after their optimisation for use in space[66].

This evidence therefore suggests that spillovers may be more apparent with innovations based on mature technologies.

4.2.3 Likelihood of commercial success

The commercialisation of knowledge, as embodied in products or processes, can reveal some aspects of the new knowledge to buyers and users of those new products or processes. This is because successful commercialisation can: i) signal that the research was productive and therefore worth pursuing, and ii) expose the knowledge embodied in the product to a large number of potential beneficiaries (customers). Similarly, new products that are not sold to customers cannot create market spillovers. For these reasons, commercialisation of a technology is a prerequisite of market spillovers and an important contributor to knowledge spillovers[67].

This view is supported by empirical evidence that demonstrates that more commercially oriented segments within the space industry specifically are associated with more spillovers. For instance, the downstream sector seems to show a higher probability of spillovers than the upstream sector, even though it is associated with a lower multiplier[68]. Similarly, the Canadian satellite communications and Earth Observation segments are characterised as the most commercially orientated and are associated with the highest spillover returns[69].

For these reasons, **projects that have higher expectations of commercial success are likely to be characterised by higher spillovers**.

[65] Jaffe, A., Trajtenberg, M. and Henderson, R. (1993). *Geographic Localization of Knowledge Spillovers as Evidenced by Patent Citations. The Quarterly Journal of Economics*, 108(3), pp.577-598. p.596
[66] Bach, L., Cohendet, P., and Schenk, E. (2002). *Technological Transfers from the European Space Programs: A Dynamic View and Comparison with Other R&D Projects*. The Journal of Technology Transfer. p.326.
[67] Jaffe, A. (1998). The importance of "spillovers" in the policy mission of the advanced technology program. The Journal of Technology Transfer, 23(2), pp.11-19. p.14
[68] Euroconsult. (2015). Comprehensive Socio-Economic Impact Assessment of the Canadian Space Sector. p.55
[69] Euroconsult. (2015). Comprehensive Socio-Economic Impact Assessment of the Canadian Space Sector. p.55

4.2.4 Incremental vs. Radical Innovation

Incremental innovation is cumulative in nature, and refers to innovation where organisations innovate in small steps based on the constant discovery of knowledge. This type of innovation is characterised by the feedback mechanisms between agents in the marketplace, in the sense that the relationships between actors (e.g. companies, individuals, organisations, universities) greatly determine the extent that incremental innovation occurs. For example, types of incremental innovation include small improvements in a manufacturing process, or more efficient management software at an office. Incremental innovation often occurs in industries where it is relatively easier to absorb knowledge from other actors, such as the automobile or microelectronics industries.

Radical innovation refers to disruptive innovations that have a significant market impact, and considerably change or replace existing business models. Likewise, the commercialisation of the personal computer and advent of the internet has radically disrupted how people work and shop.

The general spillovers literature seems to contain no evidence that incremental innovations are associated with different spillovers compared to radical innovations[70].

4.2.5 Product vs Process Innovation

Product innovations refer to new innovative products, such as the commercialisation of the tablet computer.

Process innovations refer to new processes, such as the discovery of how to synthesise a new compound more efficiently at a chemical company.

Product innovations have been shown to generate larger spillovers than product innovations, primarily because it is easier to prevent the transfer of knowledge that underpin process innovations. For example, a product that is exposed to the marketplace is more easily reverse-engineered than a process that can only be transferred through industrial espionage or the mobility of skilled employees that can be induced with higher wages to remain loyal[71].

4.2.6 Generic vs Specific technologies

Technological versatility refers to the potential for an innovation to be adapted to a wide variety of different sectors beyond the space industry. The literature suggests that generic technologies are associated with significant spillovers, while the potential for spin-offs, and therefore spillovers, appears to be very limited for very specific technological innovations[72]. This is likely because increasing versatility means a broader set of technological opportunities can be reached from the knowledge embodied in the diverse innovation. For example, miniaturisation has more terrestrial applications than space propulsion.

This positive effect holds for both **mission-oriented** and **diffusion-oriented** technologies[73].

[70] Medhurst, J., Marsden, J., Jugnauth, A., Peacock, M. and Lonsdale, J. (2014). *An Economic Analysis of Spillovers from Programmes of Technological Innovation Support*. ICF GHK.

[71] Ornagi, C. (2006). Spillovers in product and process innovation: Evidence from manufacturing firms. International Journal of Industrial Organisation, Volume 24, Issue 2, March 2006, pp 349-380. p.373

[72] Bach, L., Cohendet, P., and Schenk, E. (2002). *Technological Transfers from the European Space Programs: A Dynamic View and Comparison with Other R&D Projects*. The Journal of Technology Transfer. p.335

[73] Bach, L., Cohendet, P., and Schenk, E. (2002). *Technological Transfers from the European Space Programs: A Dynamic View and Comparison with Other R&D Projects*. The Journal of Technology Transfer. p.331.

While generic technologies are associated with more numerous technology transfers, they tend to be of low value and are associated with a long lag before economic benefits are realised. Specific technologies, on the other hand, are associated with larger economic benefits which tend to be realised much sooner[74].

4.2.7 Codification degree

The codification or standardisation of a technology (or knowledge) refers to the extent to which a technology is provided with **standards of use**. This is measured on a scale from low (**tacit**) to high (**codified**). A low codification can be defined as an initial piece of knowledge or idea from someone or a group of people. The more the idea evolves and is exchanged, the more it is codified so that the technology can be adapted for other applications and reproduced.

There is evidence to suggest that codification makes absorption of knowledge much easier, thereby improving the success of technology transfers[75]. This is because codification allows a better understanding of the technology and eases the process of adapting the technology in other areas. For this reason, SMEs may be tempted to limit the codification of knowledge to prevent the transfer of internal knowledge to their consortium partners or competitors[76].

4.2.8 Reliability

The reliability of a technology determines whether or not a technology has shown efficiency and trustworthiness. **Reliability is negatively correlated with the risk** of using a technology. The space industry can be characterised as one with very high costs and with risk-averse agents. For this reason, R&D expenditure is directed at projects that need to have a very high level of reliability. Several studies have shown that the reliability of a technology is a key determinant for the success of a technology transfer and therefore the spillovers associated with it[77].

4.3 Sectoral characteristics

Sectoral characteristics refers to the type of sector, the sector's level of competition, and the age of the sector, as detailed below.

4.3.1 Type of sector

Different industries vary depending on their willingness to take risk and innovate. Further, different industrial sectors also vary in terms of their "mechanisms of knowledge capture, organisation characteristics, [and] the ability to invest in follow-up innovations and therefore the capacity to generate spillovers".[78]

It appears that in the UK, **higher-value added sectors**, such as electrical and instruments engineering and chemical sectors produce greater innovations and spillovers than lower-value added sectors,

[74] Bach, L., Cohendet, P., and Schenk, E. (2002). Technological Transfers from the European Space Programs: A Dynamic View and Comparison with Other R&D Projects. The Journal of Technology Transfer. p.331.
[75] Verbano, C., and Venturini, K. (2012). Technology transfer in the Italian space industry: organizational issues and determinants. Management Research Review. p.104
[76] Bach, L., Cohendet, P., and Schenk, E. (2002). *Technological Transfers from the European Space Programs: A Dynamic View and Comparison with Other R&D Projects*. The Journal of Technology Transfer. p.334
[77] Petroni, G., Venturini, K., and Santini, S. (2010). Space technology transfer policies: Learning from scientific satellite case studies. Space Policy.
[78] Medhurst, J., Marsden, J., Jugnauth, A., Peacock, M. and Lonsdale, J. (2014). *An Economic Analysis of Spillovers from Programmes of Technological Innovation Support*. ICF GHK.

like food and drink industries[79]. However, this affect may be driven by differences in the quantity of investment in R&D. The relationship between spillovers and the type of sector is therefore inconclusive.

4.3.2 Level of competition

The level of competition in an industry is an important determinant for spillover generation, but the effect of competition appears to be different for market and knowledge spillovers.

One general perspective suggests that competition has the effect of increasing market spillovers, in particular. This is because competition prevents the price of an innovation, as embodied in a product, from rising to reflect the true value of the innovation. This has the effect of pushing market benefits further downstream (to suppliers further down the supply chain and ultimately to consumers)[80].

While the above theory suggests that competition increases market spillovers, the effect of competition on spillovers generally, particularly knowledge spillovers, is less conclusive. For example, **Marshall-Arrow-Romer (MAR) spillover** theory assumes that low competition generates more spillovers in total, whereas **Porter spillovers** theory and **Jacobs spillover** theory assumes more competition is beneficial. These perspectives are detailed in Box 1 below.

