INSIGHT

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INTRODUCTION

Technology spillovers are unexpected consequences of research and development (R&D), which have benefits to the wider economy. Previous studies have suggested that the social return to investment in R&D is around 70% per annum, for a ten-year period, and is approximately 2-3 times the private return to R&D.

This INSIGHT paper presents up to date evidence on the magnitude of technology spillovers specifically from the aerospace sector. It indicates a wide disparity between social and private return – approximately 4-5 times. This means that without government support to encourage this activity, private companies are likely to underinvest in R&D.

The paper also contains a supporting narrative on spillover mechanisms and case studies giving examples of how they occur.

13 SPILLOVERS: REVEALING THE BROADER ECONOMIC BENEFITS OF AEROSPACE R&D

ABOUT THE AEROSPACE TECHNOLOGY INSTITUTE

The Aerospace Technology Institute (ATI) is an independent not-for-profit company at the heart of aerospace research and development in the UK. Our mission is to raise UK ambitions, to deliver the best technology and to maximise the UK's full economic potential. We do this by providing objective technical and strategic insight, maintaining a UK aerospace technology strategy. ATI, together with Industry and Government, helps to direct UK research investments – set to total £3.9 billion between 2013 and 2026.

The ATI was established in 2013 with a remit to invest in strategic aerospace technologies for the UK, including a focus to identify potential technology spillover opportunities. To date, around £2.2 billion has been invested in over 200 research and technology projects, involving more 200 than organisations, including over 100 small and medium enterprises (SMEs), as well as universities and Catapult organisations.

> "Importantly, the aerospace spillover is found to be statistically significant to the wider non-aerospace economy."

DISCLAIMER

The Aerospace Technology Institute (ATI) believes the content of this report to be correct as at the date of writing. The opinions contained in this report, except where specifically attributed, are those of ATI, based upon the information that was available to us at the time of writing. We are always pleased to receive updated information and opposing opinions about any of the contents.

All statements in this report (other than statements of historical facts) that address future market developments, government actions and events, may be deemed 'forward-looking statements'. Although ATI believes that the outcomes expressed in such forward-looking statements are based on reasonable assumptions, such statements are not guarantees of future performance: actual results or developments may differ materially, e.g. due to the emergence of new technologies and applications, changes to regulations, and unforeseen general economic, market or business conditions.

1: EXECUTIVE SUMMARY

Technology spillovers arise from investments in research and development (R&D) when the innovating company does not capture the full commercial benefits arising from the innovation. Technology spillovers matter for the performance of the economy – innovation is a critical success factor for driving long-term economic growth and productivity.

As an unexpected consequence of R&D investment, technology spillovers are hard to measure, although several studies have tried to quantify them. The average results put the social return on R&D investments at around 70%. However, the private returns are generally much lower, which means that companies are likely to underinvest in R&D. This is an example of market failure – a key reason why the UK government supports investment in R&D, and why the ATI exists.

Qualitative evidence indicates that technology spillover from the aerospace sector is happening, but there is a lack of up-to-date, sector-specific quantitative evidence. This study seeks to quantify the magnitude of technology spillovers resulting from investments in aerospace R&D.

The approach taken in this study is top-down and statistics driven. It involves collecting large amounts of data to find a long-run statistical relationship between the stock of aerospace R&D and the output in other sectors. Its focus is on identifying and quantifying the spillovers that occur between the aerospace sector and other industrial sectors.

This study targets specific sectors into which spillover is more likely to occur. Eight manufacturing sectors (including aerospace) and two services sectors are considered. It takes a multi-national approach, drawing upon data for seven countries: US, Canada, UK, France, Germany, Spain and Italy – covering 80% of the global civil aerospace market.

This INSIGHT paper provides positive and statistically significant spillover evidence for five sectors. These sectors are:

- Automotive
- Ships, rail and other transport
- Rubber and plastics
- Machinery and equipment
- Scientific R&D services

Importantly, the aerospace spillover is found to be statistically significant to the wider non-aerospace economy. The social return to aerospace R&D is calculated as 70% to the whole economy (sustained over a ten-year period), and the private return is 15%. The five key sectors are found to account for around 90% of spillover realised to the whole economy. These findings also suggest the mix of industries present in an economy could be important to the effectiveness of the economy at benefiting from spillovers.

This paper illustrates the variety of mechanisms by which technology spillover occurs, such as supply chains, universities/catapults, dissemination, patents, people movement and networks. Spillover from aerospace R&T can even be realised more quickly in other sectors, given the comparatively long aerospace commercialisation timelines.

Key characteristics of open innovation are identified to help the ATI understand how it can help to maximise spillover from grant funded projects. The more factors in place for enabling the spillover potential, the more likely it is that technology spillover will occur, and with greater economic impact.

> “The social return to aerospace R&D investments was found to be more than four times as large as the private return”

2: WHAT ARE SPILLOVERS? WHY DO THEY MATTER?

Spillovers arise when an activity leads to costs or benefits that are not fully captured by those directly involved. For example, when an innovating company does not capture the full commercial benefits arising from the innovation.

This can mean that companies may underinvest in research and development (R&D). However, technology spillovers have a positive impact on the wider economy and are a key reason why government supports investments in R&D (by grants, tax credits and loans). This paper focuses on the economic impact of spillovers that arise from investment in R&D in the aerospace sector.

Innovation is a critical success factor for driving long-term economic growth and productivity and is estimated to contribute up to 70% of GDP growth in advanced economies[1]. Increasing R&D investment in the UK from 1.6% of GDP, to the OECD average of 2.4% by 2027, and 3% in the longer-term (OECD upper quartile) will lead to a transformative effect for the UK economy[2], in terms of private R&D investment, GDP and skills. Technology spillovers are therefore essential to the performance of the economy.

There are three main types of technology spillover[3]:

– **Market spillovers:** where the benefits arising from the use of the new technology are not fully captured in the price paid by the buyer.

– **Knowledge spillovers:** when knowledge created by one organisation passes onto others without full payment, creating value for them and their customers.

– **Network or product spillovers:** when new goods and services create demand for complementary goods in other sectors or are adapted to other markets – a ‘platform effect’.

Technology spillovers are hard to identify, measure and quantify. The innovating company is unlikely to be able to identify or measure spillovers. A case study approach could be useful. However, this may not consider the more indirect examples of technology spillovers, and even then it poses a tricky measurement and attribution challenge.

Recent evidence suggests that investment in intangible assets is becoming an increasing share of total investment and a much more important factor behind corporate success, economic performance and realising spillovers[4]. (Intangible assets include non-physical investments that cannot be easily valued or sold, such as R&D, software and staff training rather than fixed assets like land, buildings and capital equipment).

“Innovation is a critical success factor for driving long-term economic growth and productivity.”

