Department for Business, Energy & Industrial Strategy

ADVANCED PROPULSION CENTRE

Interim Impact Evaluation

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Executive Summary

Ipsos MORI, in association with George Barrett and Ecorys, was commissioned by the Department for Business, Energy and Industrial Strategy (BEIS) to complete an interim impact evaluation of the APC funding competition in September 2018. The evaluation aims to examine the early impacts of APC funding in terms of accelerating the development of low carbon propulsion technologies and the performance of firms benefitting from the programme.

Advanced Propulsion Centre

The Advanced Propulsion Centre (APC) was established in 2013 by the UK Government and the Automotive Council. The APC aims to achieve significant progress in developing low carbon propulsion technologies, anchor and attract research and development and manufacturing capability in the UK, and leverage high value manufacturing opportunities that market exploitation may provide.

Evaluation aims and objectives

This evaluation aims to provide evidence on the effectiveness of the APC funding competition in achieving its core aims. The key evaluation questions were:

1. How far has APC funding leveraged additional expenditure on new vehicle design and manufacturing technologies in the UK?
2. How far has APC accelerated the development of new vehicle design and manufacturing technologies funded?
3. How far has APC influenced patterns of collaboration both between firms in the automotive supply chain, and with academic institutions?
4. How far has the availability of APC funding led to – or encouraged – the initiation of new R&D projects in new design and manufacturing automotive technologies?
5. How far has APC led to an improvement in infrastructure such as machinery, equipment and tooling which is used to undertake R&D and helped to secure/create high wage employment in both R&D and production?
6. How far is APC expected to deliver spillover benefits?
7. What broader technological and policy developments have emerged since the APC was created, and how are these likely to influence the impact of the scheme?
8. Has APC leveraged additional inward investment spend from supported businesses and influenced their decisions to invest in the UK in any way?

The central focus of the evaluation is on the impacts of the R&D funding competitions administered by BEIS, Innovate UK and APC UK Ltd (APC UK) – an organisation established with Government and industry funding at the start of the programme. The wider contributory role of activities delivered by APC UK were not within the scope of this study. However, where relevant, its influence over the nature and impact of the R&D projects funded through the competitions have been captured and described.

Method

The evaluation was based on an analysis of administrative and monitoring records collected through in delivery of the programme, consultations with ten stakeholders in the programme, case studies of 23 project applications to the APC (16 awarded funding and seven declined), and a programme of data-linking and econometric analysis to explore the causal effects of the scheme on R&D activity, employment, turnover, investment, output and productivity. The evidence was synthesised by mapping the results to the evaluation framework agreed with BEIS, Innovate UK and APC UK at the outset of the study.

Project delivery

Thirty-nine projects were funded over the first nine rounds of the APC programme, involving the commitment of £308m in public funds. Green Book appraisals of project proposals completed by BEIS indicated that these projects were expected to deliver £1.1bn in net benefits and to have created or safeguarded 15,000 employment years by 2019/20. However, significant commercial exploitation in the form of sales of vehicles integrating APC supported technology was not expected until 2019 and beyond.

There was a strong alignment between the underlying objectives of projects funded and the objectives of the programme. Most applicants sought to improve their competitiveness and reduce dependence on external suppliers by developing frontier technologies to comply with emissions legislation. More recent competitions saw a growing focus on electrification, aligning with wider trends in the industry.

Around half of the projects funded encountered issues with timescales or challenges in spending grants as rapidly as envisaged. There was an average ten percent underspend amongst projects that have completed. Nevertheless, the case studies of APC funded projects indicated that the majority were on course to meet their technical objectives at the time of the research. It should be noted that six of 16 case study projects involved significant rescoping of their objectives and/or exploitation plans – either due to technical challenges encountered or changes in the external context that influenced the commercial context for the project.