Box 2 Theories on the relationship between competition and the level of spillovers

Marshall-Arrow-Romer (MAR) spillovers[81] are similar to geographical proximity spillovers, and refer to the idea that the proximity of organisations in a common industry increases knowledge transmission. Put differently, this theory argues that spillovers occur primarily between homogenous organisations in one sector. Further, MAR spillover theory assumes that local monopolies are beneficial for growth, given that the vast majority of innovations by the monopoly benefits itself, thereby producing additional incentive to innovate. This implies that spillovers are most optimal when local competition is minimised. For example, this theory suggests that competition would “diffuse” the incentive for organisations to innovate, resulting in less innovation for society overall.

Porter spillovers[82] also suggest that spillovers occur primarily between organisations in one sector. However, Porter spillover theory argues that local competition is beneficial for growth. Even though competition decreases the benefit to the innovator (given that competitors capture some of the spillover benefits), the overall amount of innovation is still high because of competitive pressures. Organisations that fail to innovate in the face of innovating competitors will not survive.

Jacobs spillovers[83], unlike MAR and Porter spillovers, argue that spillovers occur best in areas where there is a diversity of organisations in different industries. Inter-sectoral knowledge transfers (i.e. knowledge spillovers between organisations in different sectors) are important. Jacobs spillover

[79] Wakelin K. (2000) *Productivity growth and R&D expenditure in UK manufacturing firms*, Centre for Research on Globalisation and Labour Markets, Research Paper 2000/20.
[80] Jaffe, A. (1998). The importance of “spillovers” in the policy mission of the advanced technology program. The Journal of Technology Transfer, 23(2), pp.11-19.
[81] Glaeser, E., Kallal, H., Scheinkman, J. and Shleifer, A. (1992). *Growth in Cities.* Journal of Political Economy, 100(6), pp.1126-1152.
[82] Porter, M. (1990). *The Competitive Advantage of Nations,* Free Press, New York.
[83] Jacobs, J. (1969). *The Economy of Cities.* Vintage, New York.

theory agrees with Porter spillovers in that local competition is seen to be beneficial in accelerating knowledge diffusion.

The empirical literature is mixed but largely suggests a positive relationship between competition and innovation (and therefore spillovers)[84]. However, one study in the UK finds that markets with medium levels of competition between organisations generate the greatest amount of innovation[85] and therefore potential for spillovers. Likewise, an extension of this study suggests that the key reason that UK manufacturing industries are characterised by this inverse U-shape in this study, and not the positive relationship between competition and innovation found in the US, may be because UK organisations are more divergent in terms of technology level than the US[86].

4.3.3 Maturity of industry

It appears that in **nascent industries**, organisations are less worried about imitation. These industries tend to be characterised by greater levels of spillovers[87]. One possible explanation for this phenomenon is that innovations have less value in the early stages of a market, and so organisations have little incentive to prevent imitation.

At the organisation level, it seems that more established organisations have higher absorptive capacity and are better able to capture spillovers[88].

4.4 Environmental characteristics

Finally, it is critical to recognise that an understanding of how different variables affect spillovers is incomplete without analysing the geographical element of **where** an investment takes place. The concept of innovation systems – that is, a recognition that spillovers are heavily determined by the environmental factors in which research activity takes place – is crucial to fully understand what types of spillovers are likely to occur[89].

In other words, the level of institutional development in an area affects spillovers and innovation just as much as the type or amount of R&D funding. As stressed throughout this section, the impact of non-environmental factors is often very difficult to identify rigorously, as they are often correlated with environmental factors.

4.4.1 Patent protection

In general, the literature contains very mixed evidence on how varying levels of patent protection influence spillovers. On one hand, strong patent laws reduce knowledge spillovers because they

[84] Examples include: Nickell, S. (1996). Competition and Corporate Performance. Journal of Political Economy, 104(4):724-746, 1996. Blundell, R., Griffith, R., Reenen, J.V., (1992). Market Share, Market Value and Innovation in a Panel of British Manufacturing Firms. Review of Economic Studies, 66(3):529-554, 1999. Carlin, W., Schaffer, M., Seabright, P. (2004). A Minimum of Rivalry: Evidence from Transition Economies on the Importance of Competition for Innovation and Growth. B. E. Journal of Economic Analysis and Policy: Contributions, 3(1):1-43, 2004. Okada, Y. (2005). Competition and Productivity in Japanese Manufacturing Industries. NBER Working Paper No.11540, 2005. Hashmi, A (2011). Competition and Innovation: The Inverted-U Relationship Revisited.

[85] Aghion, P., Bloom, N., Blundell, R., Griffith, R. and Howitt, P. (2004). *Competition and Innovation: An Inverted U Relationship.* SSRN Electronic Journal. p.701

[86] Hashmi, A. (2013). Competition and Innovation: The Inverted-U Relationship Revisited. *Review of Economics and Statistics*, 95(5), pp.1653-1668. p.2

[87] Slivko O. and Theilen B. (2011). Innovation or Imitation? The effect of spillovers and competitive pressure on firms' R&D strategy choice, Universitat Rovira I Virgili/ p.4

[88] Poldahl A. (2012) The Two Faces of R&D: Does Firm Absorptive Capacity Matter?, Journal of Industry, Competition and Trade (12), Issue 2, pages 221-237. p.221

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

limit the amount of knowledge recipient organisations can capitalise upon[90,91], restrict collaboration between different research organisations, and reduce tacit knowledge sharing within organisation through the promotion of a culture of secrecy[92].

On the other hand, strong patent laws may incentivise organisations to innovate more because they are more assured their innovations will be protected, thereby leading to more spillovers at the organisation level. Further, patents codify knowledge, perhaps making the transmission of knowledge spillovers easier[93].

Given these different effects at both the organisation and system level, **strong patent laws appear to have an ambiguous effect on spillovers.**

4.4.2 Government policies

A region's **development policies**, such as the quality of infrastructure development or focus on upskilling workers is critical to ensuring high rates of knowledge diffusion[94]. Some development policies in the UK are regionally specific (for example, the Northern Powerhouse strategy for developing the economies of Northern cities in the UK[95]).

Strong government support **increases** spillovers *if* implemented effectively.

The aerospace sector shows a high level of government involvement, to the point that the sector can often directly participate in the design of industrial policies and programmes[96]. For instance, NASA put in place the Space Act Agreement, which is primarily a vehicle for external collaboration[97]. In terms of cluster impacts, which in turn create an environment more conducive to successful R&D, government support for high-quality infrastructure is critical to the success of aerospace clusters. Facilities like roads, airports, and railways can increase the reach of agglomerations, supporting the effective exchange of knowledge and resources[98].

Likewise, an adequate level of government involvement, such as through investment or effective public policies, can be a key driver for competitiveness if it does not impinge on "decisional structure and the strategic interactions of the cluster"[99].

In general, government programmes designed to promote knowledge exchange appear to be effective at extending innovations beyond the space sector[100].

[90] Cohen W. et. Al (2002) R&D spillovers, patents and the incentives to innovate in Japan and the United states, Research Policy (31), pages 1349–1367.
[91] Acs, Z., Sandersm M. (2008). Intellectual property rights and the knowledge spillovers theory of entrepreneurship. p.1
[92] van Burg, E., Giannopapa, C., and Reymen, I. M. M. J. (2017). Open innovation in the European space sector: Existing practices, constraints and opportunities. Acta Astronautica.
[93] Coe T., Helpman E. and Hoffmaister W. (2008) International R&D spillovers and institutions, National Bureau of Economic research, NBER Working Papers 14069.
[94] OECD (2016), Space and Innovation, OECD Publishing, Paris. *http://dx.doi.org/10.1787/9789264264014-en*
[95] See: https://northernpowerhouse.gov.uk/
[96] Paone, M., and Sasanelli, N. (2016). Aerospace Clusters - World's Best Practice and Future Perspectives. p.21
[97] The Tauri Group. (2013). NASA Socio-Economic Impacts.
[98] Paone, M., and Sasanelli, N. (2016). Aerospace Clusters - World's Best Practice and Future Perspectives. p.17.
[99] Paone, M., and Sasanelli, N. (2016). Aerospace Clusters - World's Best Practice and Future Perspectives. p.98
[100] British National Space Centre. (2009). Space Exploration Review.

4.4.3 University-Industry linkages

A region's **university-industrial links**, such as its ties with local universities and the frequency and closeness of collaborative research efforts is also a key driver of innovation[101]. Universities are institutions that conduct cutting-edge research, and industries located near these institutions benefit from being able to observe and use the latest discoveries in their field. Likewise, the relationship also works in the other direction; universities can appropriate knowledge and derive insights for research from industry.