3: WHAT EVIDENCE IS AVAILABLE FOR MEASURING TECHNOLOGY SPILLOVERS?

In 2015, the ATI conducted a literature review of over 20 available studies that have tried to estimate the magnitude of technology spillovers, using a wide range of approaches from case studies to statistics.[5]

Figure 1 shows the social return on investments in R&D versus the private return. In almost all instances, the social return exceeded the private return (marked by the 45° line in the chart), and by a significant margin in the majority of cases. Typically, over ten years this put the social return on investments in R&D at around 70% (but with a wide range of 20%-150%). The average social return on investments in R&D was approximately 2-3 times the private return to R&D.

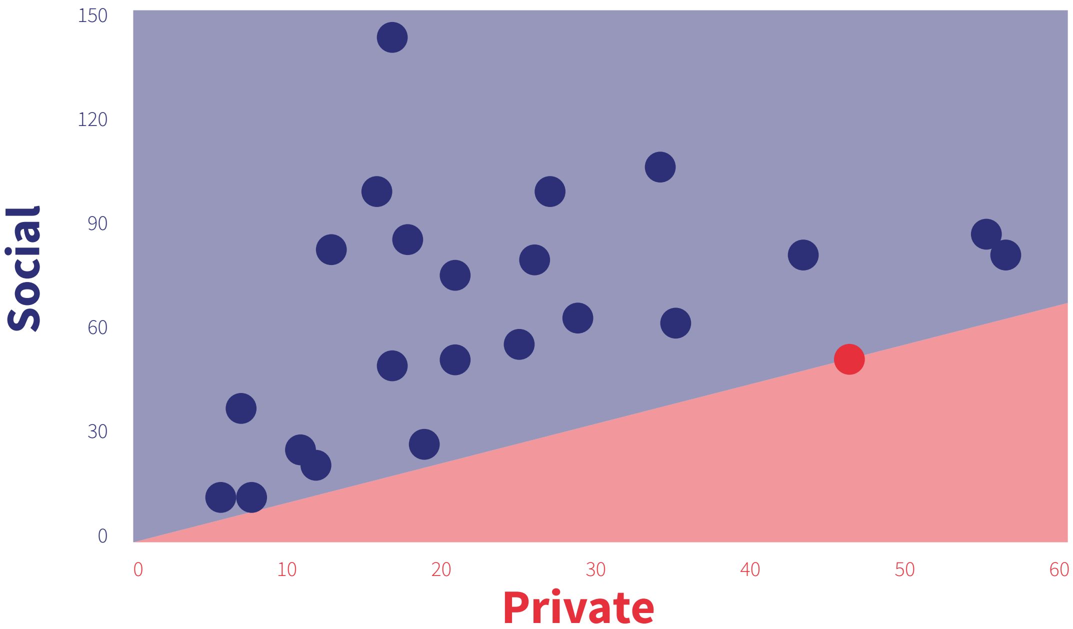


Figure 1: Private and social returns to investments in R&D (%)[6]

Most studies in the literature do not explicitly depreciate the rates of return to R&D, so an average private return of around 25% over ten years is a lot less attractive than it sounds. The most typical private annual return was 4-8%. This is generally below the weighted average cost of capital, but with significant levels of risk, meaning that innovating companies are likely to underinvest in R&D. This is a problem that the ATI Programme is actively trying to address.

Another review conducted by Frontier Economics for the Department for Business had similar findings.[7] For papers considering technology spillover between industries (for which there were 11 papers with 15 estimates), the average social return was calculated at 50%, typically over a ten-year period, with a range of 10%-140%. The ratio of social return to private return was put at an average of 2.5 times, with a range of 1-8 times.

Both literature reviews are quite reliant on the same survey paper led by Robert Hall in 2009,[8] which explains their relatively similar results. The subject papers are considered robust and come from a variety of distinguished innovation economists. However, much of the evidence originates from North America (particularly the US), focuses on manufacturing or advanced technology sectors (relevant to aerospace, but much broader in their scope) and the underlying data is only as recent as the 1980s to early 2000s.

This INSIGHT paper provides an up-to-date sector-specific estimate of the social returns to aerospace R&D investments.

4: EVIDENCE AND MECHANISMS FOR TECHNOLOGY SPILLOVERS IN THE AEROSPACE SECTOR

Aerospace is a high-value and high-technology sector, the type more likely to deliver technology spillover.[9] In 2017, the UK aerospace sector invested £1.5 billion in R&D.[10] Along with software, investment in intangible assets accounted for approximately 70% of UK aerospace total investment.[11] Spillovers are expected to account for around half of the ATI's intended economic impact.[12] It is therefore important to understand how they happen and how they can be increased.

The ATI conducts case studies on projects in its portfolio, which is currently worth £2.5 billion with over 200 organisations.[13] These frequently cite the potential application of technology in a wide range of industrial sectors beyond the aerospace sector.[14] The ATI undertook an analysis of over 150,000 global aerospace patents filed over the past 20 years.[15] Analysis of forward citations (later patents listing prior art) identified numerous examples of potential technology cross-over. Both approaches indicate that technology spillover is happening within and beyond the aerospace sector. However, neither approach quantifies the magnitude of the private or social returns of innovation.

Mechanisms

The types of mechanisms by which technology spillover occurs is important but needs a more qualitative approach to understand. Throughout this paper, case study examples have been provided for some of the key sectors in which technology spillover from aerospace is happening. These illustrate the variety of mechanisms by which technology spillover occurs and include supply chains, universities/catapults, research dissemination, patent filing, people, skills and networks. These mechanisms are summarised in Figure 2, which illustrates the routes that technology spillover may take for aerospace R&T projects. It also suggests where the benefits may end up.

Figure 2: Spillovers in the aerospace industry, as a result of research and technology (R&T) projects[16]

Type of spillover	Mechanism	Beneficiary
Market	Aerospace research can be **commercialised by other industries** before it is used on aircraft. R&T projects require a degree of technical integration in an aircraft by different companies in the **supply chain**, which need to be coordinated. This may create benefits for suppliers and customers.	– **Supply chain** – **Customers**
Knowledge	R&T projects are typically collaborative and may involve **universities** or **research centre** partners. These partners have incentives to disseminate the findings of research projects, e.g. publish academic papers or university education. **Open-access facilities**, such as Catapults, have members from a variety of industrial sectors, can create **infrastructure** or other **know-how** that can be used by other organisations, including in other sectors. R&T develops **knowledge/skills** which can be transferred through **collaborative relationships, supply chains** or **employee turnover**; particularly where there are non-competing applications of the technology.	– **People/skills** – **Collaborators** – **Competitors**
Network or product	Aerospace research makes available a kind of **common "data" or "platform"**. Those not directly involved can access and utilise the **data/platform** for their own purposes, e.g. other businesses, researchers and government. Examples include **open-access software** and **data analytics platforms**.	– **Collaborators** – **Customers** – **Competitors**

One mechanism for technology spillover that is often understated is skills. Almost 50% of the expenditure in aerospace R&D is associated with labour and salary costs, employing some 15,000 engineers and technicians in 2017.[17] Aerospace R&D therefore has a key role in developing skills. When staff move between companies or sectors they take some of this knowledge and capability with them and can exploit it, particularly where there are non-competing applications.