Leverage of additional R&D spending (evaluation question 1)

Econometric analysis exploring the impact of the programme on R&D activity provided evidence that the APC led to a 20 percent expansion of R&D spending and a 28 percent increase in R&D employment amongst lead applicants. No impacts were observed on the R&D activity of collaborators. The findings imply that programme led to an increase in overall R&D spending of between £64m and £482m by 2018. Central findings imply that 68 percent of the £404m in spending on the projects by 2018 would not have happened in the absence of the APC. There was a comparatively high estimated likelihood (73 percent) that the programme leveraged additional private R&D spending into low carbon propulsion technologies.

The case study research indicated that claims made by applicants as to why projects would not have moved forward without APC funding were mostly valid, where they related to high levels of technical risk especially in relation to high-volume LCV technology manufacturing. Case studies of projects put forward by applicants that were declined APC funding indicated that projects were not generally progressed without public support due to excess commercial and technical risk. Project proposals appeared to be genuinely marginal in the case of large firms (though it was not always clear why large OEMs would not fund the necessary development work, given the need to meet legislated emissions targets to maintain competitiveness). SMEs were more active in pursuing alternative funding sources, and there were indications that resources could sometimes be obtained to progress further R&D at a smaller scale and reduced speed.

Acceleration of technological progress (evaluation question 2)

Projects funded through the APC have moved more rapidly through the development pathway (as measured through the TRL and MRL scales) than projects that were declined funding. The projects funded are also generally on course to meet their expected reductions in tailpipe emissions. However, most projects had only partially met their project technical objectives. As noted, several projects were re-scoped in response to changing commercial opportunities and technical challenges – though the latter is to be expected in any innovation subsidy programme.

As few projects are complete, there are few examples of technologies refined with APC funding that have been integrated into new vehicle platforms. Four of the 10 completed projects had been commercialised at the time of the research, with associated vehicle sales of 1.15m units. However, it was estimated that 155,000 of those units were associated with significant manufacturing in the UK. Nevertheless, the case studies highlighted four cases in which exploitation of the underlying technologies is likely to occur in the next five years, with a significant share of the manufacturing expected to be taken forward in the UK.

Collaboration (evaluation question 3)

All APC projects required collaboration including the involvement at least one SME. A total of 142 individual partners were involved in projects funded over the first nine rounds of the APC. Case studies showed that collaboration was sought to gain access to specialist skills and capabilities whilst attempting to increase the likelihood of future R&D and/or commercial opportunities. However, the collaborative activity of leads of funded projects does not appear to have been affected by the award of a grant when compared to those lead applicants that were declined funding. Leads that received funding appear to have collaborated more with academics and less with SMEs relative to those declined funding.

Econometric analysis also suggested that the positive impacts of the programme were largely confined to the lead applicant. There was little evidence that the underlying performance of collaborators improved as a result of their participation in the programme and some models indicated that collaborators saw negative impacts. This could suggest that the programme has encouraged insourcing of higher value activities that may have otherwise been externalised.

Initiation of new R&D projects (evaluation question 4)

Case studies of projects highlighted several instances where project consortia developed new programmes of R&D that were linked to the results of an APC project. Technical outputs spilled over into adjacent R&D programmes both within and across project consortia. Without the development of skills, capabilities, test results and demonstrators as part of APC projects, case study respondents and other stakeholders indicated that the development of new avenues of R&D would not have occurred at the same rate.

Investment impacts (evaluation questions 5 and 8)

There was evidence that the programme led to impacts on the net capital investment of those awarded grants. Central estimates suggest a possible total effect of between £75m and £98m by 2018. Owing to small sample sizes, these impacts are imprecisely estimated. Allowing for statistical uncertainty, this range could extend from £22m to £161m in total. The cases studies provided examples of internal investments by OEMs to enhance or expand existing facilities, the development of new facilities as a direct result of project outputs, and wider investment in human capital, to build up supply chain capabilities in relation to electrification and Battery Electric Vehicles (BEVs) and alternative propulsions systems.

The econometric analysis also showed that the programme has led to the expansion of lead partners awarded APC funding in terms of:

- **Employment** – each grant award led to an increase in employment of 10 to 16 percent with a total impact of 2,800 to 4,400 jobs created or safeguarded, much of which appear to be focused on production activities.