For example, the Cambridge Science Park and The Research Triangle in Raleigh-Durham take advantage of university-industrial linkages. Specifically, survey evidence seems to suggest that public funding of academic research is a key driver for where private organisations locate private R&D research investments[102]. However, this evidence cannot confirm causality.

The importance of university-industry links has wide backing in the literature. For example, one study finds that exchanges between universities and industry scientists are positively correlated with the number of innovations[103]. Likewise, another study finds that in the pharmaceutical industry, the level of university-industry collaboration is a key determinant of knowledge spillovers[104]. University-industry relationships also appear to be geographically bounded[105].

Strong industry-university relationships appear to generate **more** spillovers. For example, university cultures that support technology transfer can significantly increase the number of spin-offs over time, and start-up companies tend to locate closer to research institutions[106]. In addition, key space clusters in the world (e.g. Harwell) see the involvement of universities and research institutions who actively participate in the innovation process and provide a qualified labour force through dedicated programmes[107].

4.4.4 Cooperative agreements

Companies often develop formal cooperative agreements to conduct research, such as through creating joint ventures or coordinating licensing agreements. In general, the literature seems to suggest that cooperative agreements **increase** spillovers by allowing a smoother knowledge transmission process between actors[108,109].

[101] Muscio, A. (2012). University-industry linkages: What are the determinants of distance in collaborations? *Papers in Regional Science*, 92(4), pp.715-739.
[102] Muscio, A. (2012). University-industry linkages: What are the determinants of distance in collaborations? *Papers in Regional Science*, 92(4), pp.715-739.
[103] Gittelman, M. and Kogut, B. (2003). Does Good Science Lead to Valuable Knowledge? Biotechnology Firms and the Evolutionary Logic of Citation Patterns. *Management Science*, 49(4), pp.366-382.
[104] Cockburn, I. and Henderson, R. (2003). Absorptive Capacity, Coauthoring Behavior, and the Organization of Research in Drug Discovery. *The Journal of Industrial Economics*, 46(2), pp.157-182.
[105] Almeida, Paul and Kogut, Bruce, (1997). The Exploration of Technological Diversity and the Geographic Localization of Innovation, *Small Business Economics*, 9, issue 1, p. 21-31, https://EconPapers.repec.org/RePEc:kap:sbusec:v:9:y:1997:i:1:p:21-31.
[106] Paun, F., and Richard, P. (2000). Extensive multi-domain innovation model through Aerospace Technology Adopter SMEs cluster.
[107] Paone, M., and Sasanelli, N. (2016). Aerospace Clusters - World's Best Practice and Future Perspectives
[108] Cassiman B. and Veugelers R. (2002). R&D Cooperation and Spillovers: Some Empirical Evidence from Belgium, The American Economic Review (92) Issue 4, pages 1169-1184.
[109] Lejpras, A. Stephan, A. (2011). Locational conditions, cooperation, and innovativeness: evidence from research and company spin-offs, The Annals of Regional Science, June 2011 (46), Issue 3, pages 543-575.

4.4.5 Informal relationships

Organisations often develop informal relationships, intentionally and unintentionally. Informal relationships in this context refers primarily to the level of trust and strength of relationships between organisations.

Strong informal relationships between organisations **increase** spillover likelihood and magnitude. For example, high levels of trust between companies, however developed, generally translates to a stronger cooperative network leading to more spillovers[110]. Conversely, low levels of trust limit the exchange between companies. In general, innovation systems that are 'open' – in the sense that there is trust, collaboration, and bidirectional knowledge flows between the space sector and the rest of society – tend to enhance the output and societal spillover effect of the space sector[111].

There is thus a broad consensus that **strong ties between companies can support the transmission of knowledge spillovers**, through mechanisms such as collective learning or rapid feedback[112].

4.4.6 Formal relationships

Strong formal relationships between organisations, such as the establishment of interconnections, appear to **increase** knowledge spillovers, and information exchange and collaboration[113]. Likewise, other key drivers for increasing spillovers include integrating supply chain clusters with other industries, and international partnership agreements[114,115]. **Collaboration, in general, is a key feature for successful technology transfer**[116].

4.4.7 Local and international connections

A region's **local-global links** are important for defining the extent and quality of knowledge transmission from overseas, such as through the investment of foreign organisations in the local area. For example, London has much more global investment than the UK's Northern regions[117].

More specifically, aerospace clusters are characterised by international strategic alliances, collaboration among players on an international level, the international mobility of human capital, export-oriented markets, and the wide use of offset agreements (e.g. foreign subcontracts). These factors support knowledge diffusion and the generation of international knowledge spillovers[118].

However, local relationships may still be relevant for knowledge spillovers. For instance, some scholars suggest that local relationships are more important than international ones because more

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110 Bach, L., Cohendet, P., and Schenk, E. (2002). Technological Transfers from the European Space Programs: A Dynamic View and Comparison with Other R&D Projects. The Journal of Technology Transfer

111 van Burg, E., Giannopapa, C., and Reymen, I. M. M. J. (2017). Open innovation in the European space sector: Existing practices, constraints and opportunities. Acta Astronautica.

112 Fritsch, M. Kauffeld-Monz M. (2007) The impact of network structure on knowledge transfer: An empirical application of social network analysis in the context of regional networks of innovation, Chair of Microeconomics at the Friedrich Schiller University Jena and the Max Planck Institute of Economics (Jena).

113 Paone, M., and Sasanelli, N. (2016). Aerospace Clusters - World's Best Practice and Future Perspectives.

114 CEON GmbH. (2012). Smart Specialisation in Space: The economic potential of space technology and downstream services for Europe's regions.

115 Paone, M., and Sasanelli, N. (2016). Aerospace Clusters - World's Best Practice and Future Perspectives.

116 Cohendet, P. (1998). Evaluating the industrial indirect effects of technology programmes: the case of the European Space Agency programmes.

117 House of Commons Library (2017). Foreign Direct Investment into the UK, 2016-17. Number CDP 2017/0159, 8 September 2017. p.4

118 Paone, M., and Sasanelli, N. (2016). Aerospace Clusters - World's Best Practice and Future Perspectives.

knowledge is exchanged through local ties[119]. Regardless, the evidence suggests that connections at both a local and international level are strongly conducive to the generation of knowledge spillovers.

4.4.8 Absorptive capacity

Absorptive capacity[120], defined as the ability to recognise, absorb, and transform knowledge with commercial opportunity into tangible improvements for society, is a key determinant of spillovers, at the organisation-level, sector-level, and country-level. Absorptive capacity can be assessed through several ways, such as through an organisation's level of human capital or its internal structure. These two factors affect absorptive capacity and therefore the absorption of knowledge spillovers in the following ways:

- **Level of human capital:** since the aerospace industry is heavily based on disruptive technology, highly skilled human capital is very important for achieving innovation. In addition to the quality of human capital, its size, proximity, concentration, and availability are all crucial for the absorption of spillovers[121]. For this reason, beneficiary organisations with higher levels of human capital are likely to be more successful in the absorption of technology[122].
- **Internal structure:** The evidence suggests that hierarchical organisations can impede technological transfers as they prevent the internal exchange of knowledge, whereas network-type organisations can support the diffusion of innovation knowledge[123].

At the organisation level, many studies find organisations with **higher absorptive capacities benefit from more spillovers**[124,125,126]. Empirical findings reach similar results at the sectoral level[127] and country level[128]. For example, organisations' existing capabilities were a key determining factor for utilisation of the economic benefits from participating in ESA programs[129]. More specifically, larger organisations, such as primes located upstream, tend to have higher absorptive capacities and can therefore capture the knowledge generated by smaller subcontractors. By the same logic, smaller subcontractors tend to have low absorptive capacity, so are less able to capture the knowledge generated by primes[130].