Aerospace and automotive: advanced manufacturing, technology cross-over

The aerospace and automotive industries are both advanced manufacturing sectors with a need for high-quality product design, engineering skills and manufacturing methods. They are each seeking continued improvements in product performance, particularly weight and cost reduction, and greater fuel-efficiency.

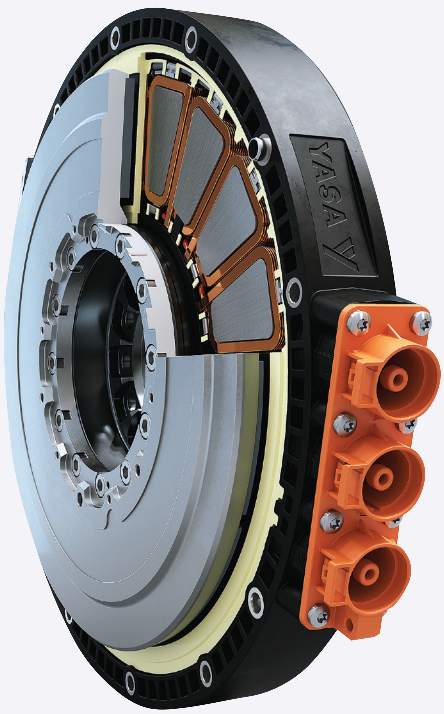
A recent example of this is the push to hybrid and electric propulsion. However, automotive manufacturing occurs at a much higher rate than aerospace, although the increasing delivery rates for single-aisle aircraft are starting to mean that automotive production techniques are becoming more appropriate for aerospace. Both industries also rely on high performing supply chains and key suppliers may sell to both aerospace and automotive.

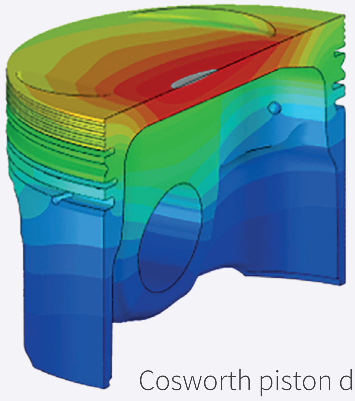
Technology cross-over: materials, manufacturing and electrification

Under the National Aerospace Technology Exploitation Programme (NATEP), Materion Aerospace Metal Composites (AMC) is collaborating with automotive pistons manufacturer Cosworth. The main aim of the Composite Metal Engine Technology (C-MET) project is to develop the use of SupremEX® metal matrix composites for aero-engine applications, to enable lighter weight designs, lower costs and realise significant reductions in aircraft emissions, (for both piston aircraft and potentially also turbo-fan engines).[18] However, the prototype pistons have been performing so well in terms of durability, that Cosworth also see potential commercial early-exploitation for motocross racing motorbikes. As a result of the project, both companies envisage sales growth to both the aerospace and automotive industries.[19]

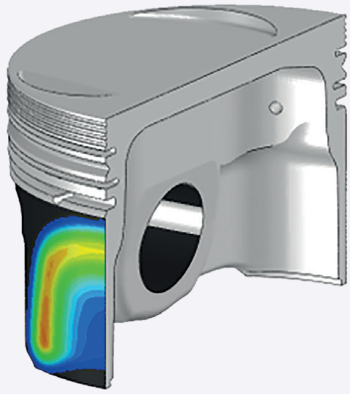
Aerospace can learn much on electrification from the automotive industry, which is currently further ahead in the introduction of hybrid and electric technologies. Areas of commonality include batteries, motors and power electronic controllers, albeit with differences in performance and certification requirements. One company seeking to bridge this gap is YASA who is collaborating with Rolls-Royce in an ATI project known as Accelerating the Electrification of Flight (ACCEL) to provide high-power, light-weight electric motors and controllers for a high-power electrical system in a demonstrator aircraft.

Chris Harris, CEO at YASA said: “We’re excited to be working with Rolls-Royce on integrating our high-power, light weight electric motors into a pure electric demonstrator aircraft. Thanks to our innovative design, YASA can deliver the smallest, lightest electric motors for a given power and torque – opening up exciting opportunities for electrification in aerospace.”[20]





Cosworth piston designs



YASA P400 axial-flux electric motor

5: AIMS, METHODOLOGY AND RESULTS

Aims

The ATI commissioned a quantitative study on spillovers specifically from aerospace R&D, conducted by Fathom Consulting. The main aims of the study were:

- To provide up-to-date quantitative estimates of spillover.
- To produce a more precise estimate on magnitude of spillover.
- To provide estimates specific to the aerospace sector.
- To assess which sectors benefit most from aerospace R&D.
- To support the ongoing case for government investment in R&D.

Methodology Overview

The approach taken to measure spillovers in this study was top-down and statistics driven, and it involved collecting large amounts of data. For this study, eight manufacturing sectors (in addition to aerospace) and two services sectors were selected, and seven major aerospace countries were included in the statistical analysis – see the technical appendix for further details on the study coverage, data collection approach and statistical methodology.

The study's focus is on identifying and quantifying the spillovers that occur between the aerospace sector and other sectors of the economy. It may pick up some spillover within companies, but is unlikely to capture spillover within aerospace, e.g. between civil, defence and space (Figure 3). An example of a defence innovation delivering spillover is the invention of the microwave oven based on military research by Raytheon.[21] Similarly, NASA cites numerous spin-off technologies from space-related R&D, such as: GPS and memory foam.[22]

Figure 3: Schematic illustrating the scope of the sector-based study approach for measuring spillovers

Other Sectors	May be captured, depends on sector/ company definition	Focus of the study
Aerospace Sector	Not spillover, these are the private returns	Unlikely to be captured, due to sector-based approach in study
	Innovating Company	**Other Companies**

Once the study had collected the data, the next step was to perform the statistical analysis. This involved conducting multiple-regression time-series econometrics, to estimate a set of equations, to understand the long-run statistical relationships between the key variables.

The analysis aimed to establish whether there was a statistically significant long-run relationship between the stock of aerospace R&D and the output, i.e. the value added, in other sectors. A range of other relevant variables were controlled, most notably other inputs in the production process, i.e. the quantity of labour and fixed capital in each sector.