- **GVA** – each grant award led to an increase in GVA of 15 to 17 percent with a total increase in the output of lead applicants awarded funding of £329m to £372m by 2018.

- **Productivity** – there were also signals of productivity gains. APC grants were estimated to lead to an increase in the wages of workers employed by lead applicants by 1.7 to 2.0 percent. There were also signals that the programme raised GVA per worker (by a range of 3 to 8 percent). The additional GVA arising from productivity gains by 2018 is estimated at between £36m and £275m.

The lifetime economic benefits of the programme will arguably largely be determined by how these productivity gains persist in the longer term. There are significant uncertainties in relation to the durability of these impacts and this evaluation could only explore short term effects.

How far is APC expected to deliver spillover benefits? (evaluation question 6)

The strongest evidence of spill-over effects from the APC programme were in the form of agglomeration and local clustering impacts. Econometric analysis was completed to examine the impact of the programme on the economic performance of the areas in which grant recipients were located and adjacent areas. These results indicated that the APC encouraged the other firms to relocate to those areas as well as producing spill-over benefits in the form of the growth and efficiency of local firms. The estimated effects were strongest in the areas in which grant recipients were located – amounting to an:

- 11 percent effect on the number of firms,

- a 17 to 18 percent effect on total employment,

- a 22 to 24 percent effect on total turnover; and,

- a six percent effect on productivity (turnover per worker).

The case studies indicated that this may have occurred where collaborators sought to reduce the costs of developing R&D and commercial opportunities with OEM and Tier 1 firms and/or gain access to specialist facilities or expertise. Knowledge spillovers were realised across organisations collaborating in the delivery of APC projects, though at this stage there was limited evidence of the imitation or replication of technologies outside of project consortia.

Impact of changes in the technological and policy context (evaluation question 7)

The broad technical areas identified in the Technology Roadmaps are thought to accurately assess key technical development in the sector. The development of energy storage and power electronics have become increasingly important as the sector accepts BEVs as the technical standard in the medium-term. This has had knock-on effects on other areas – for example the increased need for lightweighting to accommodate battery development and the decreased focus on PHEV and diesel engine development. Qualitative views provided by case study participants and stakeholders highlight that recent changes to emissions targets, an increasing focus by government and consumers on air quality and environmental issues, and complementary demand and supply-side polices to support EV development and up-take, have also increased pressure on the sector to invest in zero-emissions propulsion technologies.

List of abbreviated terms

ABS (Annual Business Survey)

ACEA (European Automobile Manufacturers Association)

APC (Advanced Propulsion Centre)

APC UK (Advanced Propulsion Centre UK Limited)

BERD (Business Expenditure on Research and Development Survey)

BEV (Battery Electric Vehicle)

BSD (Business Structure Database)

DOI (Digital Object Identifier)

GVA (Gross Value Added)

ICE (Internal combustion engine)

IHS (IHS Markit)

ISCF (Industrial Strategy Challenge Fund)

LCV (Low Carbon Vehicle)

OLEV (The Office for Low Carbon Vehicles)

OEM (Original Equipment Manufacturer)

ONS (The Office for National Statistics)

PHEV (Plug-in Hybrid Electric Vehicle)

QCA (Qualitative Comparative Analysis)

R&D (Research and Development)

SME (Micro, small or medium enterprise)

TOC (Theory of Change)

TPS (Thermal propulsion systems)

Contents

1 Introduction

The Advanced Propulsion Centre (APC) was established in 2013 by the UK Government and the Automotive Council. The APC programme aims to achieve significant progress in developing low carbon propulsion technologies, anchor and attract research and development and manufacturing capability in the UK, and leverage high value manufacturing opportunities that market exploitation may provide.

Ipsos MORI, in association with George Barrett and Ecorys, was commissioned by the Department for Business, Energy and Industrial Strategy (BEIS) to complete an interim impact evaluation of the APC funding competition in September 2018. The evaluation aims to examine the effects of APC funding in terms of early outputs and outcomes, including the technical development of low carbon propulsion technologies and the economic performance of firms.