[119] Biggiero, L., and Sammarra, A. (2010). Does geographical proximity enhance knowledge exchange? The case of the aerospace industrial cluster of Centre Italy. International Journal of Technology Transfer and Commercialisation.
[120] The term originated from Cohen, W. and Levinthal, D. (1990). Absorptive Capacity: A New Perspective on Learning and Innovation. *Administrative Science Quarterly*, 35(1), p.128.
[121] Paone, M., and Sasanelli, N. (2016). Aerospace Clusters - World's Best Practice and Future Perspectives.
[122] Various studies including: Cohendet, P. (1998). Evaluating the industrial indirect effects of technology programmes: the case of the European Space Agency programmes. Petroni, G., Venturini, K., and Santini, S. (2010). Space technology transfer policies: Learning from scientific satellite case studies. Space Policy. Verbano, C., and Venturini, K. (2012). Technology transfer in the Italian space industry: organizational issues and determinants. Management Research Review.
[123] Bach, L., Cohendet, P., and Schenk, E. (2002). Technological Transfers from the European Space Programs: A Dynamic View and Comparison with Other R&D Projects. The Journal of Technology Transfer. p.334
[124] Aiello F. and Cardamone P. (2008). R&D spillovers and firms' performance in Italy, Journal of Empirical Economics (34), pages 143-166
[125] Liu W. (2012). An Empirical Study on Factors that Affect Knowledge Spillover of FDI.
[126] Cassiman B. and Veugelers R. (2002). R&D Cooperation and Spillovers: Some Empirical Evidence from Belgium, The American Economic Review (92) Issue 4, pages 1169-1184.
[127] Poldahl A. (2012) The Two Faces of R&D: Does Firm Absorptive Capacity Matter?, Journal of Industry, Competition and Trade (12), Issue 2, pages 221-237.
[128] Coe T., Helpman E. and Hoffmaister W. (2008). International R&D spillovers and institutions, National Bureau of Economic research, NBER Working Papers 14069
[129] Hansen, M. (2010). The Economic Benefits of Participating in the ESA Programs. Nature.
[130] Bach, L., Cohendet, P., and Schenk, E. (2002). Technological Transfers from the European Space Programs: A Dynamic View and Comparison with Other R&D Projects. The Journal of Technology Transfer. p.333.

Since absorptive capacity is itself the product of investments in knowledge, investments in **R&D can both increase the degree of spillovers but also the rate at which spillovers are absorbed** and utilised by organisations. In other words, there is a **double gain from investments in R&D**[131].

Technological proximity

Beneficiaries with close technological proximity to innovators (i.e. the generators of spillovers) tend to have **more** spillovers. In other words, organisations in related sectors that are more similar to one another with more closely related technology tend to be able to exploit knowledge spillovers better[132]. This could be because the need to adapt technologies to suit the beneficiary organisation's needs is likely to be lower given closer technological proximity.

Distribution effects of space spillovers

The literature suggests that the distribution of space sector spillovers is variable across other sectors and companies. In particular, spillovers accrue mostly to similar medium/high-tech sectors and to the largest companies in a supply chain, before these innovations are eventually distributed further down the supply chain. For example:

- **Sector-level:** In a study of Italy, spillovers from space tended to convey technology to the whole manufacturing sector, and in particular, to middle/high-tech sectors. Furthermore, spillovers from the space sector tend to have higher rates of return than from other manufacturing sectors[133].
- **Organisation-level:** In a Canadian study, it seems that knowledge spillovers occur mainly between the largest contractors ('primes'), before they are transferred to smaller subcontractors and companies further down the supply chain)[134]. We can therefore conclude that spillovers are vertically distributed.

In both these cases, the distribution of spillovers is the result of variable levels of absorptive capacity as detailed in 4.4.8 above.

4.4.9 Agglomeration effects

A region with **industrial clusters** has agglomeration benefits, increasing both innovative potential and ability to absorb, generate, and diffuse knowledge. This might be because participation in a cluster generates strategic interaction between research institutions and other innovators within the cluster[135], ultimately leading to more spinoffs. For example, Silicon Valley is widely recognised as a tech cluster whose geographical concentration of tech companies is key to its status as one of the world's frontier technological hubs[136].

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131 London Economics (2012). The impact of investment in intangible assets on productivity spillovers. BUS Research Paper number 74.

132 Various studies including: Biggiero, L., and Sammarra, A. (2010). Does geographical proximity enhance knowledge exchange? The case of the aerospace industrial cluster of Centre Italy. International Journal of Technology Transfer and Commercialisation. Cohendet, P. (1998). Evaluating the industrial indirect effects of technology programmes: the case of the European Space Agency programmes. Graziola, G., Cristini, A., and Di Ciaccio, S. (2015). The Importance of the Technological Spillovers for the Returns to Space Investments, with an Empirical Application to the Italian High-Tech and Space Sectors. New Space.

133 Graziola, G., Cristini, A., and Di Ciaccio, S. (2015). The Importance of the Technological Spillovers for the Returns to Space Investments, with an Empirical Application to the Italian High-Tech and Space Sectors. New Space.

134 Paone, M., and Sasanelli, N. (2016). Aerospace Clusters - World's Best Practice and Future Perspectives.

135 Paone, M., and Sasanelli, N. (2016). Aerospace Clusters - World's Best Practice and Future Perspectives.

136 Chatterji, A., Glaeser, E. and Kerr, W. (2014). Clusters of Entrepreneurship and Innovation. *Innovation Policy and the Economy*, 14, pp.129-166.

The importance of agglomeration benefits is frequently cited in the literature as being a key determinant for spillover generation[137]. For this reason, the effectiveness of R&D funding at generating spillovers hinges on it taking place in areas where all these environmental factors are at their strongest.

4.5 Summary of evidence on key determinants of spillovers

The variables presented in the previous section, and their relationship with spillovers are summarised in Table 2 below.

Table 2 Summary of evidence on key determinants of spillovers

Variable categories	Variables	Relationship with spillover parameters	Detail
Funding characteristics	Amount of R&D Investment	**Ambiguous**	Little evidence on how rate of return varies by scale
	Public vs private funding	**Ambiguous**	Empirical evidence does not provide conclusive causal evidence
	Investment channel	**Significant**	**Research councils** generate the most spillovers
Technological characteristics	Stage of innovation	**Ambiguous**	Limited evidence that near-market investments *may* generate more spillovers, but evidence not conclusive. Instead, research that is closer to market may simply mean that spillovers are realised sooner
	Likelihood of commercial success	**Significant**	**Positive:** projects with higher expectations of commercial success are likely to have higher expected spillovers
	Technological maturity	**Significant**	**Positive:** spillovers may be more apparent with innovations based on mature technologies
	Likelihood of commercial success	**Significant**	**Positive:** projects with higher expectations of commercial success are likely to have higher expected spillovers
	Incremental vs radical innovation	**Neutral**	No evidence that incremental innovations are different from radical ones
	Product vs process innovation	**Significant**	**Product innovations** appear to generate more spillovers
	Generic vs specific technologies	**Ambiguous**	Generic technologies are associated with more numerous technology transfers; however, they are also associated with longer lags and lower economic benefits in comparison to specific technologies
	Codification degree	**Significant**	**Positive:** evidence that codification improves success of technology transfer
	Reliability	**Significant**	**Positive:** reliability a key determinant of the success of a technology transfer

[137] For example, see: Cincera, M. (2005). Firms' productivity growth and R&D spillovers: An analysis of alternative technological proximity measures. *Economics of Innovation and New Technology*, 14(8), pp.657-682.

Sectoral characteristics	Type of sector	Significant	**High-value sectors** appear to generate more spillovers. However, this affect may be driven by differences in the quantity of investment in R&D.
	Level of competition	Significant	Empirical evidence suggests a positive relationship between competition and spillovers
	Maturity of industry	Significant	**Nascent industries** appear to generate more spillovers
Environmental characteristics	Level of patent protection	**Ambiguous**	Evidence is mixed
	Government policies	Significant	**Strong developmental policies** are conducive to more spillovers
	University-Industry relationships	Significant	**Strong university-industry** links generate more spillovers
	Cooperative agreements	Significant	**Cooperative agreements** (e.g. joint ventures) generates more spillovers
	Informal relationships	Significant	**Strong informal relationships** (e.g. trust between organisations) generates more spillovers
	Formal relationships	Significant	**Positive:** strong formal relationships between organisations associated with stronger transmission of knowledge spillovers
	Local and international connections	Significant	**Positive:** connections at both a local and international level are strongly conducive to the generation of knowledge spillovers
	Absorptive capacity	Significant	**Positive:** very strongly associated with high spillovers
	Agglomeration effects	Significant	Conducive to generating high spillovers

Source: London Economics

Limitations to the literature means that it is not possible to rank the above determinants of spillovers by the strength of their effect. For this, advanced statistical techniques are required to establish the causal link between the various parameters of spillovers (magnitude, lag, duration, etc.) with each of potential determinant of spillovers.

Without this, a ranking of spillovers is only partially possible with reference to the qualitative literature that does exist. One study, for example, suggests that the 'particularly important factors' on the technology side are the: i) the diversity of the technologies, ii) their degree of maturity, and iii) the extent to which they are generic or specific[138]. These rank alongside factors related to the relationship between innovators and recipients (degree of trust, existence of absorptive capacities), and the internal structure of innovators and recipients (degree of decentralisation and vertical integration).

Even so, this qualitative study is not able to differentiate between these factors and is insufficient to inform investment decisions that aim to maximise the spillover rate of return.