Several distinct steps were performed in the statistical analysis:

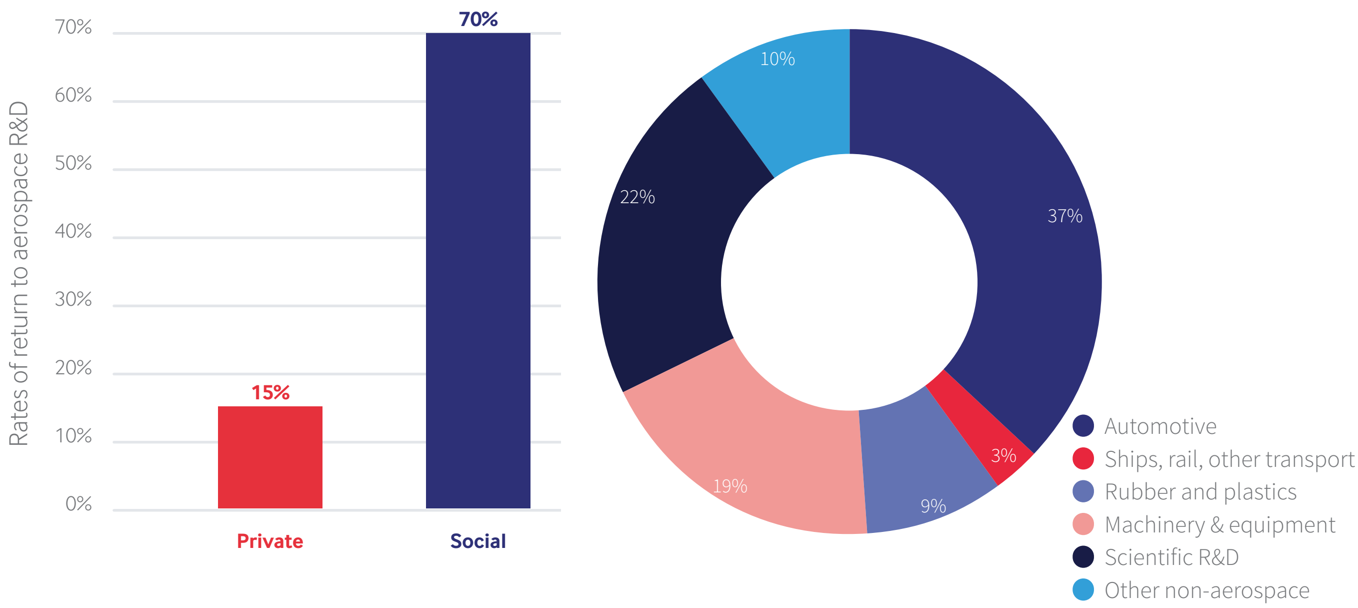
1. A baseline specification was estimated for the production function for each sector, excluding spillover.
2. An enhanced specification was estimated to test for which of target sectors there was a statistically significant relationship between the stock of aerospace R&D and the output in that sector.
3. An 'error correction' specification was estimated, in order to understand how quickly the benefits of spillover would be realised in each of these other sectors, and over what time period.
4. The results were discounted into present day values, to allow a suitable comparison over time.

Key results and interpretation

The analysis found that spillover was positive and statistically significant for five of the sectors: automotive, ships, rail and other transport, rubber and plastics, machinery and equipment, and scientific R&D services. Another key finding was that spillover was also statistically significant to the wider non-aerospace economy.

Over ten years, the total social return on aerospace investment in R&D was found to be 70% across the whole non-aerospace economy, and the private return was found to be 15% (Figure 4). This means that the social return to aerospace R&D investments was found to be more than four times as large as the private return, and indicates a compelling case for government support to aerospace R&D. The five key sectors were found to account for 90% of spillover realised to the whole wider non-aerospace economy (Figure 5). The largest spillover effects were for the automotive, machinery and equipment and scientific R&D services sectors.

Figure 4: Aerospace private/social return to R&D (left) and Figure 5: Aerospace R&D spillovers by sector (right)



A possible interpretation for the sectors identified as statistically significant for aerospace spillover is:

- **Automotive and other transport sectors (ships, rail etc.)**: the sectors have relatively similar product requirements and manufacturing methods.
- **Plastics and rubber**: aerospace has been a major innovator of composite technology, which has been used in many other industrial sectors.
- **Machinery and equipment**: includes a wide range of products from manufacturing equipment to nuclear, power generation, oil and gas, and medical equipment.
- **Scientific R&D**: includes research centres such as Catapults and university spin-outs – these types of organisations have been very active to date in the ATI Portfolio, helping to deliver R&D activity.

For the sectors that were not as statistically significant in the analysis, a possible interpretation is:

- **Metals**: aerospace is a relatively small purchaser of metal products. The metals sector is also dominated by steel production, rather than non-ferrous metals.
- **Electronics/electrical**: aerospace probably benefits from innovation in these sectors, rather than the other way around, due to the much longer product cycles in aerospace.
- **Transport services**: this is a broad category which may dilute the measurable spillover.

Finally, a few ideas on which other sectors might realise spillover from aerospace R&D. It could include some of the sectors which were not statistically significant (because it was too small to measure). It could also include other manufacturing sectors, such as aviation fuels or repair and maintenance, or service sectors such as engineering services. Or, more imaginatively, even financial services, leasing services, data analytics, entertainment or hospitality – perhaps realised through aircraft operation (rather than manufacture).

Renishaw: an aerospace spin-out that became a £1 billion machinery and equipment company[23]

The year is 1972, and a Rolls-Royce engine development programme has problems. Sir David McMurtry, then Assistant Chief Designer at Rolls-Royce, is summoned to solve an inspection issue on Concorde's Olympus engines: how to measure a 5mm wide instrumentation pipe for the supersonic aircraft.