1.1 Evaluation aims and objectives

This evaluation aims to provide evidence on the effectiveness of the APC funding competition in achieving its core aims. The key evaluation questions, as stated in the Terms of Reference, are as follows:

1. How far has APC funding leveraged additional (direct) expenditure on new vehicle design and manufacturing technologies, both amongst beneficiaries of APC funded R&D projects and their suppliers? To what extent would any leveraged expenditure have occurred at all, at a slower rate, at higher risk and/or outside the UK in the absence of APC funding?
2. How far has APC accelerated the development of new vehicle design and manufacturing technologies funded through the projects (i.e. progress through Technology Readiness Levels)?
3. How far has APC influenced patterns of collaboration (or introduced new ones), including increasing the volume and strength of collaborative relationships both between firms in the automotive supply chain, and with academic institutions?
4. How far has the availability of APC funding led to – or encouraged – the initiation of new R&D projects in new design and manufacturing automotive technologies (i.e. projects that would not have come to fruition in the absence of APC funding)?
5. How far has APC led to an improvement in the infrastructure such as machinery, equipment and tooling which is used to undertake R&D and helped to secure/create high wage employment in both R&D and the longer-term manufacturing during production?
6. How far is APC expected to deliver spillover benefits based on evidence on the nature and extent of collaborations/supply chain outputs?
7. What broader technological and policy developments have emerged since the APC programme was created (including the emergence of preferred technological standards), and how are these likely to influence the impact of the scheme?

8. Has APC leveraged additional inward investment spend from supported businesses as a result of the funding, and influenced their decisions to invest in the UK in any way?

The central focus of the evaluation is on the impacts of the R&D funding competitions administered by BEIS, Innovate UK and APC UK Ltd (APC UK) – an organisation established with Government and industry funding at the start of the programme. However, the wider contributory role of activities delivered by APC UK were not within the scope of this study. However, where relevant, its influence over the nature and impact of the R&D projects funded through the competitions have been captured and described. This study builds on process evaluation research completed in 2015 and 2017 which focused on issues of how programme design could potentially be enhanced to maximise the impact of the scheme.

1.2 Method

The evidence generated as part of this evaluation was collected using the following methods:

- **Analysis of management and secondary data:** An analysis of administrative and monitoring records collected through the delivery of the programme was completed to provide an overview of the performance of the APC portfolio against expectations at an aggregate level and to identify sources of variability across the projects funded. In addition, use was made of microdata available through the ONS, ACEA and IHS to provide an overview of recent UK automotive sector trends and any vehicle production activity that integrated APC funded project technology.

- **Stakeholder consultations:** Ten stakeholder consultations were completed between February and March 2019 to gather strategic views on the impacts of the portfolio of projects funded through the APC to date, and the context in which the programme operates. The organisations engaged in the consultation were: APC UK, The Automotive Council, the Department for Business, Energy and Industrial Strategy, the Department for International Trade, the High Value Manufacturing Catapult, the Office for Low Emission Vehicles and the Society of Motor Manufacturers & Traders (SMMT).

- **Project case studies:** Twenty-three applicants to the APC (16 awarded funding and seven declined) were invited to take part in theory-based case studies, which were completed between March and June 2019. These case studies explored the underlying intervention logic of each project to develop an understanding of its anticipated and realised outcomes and the decision-making context within which they were designed and delivered. Each case study incorporated a review of application and monitoring information, wider information describing the market context for the project, and interviews with lead and collaborating partners, the project monitoring officer and the APC delivery lead. This evidence was triangulated to provide an assessment of the contribution of APC funding to the outcomes observed.

  Project case studies were sampled purposively to include a mix of projects with different characteristics across the following factors: technology and vehicle type, grant funding sought, application quality, consortium size, duration and competition round / project end date. The sample included proposals submitted that were declined funding, to support inferences regarding the causal role of APC funding in producing the outcomes of interest. In recognition that a substantial amount of research had previously been completed with applicants for funding (with the most recent evaluation exercise taking place in 2017), three types of case study were conducted:

- **Full case studies of successful projects (9):** Successful projects that had not been previously sampled as part of past evaluation exercises.