The influence of each individual factor is also not entirely clear. This is because some factors have a simultaneous though variable influence on: i) the generation or absorption capacities of innovators and recipients, respectively; or ii) at the individual organisation and industry level. For example:

[138] Bach, L., Cohendet, P., and Schenk, E. (2002). *Technological Transfers from the European Space Programs: A Dynamic View and Comparison with Other R&D Projects*. The Journal of Technology Transfer. p.335

- **Increased competition** has the effect of reducing the private returns to innovation, even if they increase market spillovers by pushing surplus downstream. While the literature is mixed, it nevertheless suggests a positive relationship between competition and spillovers.
- **Strong patent laws** reduce knowledge spillovers because they limit the amount of knowledge recipient organisations can capitalise upon, but they may increase the individual incentives facing innovators to innovate. Strong patents laws therefore appear to have an ambiguous effect on spillovers.
- In **nascent industries**, organisations have little incentive to prevent imitation, hence an increased likelihood of spillovers. However, at the organisation-level, more established organisations have higher absorptive capacities to capture spillovers.

The overall effect of these factors on spillovers is not known empirically. More quantitative work must therefore be done in this area.

5 Case studies

This section presents case studies on the impacts associated with six space programmes that have received UK Space Agency funding. They have been developed from secondary data and consultations with programme stakeholders and participants.

The objective of these case studies is to provide a rich account of the impacts that are associated with space programmes, these case studies have therefore been chosen to cover a diverse range of programmes and funding channels (national and ESA programmes) and capture realised impacts (i.e. programme has progressed sufficiently). These six case studies are detailed below. Common themes across these case studies are also outlined in Section 5.4.

- **Space for Smarter Government Programme (SSGP):** a national UKSA programme that aims to promote the uptake of space products and services in government. The focus of the case study is on the ‘Air Quality Hotspot Mapper’ project that was supported by SSGP grant funding.
- **National Space Technology Programme (NSTP):** the UK Space Agency’s national capability programme that provides grant funding to organisations looking to develop space technologies.
- **Synergistic Air-Breathing Rocket Engine (SABRE):** the UK government committed £60 million of funding to support the development of Reaction Engine’s unique SABRE concept.
- **Herschel Spire:** part of an ESA space observatory mission with UK involvement. Spire represented one of its three scientific instruments.
- **ExoMars:** a joint ESA-Roscosmos astrobiology project to search for life on Mars, with UK involvement.
- **Rosetta:** an ESA funded space probe to improve our understanding of the origin and evolution of the Solar System with UK academic and industrial involvement. The focus of this case study is on the Open University’s contribution to Rosetta’s Philae lander.

These case studies and a synthesis of common themes are presented below.

5.1 Space for Smarter Government Programme (SSGP): Air Quality Hotspot Mapper

The UK Space Agency's Space for Smarter Government Programme (SSGP) is a strategic, national, programme established in 2014 to drive the uptake and use of space products, data and services across government departments. This is intended to support government, as end users, to adopt applications that will save money and support more effective policy decisions, and stimulate innovation and growth in industry, as potential suppliers of these products.

With an annual budget of £1.3-1.5m, the programme achieves these outcomes through a series of training workshops, events, engagement with stakeholders, and grants and competitions. One notable project is the Air Quality Hotspot Mapper (AQHM), developed by the University of Leicester and later exploited by its spin-out company, EarthSense.

In this instance, SSGP funding supported three distinct phases of the project: i) engagement with potential end users and delivery partners, and demonstration of the product's utility; ii) development of an operational pilot service, and iii) delivery of an operational service to end users in pilot areas.

Three years into the project, the following outcomes have been identified as a result of SSGP funding:

- **Internal effects:**
  - The combination of funding and softer support from SSGP allowed the University of Leicester, and later EarthSense, to transform 15 years of academic research into a viable air quality product using satellite data. Engagement with relevant stakeholders suggest this would not have been possible without SSGP funding. This product has been used by Leicester City Council and Rotherham Metropolitan Borough Council to identify air quality hotspots and improve their decision making and mitigation efforts against poor air quality. Following its origins in the project, EarthSense is now a fast-growing company with 12 staff and ambitions to turnover six figures in 2018. Consultations with stakeholders suggest that approximately 80% of this is attributable to SSGP.
  - EarthSense has been able to leverage the profile and expertise gained from the SSGP project to win further grant funding from the European Space Agency (ESA) and Innovate UK to develop commercial air quality products in other areas e.g. for the logistics and intelligent transport markets. EarthSense now offers a range of products to customers across a variety of markets, including air quality sensors, air quality modelling, and national data services.
- **Spillovers (realised):**
  - SSGP funding enabled the University of Leicester to partner with Geospatial Insights Limited (GIL) to support the launch of EarthSense. Some of GIL's air quality related growth may therefore be attributable to SSGP.
  - EarthSense data was used to underpin the BBC's free-to-use 'MappAir' service which provides postcode level data on traffic pollution. This service was accessed by a total of 2 million users within the first 48 hours of launching.
  - EarthSense works with local suppliers to deliver its air quality products. Their business with EarthSense is therefore attributable to SSGP.
  - EarthSense's air quality information provides one conveyancing customer with a competitive advantage relative to competitors that do not have this data.

  - EarthSense's air quality data can be used by hybrid HGV companies to manage their emissions in emission-controlled areas (smart cities). This application is in the process of being piloted.
- **Spillovers (potential):**
  - EarthSense's air quality data can be used to support more emissions-friendly and therefore more sustainable logistics activities of companies. This application is in the process of being piloted.
  - On the assumption that satellite-derived EO is used to support LAQM and therefore the adoption of more effective air quality interventions across all local authorities in the UK, the potential benefits of satellite-derived EO is estimated at £4.1 million annually. This is based on the assumption that effective interventions reduce emergency hospital admissions for air quality-related emergencies (Chronic Obstructive Pulmonary Disease and asthma), and therefore the associated cost of these emergency admissions to the NHS[139].

5.2 National Space Technology Programme (NSTP)

The NSTP is the UK Space Agency's national capability programme. It aims to support the sector by providing grant funding to organisations looking to develop space technology and capabilities. Funding is aimed at low to medium Technology Readiness Levels (TRL) to accelerate innovation and its commercialisation, in line with the themes set out in the UK's National Space Strategy.

Funding ranges from £10k to £1 million, covering all activities from fundamental research, feasibility studies and proof of concept work, through to industrial research and development. The second phase of NSTP (NSTP2) funded 120 projects, with awards totalling £8.4 million, or an average of £69K per project[140].

Most NSTP2 projects have only recently concluded or are still ongoing. As a result, the final outcomes of the project will only be realised and evidenced over the course of several more years. Nevertheless, the following programme impacts have been reported to date:

- **Internal effects[141]:**
  - Most surveyed organisations in receipt of NSTP2 funds reported an increase in the Technology Readiness Level (TRL) of their project between the time of application and the completion of the grant. In other words, NSTP2 funds supported the progression of R&D from early / proof of concept stage towards the end goal of commercialisation. As a result, 80% of project leads were able to report that their project has been de-risked to some degree. More specifically, 63% reported that NSTP funding has reduced the cost of their project or technology, and 77% reported that the funding has reduced the time to market.
  - Even at this early stage, two of the 41 projects consulted for the evaluation reported an actual increase in commercial revenue as a result of the projects supported by NSTP. Nearly all projects (90%) expect the NSTP project to lead to additional revenue in the future.

[139] London Economics (2018). *Value of satellite-derived Earth Observation capabilities to the UK Government today and by 2020. Evidence from nine domestic civil use cases.*
[140] Technopolis Group (2018). National Space Technology Programme 2 Evaluation 2018. Final report.
[141] Technopolis Group (2018). National Space Technology Programme 2 Evaluation 2018. Final report.

- All but one surveyed organisation reported that they had used NSTP to develop knowledge or technology in other areas of their organisation.
- 98% of surveyed organisations reported that the attractiveness of their organisation as a space R&D partner has increased because of their involvement in the programme.
- 93% of all organisations report an increase in the visibility and reputation of their organisation because of their involvement in NSTP.
- Almost half of all sampled organisations (48%) reported that NSTP would have a high impact on their national competitiveness, with 68% reporting that NSTP would have a medium or high impact on their international competitiveness.

5.3 Synergistic Air-Breathing Rocket Engine (SABRE)

In 2016, the UK government committed £60 million of funding via the UK Space Agency and the European Space Agency to support the development of Reaction Engines Limited's (REL) Synergistic Air-Breathing Rocket Engine (SABRE). SABRE represents a design for a reusable hybrid rocket and jet engine – a concept that could save weight and support transport to orbit without the need for multiple propellant stages as required by today's rockets[142]. This could revolutionise access to space.