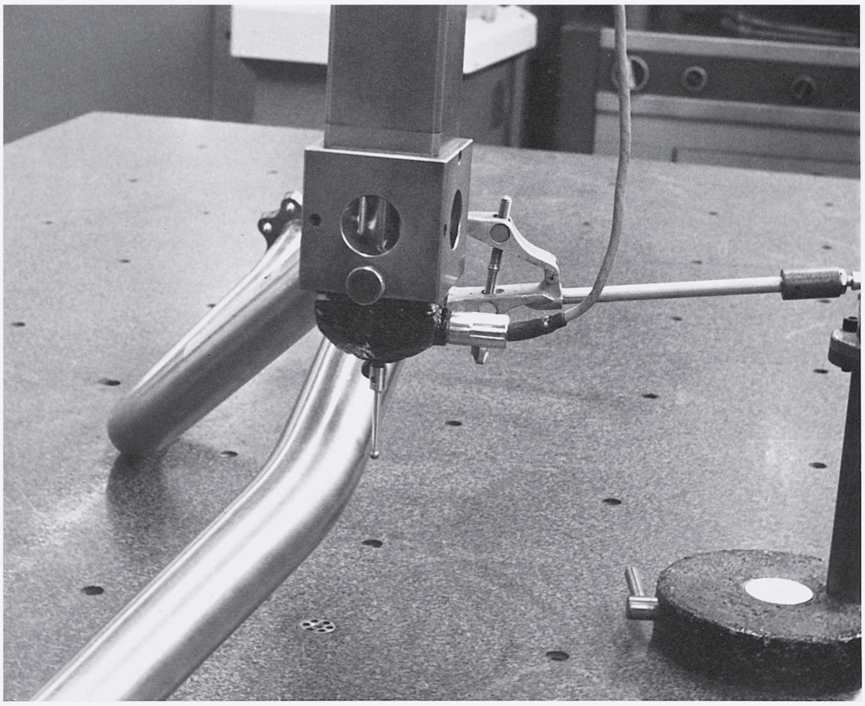
"Because they couldn't measure it, everything was on hold," recalls McMurtry, explaining that with aircraft components, you must verify that every part conforms exactly to the design drawings. The Rolls-Royce team couldn't get any readings, because the machine would keep knocking the part out of the way. He instantly knew what was required: a device that 'at the point of touch freezes the reading'". The problem was that no such device existed.

McMurtry went home with this challenge. "I just picked up what I had, put it in the lathe and started cutting and designed it as I went," recalls McMurtry. It solved the problem with the Concorde engine development programme. It also proved the genesis of the first touch-trigger probe, a 3D measurement sensor capable of rapid and accurate inspection.

Instantly, McMurtry knew the probe had commercial potential. Swiftly, he had a dozen orders. Rolls-Royce allowed McMurtry to pursue the commercialisation of the prototype probe (the patent was under license from Rolls-Royce, who received 10% royalties until their share was bought out in 1976). So, together with Rolls-Royce colleague John Deer, McMurtry founded the company Renishaw, initially assembling components in John's spare bedroom.

Renishaw has grown impressively over the 45 years of the company's existence. It now employs around 5,000 people worldwide (with 3,000 in the UK) and has a company value of around £3 billion.[24] It has become a world-leading manufacturer, whose metrology skills are today crucial to every new car on the road and plane in the skies, as well as many other applications spanning the medical and nuclear power industries.

Renishaw is still innovating and is the owner of around 1,800 patents or pending patents – with McMurtry himself named on over 200 patents. One example of this is additive manufacturing (also referred to as metal 3D printing). Renishaw is a world-leader in this field and is the only UK business that designs and makes industrial machines which 'print' parts from metal powder. Additive manufacturing has the potential to transform manufacturing processes across a wide range of industrial sectors, including aerospace, automotive and medical.



Archive image of the first Renishaw probe

6: MAXIMISING TECHNOLOGY SPILLOVER

The ATI can help to maximise technology spillover through the adoption of several key characteristics of an open innovation system (Figure 6). The more factors that are in place for enabling the spillover potential, the more likely that technology spillover will occur, and with a greater economic impact.

Some of these factors could be considered as technology, market or sector characteristics:

- **How widely applicable is the technology** to a range of industrial sectors, e.g. multi or general-purpose technologies? Some technologies may be very specific to aerospace, whereas other technologies could have lots of potential applications in other sectors.
- **How well characterised is the technology for dissemination?** Technologies that can be well codified (less reliant on know-how) may have greater potential for knowledge transmission.
- **What is the market and industrial structure?** Evidence suggests that high-value added industries, such as aerospace, may generate more potential for technology spillover. Also, the evidence suggests that more emerging industries may have greater technology spillover potential.
- **How ready is the sector to absorb new ideas?** The evidence here suggests that sectors with higher levels of R&T and human capital/skills have greater readiness to realise technology spillover.

Figure 6: Factors in an open innovation system capable of increasing the potential for knowledge spillover[25]

Characteristics of open innovation system	Factors increasing spillover potential	Factors with ambiguous impacts on the potential for spillover
1. Technology and nature of innovation	– Multi and general-purpose technologies (in the long run)	
2. Market and industrial structure	– High value-added industries, with multi-purpose applications – Nascent/emerging industries	– Higher level of competition – Higher capital/factor intensity – Higher market concentration
3. Institutional set-up		– Government funding for procurement / use of government assets or data
4. Actors	– Active role of universities and research institutes in technology development	
5. Relationships between actors	– Network ties and cooperative agreements among actors – Geographic clustering of actors	
6. Transmission mechanisms	– Low costs of knowledge transmission – linked to type of knowledge (codified) – Diversity of mechanisms	– Interaction with international trade / foreign direct investment (FDI) – IP protection, e.g. patent filing
7. Absorptive capacity	– High levels of absorptive capacity, e.g. levels of R&T and human capital/skills	– IP protection, e.g. patent filing

Other factors are more focused on the actors involved in conducting the R&T. For example, are there multiple partners involved in R&T projects, whether that be suppliers, universities, research partners or even competitors?

How strong are the relationships between these actors and what are their terms? Is intellectual property very tightly controlled by some partners or is there potential to disseminate the research findings or commercialise technologies, particularly in non-competing applications?

The ATI encourages prospective applicants to put as many of these factors in place as practically possible when applying for R&T funding and they are explicitly considered as part of the project assessment process. ATI will work with companies to identify partners who may help maximise the impacts of a project.

Composites: wonder materials developed by aerospace, with many cross-sector applications

The UK aerospace and defence industry led the development of composite materials (carbon fibre reinforced polymer) during the 1950s and 1960s. The major benefits are weight reduction, strength and fatigue resistance leading to more fuel-efficient aircraft.[26] Aerospace has used composites materials ever since, although initially focused on non-structural parts. But, for the Airbus A350 airframe, which first entered into service in 2013, over 50% is composite materials.[27]

The road to commercialisation

Commercialisation in other sectors has sometimes been quicker than in aerospace, where the product certification barriers are typically considerably higher. An example of this is the first carbon monocoque racing car – the McLaren MP4/1 (British) in 1981. This was followed by road car use in the McLaren F1 supercar in 1992. Now, BMW are making composite panels for the mass market i3. Jaguar Land Rover and Honda are also pursuing composites. The adoption of composites in automotive has been relatively slow due to their high materials costs but this is expected to fall, leading to greater adoption, thereby reducing car emissions and also extending the range of electric vehicles.

The global demand for composite products is set to increase by 4.1% per year over the next 5 years. The global composites market is predicted to be worth $105.8bn by 2020, up 55% from 2013. In the UK, the composites market stood at £2.3 billion in 2015, from aerospace as well as a range of industrial sectors.