- **Light touch case studies of successful projects (7):** Where case study research had already been completed as part of prior research, a 'light touch' approach was adopted. This sought to update existing findings and focused on any developments since the previous project cases were compiled. These involved fewer and shorter interviews and made use of previous evaluation findings.

- **Projects not awarded APC funding (7):** As noted, projects that were not successful in their grant applications were also sampled in the case study research. These were selected to provide mixed coverage of declined applications across the strength of the proposal (approximated by its independent assessment score), number of partners, year of application, and type of vehicle. These included shorter interviews with those responsible for compiling the original proposal, as well as those responsible for taking the development forward where relevant.

  While carrying out the case study fieldwork, two projects that were not awarded APC funding were identified as being connected to two projects that were later awarded funding.[1] In both cases, the original unsuccessful applications were modified, re-submitted and successful in receiving APC funding. As such, the evaluation is based on 21 case studies of individual projects.

- **Qualitative Comparative Analysis (QCA):** The evidence on outcomes and key dimensions of context gathered through the case studies were coded against the overarching theory of change to support systematic comparative analysis using QCA methods. The main aim of this analysis was to determine under which conditions the funding awarded through the APC had a causal role in producing technical or commercial success and how project characteristics affected these results.

  The strength of the QCA in providing measures of causality was limited by challenges encountered in obtaining high quality data on project proposals that were not awarded funding. In some cases, the project teams that had been assembled to deliver the R&D project were disbanded following the declined application, meaning it was sometimes challenging to obtain detailed information further development work took place. As such, the QCA results should be understood as providing measures of association rather than causality.

- **Data-linking and econometric analysis:** The Company Reference Numbers (CRNs) of applicants for APC funding were linked to sources of administrative and secondary datasets held within the ONS Secure Research Service to provide longitudinal data describing their R&D activity, employment, turnover, investment, output and productivity. A series of econometric analyses were completed using these data sources to quantify

[1] These included SOHmatiX and UK-ABSC (lead applicant: AGM Batteries) as well as Integrated Advanced Hybrid Powertrain and Speed V (lead applicant: McLaren).

the firm and worker level impacts of the programme. The data was also used to explore spill-over effects mediated by clustering of activity in proximity to those firms awarded grants. The approach to assessing spill-overs followed methods adapted from other studies that have sought to investigate the spatial impacts of economic development programmes[2].

The econometric analyses were largely driven by comparisons between firms that were awarded funding and those that made an application but were declined. It should be noted that there was evidence of systematic differences between the two groups. Companies awarded funding tended to be larger in scale and invest larger amounts in R&D, and this could limit the internal validity of these results. A set of robustness checks were completed by restricting the analysis solely to firms benefitting from funding (mitigating against this problem). These findings produced broadly comparable results. However, there was uncertainty regarding the magnitude of effects and margins of error have been presented through the report. In addition, as the analyses did not control for other subsidies or local economic development initiatives, the findings presented may capture both the direct and indirect impacts of the APC on the outcomes of interest.

- **Synthesis:** The evidence was synthesised by mapping the results to the evaluation framework agreed with BEIS, Innovate UK and the APC UK at the outset of the study. Where the data sources produced contrasting results (such as differences between views of stakeholders or between the overall assessment of stakeholders and applicants), these differences were analysed – and as far as possible reconciled - by weighting the evidence collected by quality, consistency and its broader context (such as the likely interests of different stakeholders) and validated possible using objective data, for example gathered from management information.

1.3 Limitations of the evaluation

The evidence and conclusions presented in this report are subject to the following limitations:

- **Results are based on self-reported evidence:** The evidence is to a large degree based on thematic and comparative analysis drawing on the views and perceptions of applicants and stakeholders. While outcomes reported in case studies have been quantified and validated where possible, reported outcomes may be associated with a degree of measurement error, especially where validation was not possible (e.g. where some aspects were withheld due to commercial sensitivities). Although the case studies covered a material share of the projects receiving funding from the programme between APC1 and APC9 (16 of 40) and were selected to reflect the characteristics of the overall portfolio, there are some limits to how far the findings of their evaluations can be generalised.