As the only viable source of funding in 2016, the UK government's support enabled REL to develop, and ultimately de-risk, their concept to a level that has attracted a further £49.5 million in private capital. In this way, UK government funds helped bridge the 'technological valley of death' between the early and commercial stages of innovation. As a result, REL is on course to launch a ground-based demonstration test of SABRE in 2020.

While SABRE remains at a pre-revenue R&D phase, it is associated with the following impacts:

- **Internal effects:**
  - REL has grown from 50 to 180 employees since the start of the UK grant.
  - REL has begun construction of a new engine test facility in Westcott Buckinghamshire. This test facility will support the testing of subsystems and the SABRE engine core in 2020[143].
  - REL has received considerable press attention. This has enhanced REL's reputation as a leading innovator within the UK space industry.
  - The joint UKSA-ESA grant helped signal the viability of the concept and helped progress the technology to a stage where it was attractive to outside investors. As a result, REL has been able to attract a further £49.5 million in private capital, including £21 million from BAE Systems plc, and £28.5 million in equity. These funds will be used to support the development of the core SABRE propulsion system and the development of crucial subsystems, like the heat exchanger, that have valuable applications across a number of non-space markets.
- **Spillover effects (potential):**
  - The SABRE concept is underpinned by a pre-cooler heat exchanger that can cool an incoming stream of air from 1000 °C to – 150 °C in one hundredth of a second. This heat exchanger has applications in a number of markets that also have extreme thermal management needs. Examples include: pre-cooling technology for high-

[142] Please see: http://m.esa.int/Our_Activities/Space_Engineering_Technology/ESA_commits_to_next_stage_of_UK_revolutionary_rocket_engine
[143] Please see: https://www.reactionengines.co.uk/news/westcott-test-site-tf1-1-year-construction

performance automotive; industrial heat recuperation; battery cooling systems; and cooling systems for power stations. These examples have been identified in an independent market opportunities report which REL commissioned in 2017. REL are currently in the early-stage process of exploring spin-off possibilities into these markets.

- Longer-term, SABRE has the potential to offer substantial value in the aviation sector by improving the fuel efficiency and contributing to a reduction in the sector's environmental footprint. Rolls Royce have invested in SABRE to help unlock this value.

5.1 Herschel Spire

The Herschel Space Observatory was an ESA-funded astronomical satellite that launched in 2009 and operated until 2013. Hershel was a space observatory with the largest infrared telescope ever flown in space. It carried three scientific instruments, of which SPIRE was one. Cardiff University was the lead institute in an 18-institution consortium that included over 150 scientists, engineers, and managers from Canada, China, France, Italy, Spain, Sweden, the UK, and USA[144]. SPIRE's main objectives were to provide a better understanding of far-infrared light by studying wavelengths between 194 and 671 µm, making a key contribution to Herschel's broader objective to investigate the formation and evolutionary processes of stars and galaxies.[145]. The total UK public investment cost for SPIRE was **£16.5m** from the Science and Technology Facilities Council and UK Space Agency[146], out of a total budget of approximately £80m (€90m).

It appears that SPIRE generated market, knowledge, and network spillovers across a variety of areas, including revenue, educational, reputational, and international cooperation benefits. In total, this amounted to **more than £4m** in spillovers in GVA terms[147].

- **Internal effects[148]:**
  - Publicly funded SPIRE institutes in the UK awarded contracts to industry worth approximately £1.25M for various instrument hardware components.
  - SPIRE supported the development of Cardiff University spin-out company QMCI Ltd.
  - Cardiff University where able to develop a strong relationship with Airbus, resulting in their involvement in a UK consortium to contribute to a joint EU-Japanese astronomical observatory, and over £4 million in follow-up contacts (£250K for a feasibility study on an EO satellite, and £4 million for a follow-on contract).
  - Cardiff University's involvement in SPIRE has enabled it to develop a strong status as an international centre of excellence in astronomy instrumentation. This has resulted in requests for numerous research collaborations. The UK Astronomy Technology Centre in Edinburgh participated in SPIRE as its first major space project, gaining valuable experience enabling it to bid successfully for leadership of the European consortium for one of the instruments on NASA's JWST, the most ambitious space observatory ever built.

[144] Herschel (2010). *SPIRE in depth*. Available at: http://herschel.cf.ac.uk/mission/spire
[145] Herschel (2010). *SPIRE Flyer*. Available at: http://herschel.esac.esa.int/Docs/Flyers/SPIRE_flyer_20May2010.pdf
[146] London Economics (2015). *Return from Public Space Investments.*
[147] London Economics (2015). *Return from Public Space Investments.*
[148] Various, including: consultations with Cardiff University and UK Space Agency (2017). Impact evaluation report. Herschel SPIRE Instrument. London Economics (2015). Return from Public Space Investments. https://www.gov.uk/government/publications/impact-evaluation-report-herschel-spire-instrument

    - Experience developed for SPIRE by Cardiff University and RAL-Space in instrument modelling and data-processing software has been leveraged for the ESA ARIEL mission (a satellite that will be dedicated to the characterisation of extra-solar planets).
    - Cardiff University were able to develop and enhance laboratory facilities and techniques for Herschel Spire that have also been used to support the commercial exploitation of the university's work through QMCI.
- **Spillover effects:**
    - QMCi is a spin-out company from the Cardiff Astronomy Instrumentation Group SPIRE that generated sales of **£0.4m** from 2008-2015[149] based on the commercial applications of technology developed for astronomical instruments. This includes detector technology for security imaging applications.
    - An additional spin-out company, Sequestim Ltd., has since been formed to develop working systems for passive stand-off security scanning in airport-style security, using based on Cardiff AIG cryogenic detector technology.
    - Knowledge from SPIRE has been transferred to Mexico to help develop an astronomical camera for a joint-UK- Mexico telescope, via a project funded by the Newton Fund.
    - SPIRE enhanced the UK's reputation as a centre for astronomical instrumentation, given the engagement of a large number of institutions in France, Spain, Sweden, Italy, US, China, and Canada, and the acclaimed scientific success of the project worldwide. This has enabled significant UK participation in new space projects such as JWST, ARIEL (as noted above), SPICA (a joint European-Japanese observatory), and LiteBIRD, a proposed Japanese-led mission to study the early Universe. The UK SPICA team includes Airbus UK as the consortium's industrial partner.
    - A spin-off company called Blue Sky Spectroscopy was founded in Lethbridge, Alberta, Canada to process SPIRE data and to develop the SPIRE spectrometer technology for commercial applications[150].
    - SPIRE has contributed to an increase in the uptake of STEM subjects: SPIRE team members actively contributed to the recruitment and teaching of 200-300 undergraduate students for research-led teaching programmes and 2,000-3,000 students in lecture-teaching programmes. There were also around 10 postgraduates directly involved in SPIRE instrument development and over 50 UK postgraduates relying on SPIRE's data.
    - Several substantial UK-led European Union FP-7 programmes emerged from Herschel-SPIRE (HELP, Dustpedia, SPACEKIDS).
    - SPIRE has set a technological benchmark for the next generation of astronomical instruments, in terms of both instrument performance and the quality of its data products.

5.2 ExoMars

ExoMars (Exobiology on Mars) is a two-part astrobiology project designed to search for evidence of life on Mars. The first part – consistency of the Trace Gas Orbiter and the entry, descent, and landing and demonstrator module (EDM) – launched in 2016, placing a satellite into Mars orbit, and the

[149] London Economics (2015). *Return from Public Space Investments.*
[150] Canadian Space Agency (2013). *The Herschel Space Observatory.* Available at: http://www.asc-csa.gc.ca/eng/satellites/herschel/default.asp

second part is expected to launch in 2020 to land a rover on Mars' surface[151]. ExoMars' scientific objectives include searching for evidence of past Martian life, examining water and geochemical distribution, investigate Mars' deep interior, study the surface environment for hazards, and plan for a sample return flight in the 2020s[152]. Funding for ExoMars consisted of **£205m** in public investment and very low amounts of private investment[153].

Evidence on ExoMars' spillovers is relatively limited. One reason is because the second phase of ExoMars has not yet launched, and the first phase occurred only recently (i.e. 2016.) Nevertheless, the public investment is associated with a number of impacts.