UK exploitation of composites opportunities

UK cross-industry strategy has been developed by the Composites Leadership Forum to deliver, develop and diversify the UK composites industry, aiming to double the UK's output by 2020, and potentially increase growth by up to 12% per year to 2030.[28]

The National Composites Centre (NCC) – an open-access research and technology organisation, part of the High-Value Manufacturing Catapult network – is key to enabling this. The NCC is a world centre of excellence, hosting over 300 specialist researchers, engineers and innovators, and spearheads major R&D programmes that will help define the future of composites. Its industrial-scale facilities support all sectors including aerospace, automotive, construction and fast-moving consumer goods; with over 50 business members, from a wide variety of industrial sectors.

ATI invested around £24 million during 2018 in new facilities, capital equipment and machinery, with the Local Enterprise Partnership investing a further £4m. Its primary purpose was to support major aerospace R&T programmes, such as the Airbus Wing of Tomorrow programme; as well as companies such as GKN, Spirit, Rolls-Royce and GE Dowty for structures, engine and propeller manufacturing projects. Sectors including automotive, construction, marine, oil, gas and renewable energy also stand to benefit. For example, high-speed injection moulding, over-braiding and automated forming methods have multiple applications in the automotive industry where manufacturers demand one-minute cycle times and production-line-ready parts straight out of the mould.[29]

One company benefiting from the expertise provided by the NCC is Hexcel. Hexcel's £7.4 million four-year Multi AXial Infused Materials (MAXIM) project will develop cost-effective materials and manufacturing solutions for large aerospace and automotive composite structures. Hexcel is investing in expanding its Leicester plant by installing state-of-the art machinery, equipment and facilities.

Thierry Merlot, President – Aerospace, Europe/MEA/Asia Pacific, Hexcel: "Investment in this project in Leicester will allow Hexcel to advance key Out of Autoclave technologies that can provide a step change in the cost-effective production of composite parts for commercial aircraft and passenger cars."[30]

National Composites Centre equipment

7: CONCLUSIONS

From the results of the statistical analysis and qualitative research, it is clear that aerospace drives technology spillover and is significant to creating value in the wider economy. These are important findings, drawn from aerospace-specific analysis and identifying which individual sectors are most likely to benefit from spillover. The ATI is not aware of any comparable analysis that exists for the aerospace sector, nor of recent quantitative evidence available on technology spillovers more widely.

Some key conclusions and recommendations from this study are:

- Investment in aerospace R&D delivers significant technology spillover to other industrial sectors. This is an example of market failure and justifies government support in aerospace R&D. Without it, aerospace companies are likely to underinvest in R&D.
- There are interdependencies between key industrial sectors. Maintaining strong automotive, marine, rail, machinery and equipment, plastics and scientific R&D services sectors is important to maximise the spillover potential from aerospace R&D investment. Some of these sectors may need to be strengthened in the UK.
- The benefits of effective collaboration, dissemination and intellectual property (IP) management are important for driving spillover from aerospace R&D investments. ATI encourages applicants to put as many of these factors in place as possible when applying for funding and is considered during the project assessment process. ATI will work with companies to identify partners who may help maximise the impacts of a project.

However, by its nature, the statistical analysis is backward looking, highlighting sectors where spillover can be shown to have already take place. The ATI's Technology Strategy, Raising Ambition (2016) identified five cross-cutting technology themes which lend themselves to benefiting from spillover: high-value-design, digital economy, additive manufacture, autonomy and through-life services.[31] It also identified within the technology roadmaps where technology needs were shared with other sectors like automotive and defence – examples including battery and motor technology, thermal management and sensors.

But will aerospace continue to drive spillover benefits in the future? The industry has achieved remarkable feats of engineering in its time, but will it continue to lead technological advancements? The ATI believes this will continue to be the case. Flight imposes tough physical constraints on the designer that demand ever more ingenious ways of extracting performance – making it a hard industry in which to compete, but a great industry for pushing the limits of technology. And people are again seeking to exploit technologies in novel ways with the advent of electric and autonomous flight. In doing so, the sector will continue to break new ground.

“...people are again seeking to exploit technologies in novel ways with the advent of electric and autonomous flight. In doing so, the sector will continue to break new ground.”

TECHNICAL APPENDIX:

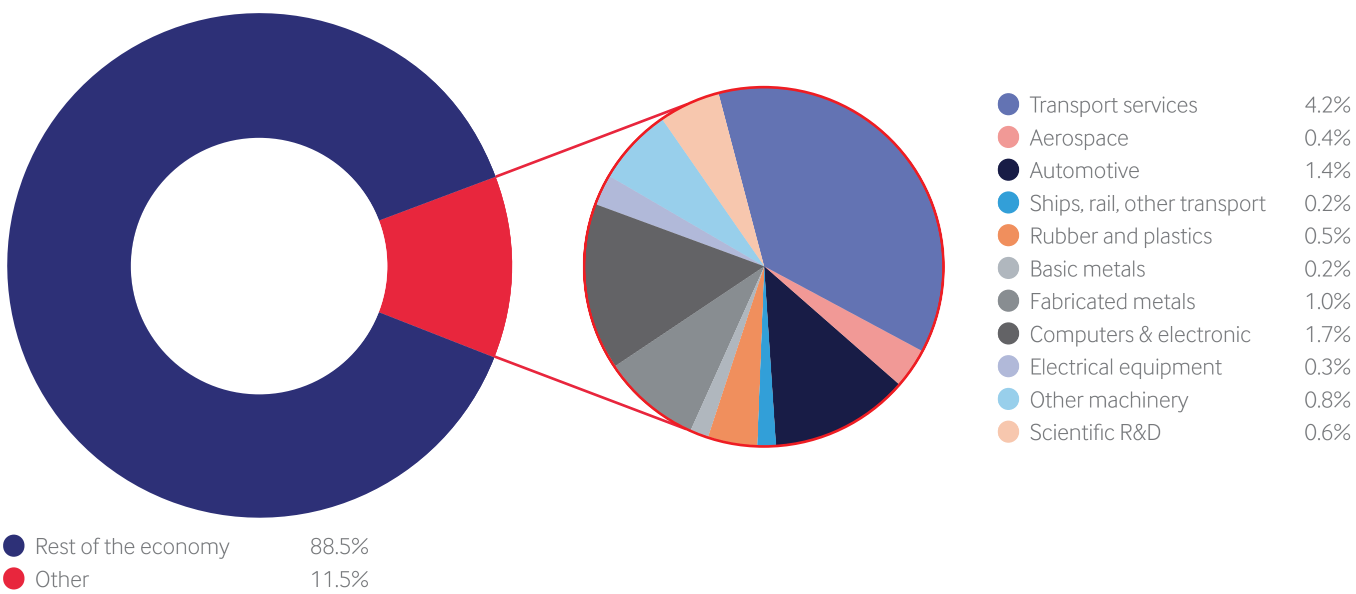
This technical appendix provides further details on the data collection and statistical analysis presented in this study.