- **Internal effects:**
  - The project is estimated to be worth £200m to businesses in the UK. In GVA terms, this amounts to £67.5m.
- **Spillover effects (realised)**[154]**:**
  - ExoMars developed welding techniques used to manufacture aluminium cans that could save 12% on raw materials, or **£100m** in total. It is estimated that Rexam plc could have saved **£242m** on raw materials in 2014 had the company implemented the technique[155].
  - ExoMars involves a regularly updated blog that keeps the general public updated about recent developments, including progress of successes, such as aerobreaking and flux reduction manoeuvres[156]. This could inspire young readers into studying STEM fields.
  - ExoMars involves joint cooperation between the ESA and the Russian space agency, Roscosmos[157].
- **Spillovers (potential)**[158]**:**
  - Buggies for airport transport could contribute **£10.2m** to UK GDP.
  - Navigation sensors in areas with no GNSS access could contribute **£7.2m** to UK GDP.
  - Software architecture on Shannon class lifeboats (RNLI) could contribute **£3.5m** to UK GDP and result in **multi-million-pound** contracts for Warrior armoured vehicles.
  - Control systems for water pipe clearing.
  - Using the miniaturised Raman instrument from ExoMars for investigating nuclear waste and characterising the degradation of active ingredients in pharmaceuticals.
  - Using sterile environments from ExoMars in other applications.
  - ExoMars' extraction technologies led to technology used to extract petroleum from rocks and treating heavy oil.
  - Algorithms from ExoMars can be used to better detect melanoma.
  - Laser-based technologies from ExoMars used to find defects in steel production.

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[151] Chang, K. (2016). *ExoMars Spacecraft Enters Orbit Around Mars as Word from Lander Is Awaited*. Nytimes.com. Available at: https://www.nytimes.com/2016/10/20/science/esa-mars-lander.html [Accessed 24 May 2018].
[152] ESA (2018). *ESA - Robotic Exploration of Mars*. Available at: http://exploration.esa.int/mars/
[153] London Economics (2015). *Return from Public Space Investments.*
[154] London Economics (2015). *Return from Public Space Investments.*
[155] Rexam PLC (2015) Annual Report 2014, https://www.rexam.com/files/reports/2014ar/
[156] ESA (2018). *ESA - Robotic Exploration of Mars*. Available at: http://exploration.esa.int/mars/
[157] ESA (2018). *ESA - Robotic Exploration of Mars*. Available at: https://m.esa.int/Our_Activities/Space_Science/ExoMars/What_is_ExoMars
[158] London Economics (2015). *Return from Public Space Investments.*

5.3 Rosetta

Rosetta was an ESA funded space probe launched in 2004 with the objective of supporting our understanding of the origin and evolution of the Solar System. This involved an in-depth analysis of comet 67P/Churyumov-Gerasimenko using instruments on-board both the Rosetta Orbiter and its lander Philae which was deployed on the surface of the comet. Rosetta was a cornerstone mission in ESA's first long-term science programme (H2020), approved in 1993[159].

The total mission cost of Rosetta was nearly €**1.4 billion**, from the start of the project in 1996 to the mission's end in 2015[160].

Rosetta had significant UK involvement from industry and academia.

- **Internal effects:**
  - UK scientists were involved in ten of the 21 experiments that Rosetta carried out during its mission. This includes teams from: The Open University (Ptolemy instrument and MUPUS); Armagh Observatory (OSIRIS instrument); Imperial College London and UCL's Mullard Space Science Laboratory; Oxford University (VIRTIS); Queen Mary University of London (CONSERT), and the Science & Technologies Facilities Council's (STFC) Rutherford Appleton Laboratory[161].
  - The following UK companies were involved in the mission:
    - Airbus Defence and Space was the major subcontractor for the platform;
    - e2c designed and supplied high performance imaging devices;
    - SciSys UK Ltd who were response for the spacecraft Mission Control System development and maintenance;
    - VEGA Group plc who were involved in various aspects of the mission, including spacecraft design;
    - Logica (now CGI) who helped build the software technology for the mission;
    - AEA Battery Systems Limited who provided innovative batteries for the spacecraft and lander;
    - AEA Technology developed the Micro-Imaging Dust Analysis System (MIDAS);
    - Polyflex Space Ltd provided the tanks to store the helium used by the lander; and
    - SSTL who designed the momentum wheel that stabilised the probe for landing.
- **Spillovers (realised)[162]:**
  - Following involvement in the Ptolemy instrument, The Open University (OU) are taking some of the mass spectrometry technology from that mission to support instrument development for an ESA-Russia collaborative mission to look for water on the Moon. The Open University and its subcontractors and suppliers (including Airbus Defence and Space Limited, RAL Space and several UK SMEs) will win contracts of ~€13M for this project named 'PROSPECT'. Additionally, UK will have a role in science exploitation

[159] ESA (2018). *ESA - Robotic Exploration of Mars*. Available at: https://www.esa.int/Our_Activities/Space_Science/Rosetta/Frequently_asked_questions
[160] ESA (2018). *ESA - Robotic Exploration of Mars*. Available at: https://www.esa.int/Our_Activities/Space_Science/Rosetta/Frequently_asked_questions
[161] Please see: https://www.gov.uk/government/news/end-of-an-era-uks-role-in-european-rosetta-mission-now-complete
[162] The content of this sections is based on interviews with scientific staff at the Open University who were involved in the Rosetta mission. Further details can also be found here: http://www.open.ac.uk/people/ghm2

and may operate the Ground Segment. This represents both an internal benefit for the OU, but a spillover for the broader space and academic sectors.

- The Ptolemy sensor technology has been spun-off to support several applications in the other areas:
  - These sensors have applications in other areas of space, including space exploration and space mining;
  - The OU's sensor technology has been spun-off to support a BAE Systems and the UK's Ministry of Defence contract to develop an air monitoring system for submarines. Consultation estimates suggest that five jobs have been created on the back of this work.
  - The OU's sensor work has supported a sector-disruptive technology for a fragrance company.
  - The OU led an international consortium that was awarded a Wellcome Trust Strategic Translation Award in 2008 to develop a novel diagnostic test for tuberculosis

- **Spillovers (potential):**
  - The pressure control valve technology used for Ptolemy, is receiving STFC funding to support commercialisation, and is attracting interest from NASA. SSTL are also evaluating the technology for satellite propulsion applications. The device was a finalist in the 2014 Space Propulsion Innovations Competition.

5.4 Common themes across case studies

Across the six case studies detailed above, several common themes can be identified which underscore the uniqueness of space as an environment for generating spillovers, and the importance of UK public funding and other supporting sources of investment. These themes are detailed below:

- **Importance of UK public funding:** Across all case studies, the critical role of UK grant funding in enabling the programmes to take place at all was identified. For the four fundamental science programmes, this is because the UKSA was acknowledge as the only viable source of funding that could support the large (£ millions) and long-term (multi-decade) scale of investment that is required. Similarly, the prospect of commercial applications is uncertain and very long-term, so these projects are not attractive to the private sector. For programmes at higher TRLs, such as SABRE and NSTP, UK government funding is still required to de-risk technologies and bridge the 'technological valley of death' between the early and commercial stages of innovation. For this reason, the impacts associated with these programmes can be considered 'additional'.
- **Space as an integrator and enhancer of terrestrial technologies:** The harsh environmental characteristics of space places specific design constraints on space technologies (e.g. a need to be compact, light-weight, low power, robust in the face of extreme heat and radiation). To address these challenges, space programmes typically refine and integrate different terrestrial technologies that can later spin-out of the space sector and add value to terrestrial applications. Space therefore has an important role as an integrator and enhancer of terrestrial technologies.
- **Space programmes are suited to large-scale spillover generation:**
  - Space programmes are designed to provide answers to specific scientific challenges with significant constraints. As a result, they involve large network of multi-disciplinary

  - teams with significant resources over very long periods of time. This environment provides a unique opportunity for long-term knowledge accumulation that can 'spillover' into other areas.
  - Successful delivery of these programmes to time and budget milestones require a commercial mode of working which can be transferred to support the successful commercialisation of spin-out innovations.
  - It was mentioned that academics are sometimes motivated to spin-out their academic findings to obtain a funding stream that can sustain the research team together after the space mission has concluded.
- **Importance of supporting programmes and investment:** For the fundamental science programmes, commercialisation of space technologies would occur through three main channels: academic spin-outs, licensing agreements, and joint partnerships between industry and academia. In the first case, examples of successful commercialisation would often involve additional incubator and business-mentoring programmes (e.g. ESA, Innovate UK, Satellite Applications Catapult) to provide academics/researchers with the commercial skills to develop and market their early-stage technologies into commercial products and services. In this and other cases, further investment was often required to commercialise the early technology.
- **Impacts are long-term:** Given the long-term and early-TRL nature of space programmes, spillovers may not be observed for many years after specific mission milestones have been reached. In addition, since spillovers often result from research-led spin-outs of mission innovations, spillovers are only apparent once research teams complete their involvement in their mission.

6 Conclusions

This study set out with three objectives: i) to provide a framework for space-specific spillovers; ii) to detail the variables that influence spillovers, and iii) present case studies of the spillovers associated with UK Space Agency investments in space research and technology. A summary of the findings associated with each of these objectives is presented below. Recommendations for future research are also presented.

6.1 Framework

The spillover literature is characterised by an inconsistency in terminology, definitions, typologies, and methodologies. This study addresses this gap by providing a framework to define spillovers, differentiate between the sources of spillovers, and identify the parameters that influence spillovers.

This framework suggests that spillovers are of three types: knowledge, market, and network. At a high-level, they are transmitted by the movement of labour between organisations; knowledge exchange between workers; international exchanges, such as through trade, FDIs, and direct learning, and via the commercialisation of innovation.

6.2 Magnitude and determinants of spillovers

This report also presents quantitative evidence on the magnitude of spillovers.

Most reviewed studies adopt definitions of economic impact that are inconsistent and narrower than the definition of spillovers used in this study. For this reason, it is difficult to synthesise any common findings. Even so, the benefits of R&D to innovating organisations (i.e. ripple effects) appear to be approximately £3-4 in impact for each £1 of public expenditure, with spillover impacts being significantly larger. There is also consensus that the spillover lags for space projects are the order of 3-5 years, with impacts being realised sooner for companies providing downstream services or contract manufacturing services, and longer for companies developing their own products.

This report also identifies the key variables that influence spillovers across four areas: funding characteristics; technological characteristics; sectoral characteristics, and environmental characteristics. This evidence is intended to provide the UK Space Agency with a developing basis for differentiating between various public investment proposals within the sector and make a convincing case for limited public funds more broadly.

Environmental factors appear to have a dominant influence on spillover impacts, while on the technology side, important factors seem to be: i) the diversity of the technologies, ii) their degree of maturity, and iii) the extent to which they are generic or specific. These rank alongside factors related to the relationship between innovators and recipients (degree of trust, existence of absorptive capacities), and the internal structure of innovators and recipients (degree of decentralisation and vertical integration).

While the influence of these key variables has been described qualitatively, limitations to the literature means that it is not possible to rank the key determinants of spillovers in quantitative terms by the strength of their effect. For this, advanced statistical techniques are required to establish the causal link between the various parameters of spillovers (magnitude, lag, duration, etc.) with each of potential determinant of spillovers. This will also make it possible conclude on the impact of variables that have an ambiguous influence on spillovers because of their differing effects on the absorption of spillovers and the incentive to innovate at the organisation and sector level. These 'ambiguous' determinants include the influence of the level of competition, strong patents laws, and the nascency of the industry.

6.3 Case studies

To provide a rich account of spillover impacts, this report also presents case studies on the impacts associated with six UK space programmes – covering both UK and ESA funding channels.

Across the six case studies, there is strong evidence of high public returns from the UK's space programmes. The following common themes have been identified which underscore the uniqueness of space as an environment for generating spillovers:

- The critical role of UK grant funding in supporting the realisation of spillover impacts from space programmes is strongly identified;
- To address the difficult design challenges of the space environment, space programmes have an important role as an integrator and enhancer of terrestrial technologies;
- Space R&D programmes typically involve large network of multi-disciplinary teams with significant resources over very long periods of time. This environment provides a unique opportunity for long-term knowledge accumulation that can 'spillover' into other areas;
- Supporting programmes and investment are often required to support the commercialisation of the outputs of space R&D outputs, and

- The long-term and early-TRL nature of space programmes mean that spillovers may not be observed for many years after specific mission milestones have been reached.

6.4 Recommendations for future research

The influence of key variables on spillovers has been described qualitatively. However, quantitative econometric studies are required to establish causal link between the various parameters of spillovers (magnitude, lag, duration, etc.) with each of potential determinant of spillovers. This will make it possible to rank the relative influence of these determinants.

To support this, UK space and research programmes need to be systematically designed to collect key quantitative data on programme outcomes (such as the pre- and post-programme turnover, employment, IP, research paper count of programme participants, technology transfers, spin-offs/outs, users, consortia and networks) from the outset.

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ANNEX

Annex 1 Methodology

This study was conducted in three phases:

- **Phase 1 – Framework development:** rapid review of the literature to support the development of a framework to define and detail the main parameters, types and channels of spillovers.
- **Phase 2 – Review of evidence:** systematic literature review to quantity the main spillover parameters in the space sector, and to identify the key determinants of spillovers in both the general and space-specific literature.
- **Phase 3 – Case study development:** desk-based research and structured consultations with space industry participants and stakeholders in six UK Agency programmes to support the development of six case studies on the impact of UK Space Agency programmes.

A1.1 Phase 1 – Framework development

The first task phase involved a rapid review of the general theoretical literature on R&D spillovers. Relevant content from this literature – covering spillovers terminology, categories, transmission mechanisms and parameters – was extracted in a master document that was used to ultimately support report drafting.

A1.2 Phase 2 – Review of evidence

A systematic method of the literature was used to find evidence on the magnitude of spillovers in the space sector and how this is affected by key determining variables.

To start, a Boolean search[163] was conducted on Google Scholar using relevant keywords to identify literature that is both 'space' and 'spillover' related. Keywords were separated into two groups: (1) space-related keywords and (2) spillover-related keywords. The Boolean search was conducted on both groups of key words. To prioritise effort, keywords were classified into three tiers of relevance (Tier 1 being the most relevant).

The systematic literature search was restricted to the millennium. Papers before 2000 were already systematically covered by London Economics as part of the 2015 'Return from Public Space Investment' study for the UK Space Agency. The database of papers and content extracts from this study were therefore reviewed directly.

In addition, seminal papers before 2000 that were commonly referenced in papers covered by the systematic literature review or highlighted by consultees were also reviewed.

Once the literature extraction was complete, each paper was reviewed manually for relevance to both 'space' and 'spillovers'. In total, the literature review yielded more than 1,000 references from Google Scholar, but after manual review for relevance and duplicates, approximately 200 relevant papers were identified. Of this, 80 were identified as top priority papers.

At this point, this list was further filtered for the quality of evidence, based on the study's methodology, sample size, etc. This process resulted in a final list of approximately 41 relevant

[163] A Boolean search is a type of search allowing users to combine keywords with operators (or modifiers) such as AND, NOT, and OR to further produce more relevant results.

papers. Further papers were identified iteratively as the content of these 41 papers were systematically extracted into a structure spreadsheet. Common themes and significant findings were highlighted to support the report draft.

A1.3 Phase 3 – Case study development

This phase aimed to produce six in-depth studies to demonstrate the impact of six priority UKSA space programmes. The content for these case studies were sourced from: i) background material sourced from UKSA and project teams, and ii) from consultations.

The priority programmes were chosen in consultation with UKSA Considering the following criteria:

1) R&D programmes that have been completed and had sufficient time elapse since the end of the programme (this will make it easier to observe long-term spillover effects);
2) R&D programmes with stakeholders that are still in contact with UKSA/LE and are happy to divulge details of their programme;
3) A need to ensure a diverse range of R&D of programme (covering full spectrum of TRL stages);
4) R&D programmes with sufficient data and evidence on the inputs, activities, and outputs of the programme (jobs created, products developed, revenue earned, patents produced, exports, etc.), and
5) R&D programmes which the UKSA has strategic reasons for highlighting.

For each of these six programmes, London Economics researched and populated a list of consultations invitees with details of their relationship with their respective programmes. This involved consultations with the UKSA project team and desk-based stakeholder mapping.

A process of evidence-gathering consultations was then conducted. This took the form of a phone interview which was structured by a pre-prepared topic guide that was tailored to each consultee based on the content of the preliminary desk-based assessment of the programme. Key questions of focus included:

- The **inputs** and **activities** associated with the project/investment.
- Has there been a rise in the **Technology Readiness Stage** of the project in question?
- Has the programme supported the **development of innovation** (new patents, technologies)?
- Did the grants produce any innovative **products** or **services**?
- Where there any improvement in **revenue** and **performance/profitability**?
- Any **displacement** and **substitution** effects, i.e. would the project have occurred without UKSA funding?
- Did the project have any other effect on **UK competitiveness** as a result of the investment?
- Were there any **spin-ins** inside/outside the space sector? Was the company able to serve a new market?
- To what extent can these effects be **attributable** to UKSA investment?
- What is the **counterfactual**? What would have happened to the beneficiaries of the funding without it?

These questions were informed by the UKSA's *Evaluation Strategy.*

Following write-up of the consultation material, all content from this phase was used to draft a concise case study for each of the six priority programmes.

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