Study coverage

For the statistical analysis conducted in this study, the decision was made to target specific sectors, where spillover may be more likely to occur. It would therefore be more likely to detect technology spillovers and find statistically significant results, where their magnitude is greater. A further advantage of this approach is that it helps to understand specific sectors where and how technology spillover from aerospace is occurring.

For this study, eight manufacturing sectors (in addition to aerospace) and two services sectors were selected. The manufacturing sectors selected were automotive, other transport (ships, rail etc.), rubber and plastic, basic metals, fabricated metals, electrical equipment, computers and electronic equipment and other machinery and equipment. The two service sectors selected were scientific R&D services and transport services[1]. Collectively, these sectors represent just over 10% of the UK economy, measured by their output, i.e. sector value added in 2013 (Figure 7). In addition, the whole non-aerospace economy, i.e. the whole economy minus aerospace, was also included for analysis.

Figure 7: UK Value Added for Target Spillover Sectors, 2013[32]



It is worth noting that for the aerospace sector, the unit of measurement is the "manufacture of aircraft and spacecraft and related machinery", i.e. SIC code 30.3. This SIC code therefore includes both the manufacture of military aircraft and spacecraft, in additional to civil aircraft. This means that potential spillovers originating from defence aerospace (dual-use applications) and also the space industry will not be explicitly measured by the statistical outputs, as these activities are both captured within the same SIC code as civil aerospace manufacturing. It should also be noted that the "repair and maintenance of aircraft and spacecraft", i.e. SIC code 33.16, is not being captured by this study.

The decision was made to take a multi-national approach, rather than just drawing upon UK data. This has the advantage of drawing upon more data (most data for the key variables of interest is only issued on an annual basis at a sector level). This makes it much more likely that any results will be statistically significant. The potential drawback of this approach is that it requires greater similarity in the production function format, i.e., it imposes some econometric restrictions. The seven countries selected were: the US and Canada, UK, France, Germany, Spain and Italy. All are OECD members – developed economies – meaning that the similar production functions assumption is more likely to be a reasonable approximation. The countries represent around 80% of the global civil aerospace market.[33]

1 Ideally, ATI would have specifically analysed the aviation services sector, but the data availability was insufficient to do this.

Data sources

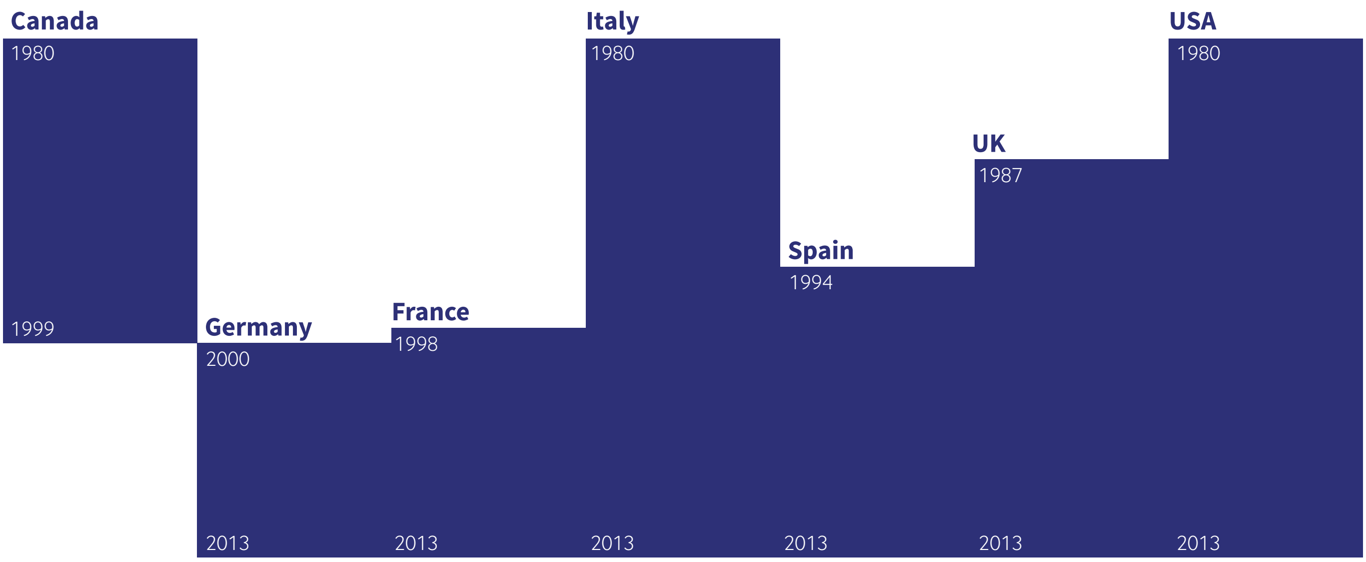
A major activity undertaken in this project was to collect sufficient data of an appropriate quality and length of time series to effectively conduct the econometric analysis and to deliver robust results. Key data had to be gathered on a wide range of variables including output, employment / hours worked, capital and R&D investment etc. The major data source for collecting the data for this was the OECD STAN or ANBERD databases.[34]

As mentioned, at sector level, most of this data is published on an annual basis. Therefore, in order to maximise the sample size for the statistical analysis, the data collection went back as far as practically possible. For most target countries and sectors, data was available from at least the 1980s onwards. A few adjustments were made to the collected data to make it as consistent as possible. These included:

- Splicing together the data series, to cover for changes in sector classifications/definitions
- Converting all data to a common currency using PPP exchange rates
- Constructing estimates of average hours worked (all-engaged, includes self-employed)
- Estimating rates of depreciation for fixed capital and R&D – these were common across countries, but varied across sectors[35]

A pragmatic approach was used to resolve each of these key data issues, drawing upon economic theory or published papers, or filling data gaps using averaged data from other relevant sectors or countries. For each sector, typically there were around 160-220 observations in the study sample (Figure 8).

Figure 8: Schematic highlighting data availability for the aerospace sector



Methodology

The approach taken to measure spillovers in this study was top-down and statistics driven. It involved collecting large amounts of data and conducting multiple-regression time-series econometrics. It attempts to find a long-run statistical relationship between the stock of aerospace R&D and the output in other sectors, controlling for other relevant explanatory variables. This entails estimating a ‘production function’ for aerospace and several other industrial sectors. Essentially, this means that sector output is considered as a function of total hours worked, and the stocks of both fixed capital and R&D capital. Several other explanatory variables were used including: the level of education, the openness of economy, the impact of recessions – all of which are known to have an impact on sector outcomes.

The study approach is aligned to the most common approach taken by the economics literature for quantifying technology spillover. So long as the data is carefully collected, the production function based on suitable economic theory and sufficient explanatory variables are included, it is considered a robust and effective approach.[36] The main drawback of this approach is that it is less likely to explain the specific mechanisms by which the spillover is occurring.

There were four distinct steps performed to achieve the key statistical results:

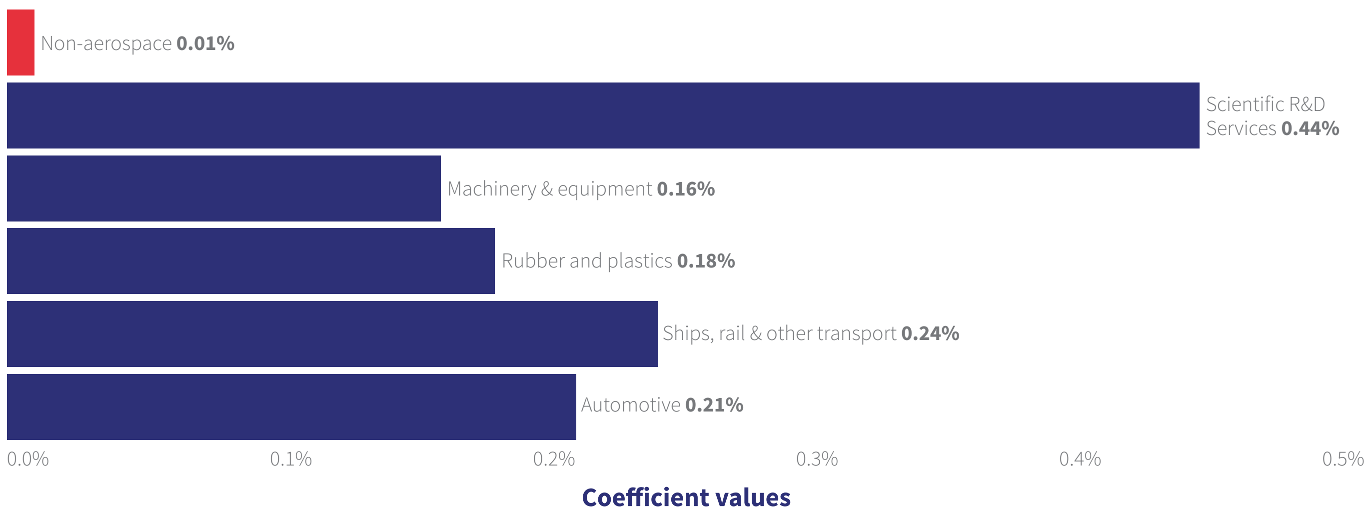
The first step was to estimate the coefficients of the baseline production function. The coefficients were generally statistically significant and correctly signed, according to the expectations provided by economic theory. A choice was made between including the global R&D stock versus the own-country R&D stock (this was generally dependent on the extent of globalisation within each sector). Several sectors were found to have increasing returns to scale, indicating relative monopoly or oligopoly behaviour.[37]

Secondly, an enhanced specification was estimated to include the stock of aerospace R&D capital as a variable in the equation. This means estimating whether the stock of aerospace R&D had a positive and statistically significant relationship with output (value added) for these sectors, controlling for other factors included within the production function (such as labour, fixed capital and a few other variables: education, openness of economy, impact of recessions).

The initial econometric results are shown in Figure 9, which shows the relative magnitude of the estimated coefficients – the higher the coefficient the greater flow of the technology spillover between aerospace R&D and these sectors. For example, for a 1% increase in the stock of aerospace R&D, leads to a 0.44% increase in the output for scientific R&D services, a 0.2% increase in the output of the automotive manufacturing sector and a 0.013% in the output of the wider total non-aerospace economy (including these five significant sectors).

These results, whilst interesting, are in themselves perhaps a little hard to interpret. These sectors are of different size, so the overall coefficient magnitude in itself does not reveal too much.

Figure 9: Spillover coefficients for significant sectors



To properly interpret these results it is also necessary to understand the 'speed of adjustment' to an economic shock, i.e. how quickly are the spillover benefits from increasing investment in aerospace R&D realised in these sectors. It is also sensible to appropriately depreciate and discount the social returns over time.

The third step, therefore, was to estimate error correction models, to determine how quickly a given increase in aerospace R&D investment would benefit these other sectors, and what the magnitude of its impact would be. The average speed of adjustment for the sectors considered in this study was found to be 24%. This means that, in response to a shock, such as an increase in the level of aerospace R&D, 24% of the gap between current and potential output would close each year, i.e. for spillovers, 24% of the spillover benefits from aerospace would be realised within one year.

Fourthly, the estimated increases in value added arising from an increase in aerospace R&D were discounted back into present day values, so that the spillovers to different sectors can be compared on a like-for-like basis over time.

To calculate the social return for the non-aerospace economy as a whole, it was then a matter of calculating the extra value-added arising from a given increase in aerospace R&D – using the estimated coefficient and speed of adjustment. The social return is expressed as an average of the additional output realised over a ten-year period. The same process was undertaken for each of the individual sectors that were identified as being statistically significant. These sector-specific spillover effects were then subtracted from the overall non-aerospace spillover estimate (weighted by the relative sector sizes), to understand how much of the overall spillover effect is accounted for by these five sectors.

As stated, many papers in the literature do not explicitly depreciate the private and social rates of return to R&D, which is not considered to be realistic. Therefore, this means that although the spillover results of this study seem comparable to the literature, they may be in fact higher. This is because the rate of depreciation for aerospace R&D expenditure has been set at 24% in this study, based on evidence from the OECD found during the data collection.[38]

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GLOSSARY

ANBERD	Analytical Business Enterprise Research and Development
FDI	Foreign Direct Investment
GDP	Gross Domestic Product
GFCF	Gross Fixed Capital Formation
GPS	Global Positioning System
IP	Intellectual Property
NASA	National Aeronautics and Space Administration
NATEP	National Aerospace Technology Exploitation Programme
NCC	National Composites Centre
OECD	Organisation for Economic Co-operation and Development
OEM	Original Equipment Manufacturer
ONS	Office for National Statistics
PPP	Purchasing Power Parity
R&D	Research and development
R&T	Research and Technology
SIC	Standard Industrial Classification
SMEs	Small and Medium Enterprises
STAN	Structural ANalysis

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The **Aerospace Technology Institute** (ATI) is an independent not-for-profit company at the heart of aerospace research and development in the UK. Our mission is to raise UK ambitions and lead technology in air transport to maximise the UK's full economic potential. We do this by providing objective technical and strategic insight, maintaining a UK aerospace technology strategy, and together with Industry and Government, direct match-funded research investments – set to total £3.9bn between 2013 and 2026.

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