- **Incomplete access to case study information and records:** Case studies were based on information collected and assessed through multiple research methods. Case studies were sometimes based on incomplete evidence and information. It was difficult to engage senior commercial managers in the research in some OEMs. In some cases,

[2] For example, Gibbons et al (2017) The Local Economic Impacts of Regeneration Projects: Evidence from the UK's Single Regeneration Budget.

personnel and/or organisational changes also meant that those responsible for drafting APC applications were not available to interview.

- **Challenges in assessing R&D spillovers:** Despite requests by the evaluation team, most project case study interviewees were unable to provide records of academic publications (DOIs) or patent IDs to support the evaluation, mainly because they did not hold the information. As such, a quantitative analysis of R&D spillovers resulting from academic publications and patent registration activity could not be completed as part of the evaluation. Moving forwards, it is advised that BEIS collects details of these knowledge outputs to enable more systematic investigation in the future.

- **Timescales and risk:** The APC supports R&D in an industry characterised by long product development lifecycles. Although the projects funded typically start at a relatively high level of technological readiness (TRL5), project teams often need to deal with major engineering challenges and there is relatively high level of risk and uncertainty regarding how far and when the anticipated technological and economic outcomes of projects will be realised. The first APC projects received funding in 2014 and available monitoring information suggests 18 projects of 40 were complete as of August 2019. As such, it remains too early to identify concrete economic benefits from most of the portfolio at this interim stage.

- **Econometric findings:** The econometric findings are driven by administrative datasets that are used by ONS to produce national statistics, and issues associated with measurement error are considered less problematic. However, some key results in relation to the programme's impacts on R&D activity, capital investment, GVA and GVA per worker are based on ONS surveys that are mandatory for large firms (who are required to provide data annually) and samples of SMEs (who will complete the surveys less regularly). As such, the estimates of the overall impact of the programme on these outcomes will be skewed to some degree towards its effects on large firms. Additionally, econometric analyses provided estimates of average effects. However, the evidence indicated that success was often driven by outliers (as is typical for innovation programmes). This was explored further by examining effects on subgroups of the beneficiary population, which indicated that the impact of the programme was heterogenous across groups (e.g. leads and collaborators). This created some challenges in grossing up the findings to the population of firms, as described more fully in the Annex F.

1.4 Report structure

The remainder of the report is structured as follows:

- **Section 2** presents the programme Theory of Change and its context.

- **Section 3** presents an overview of the inputs, activities associated with the programme to date.

- **Section 4** presents the evidence on the R&D activity and collaboration outcomes of the programme.

- **Section 5** presents the direct outcome and impacts of the programme.
- **Section 6** presents evidence on the indirect outcomes of the programme, covering spill-over effects, capital expenditure and investment and wider trade activity as a result of APC funding.
- **Section 7** concludes and identifies a set of lessons from the delivery of the programme at this interim stage.

The following appendices are also included:

- **Appendix A:** Context review
- **Appendix B:** Spill-over effects framework
- **Appendix C:** Overview of BEIS monitoring data received by Ipsos MORI
- **Appendix D:** Technology and Manufacturing Readiness Levels summary
- **Appendix E:** Econometric analysis
- **Appendix F:** QCA
- **Appendix G:** Future economic impact evaluation

2 Advanced Propulsion Centre

This section provides an overview of the APC programme. This includes a discussion of the programme's rationale and objectives, the context in which it was delivered, and its anticipated outcomes and impacts. The analysis was informed by a review of relevant academic literature and policy documents and views collected in the consultations with BEIS, Innovate UK and APC UK Ltd (APC UK) representatives during the evaluation design phase. The context review was compiled by synthesising official public and private secondary policy documents and data, and validated using views collected from stakeholders and case study interviewees.

2.1 Programme overview and rationale

The APC was launched by the UK Government and the Automotive Council in 2013 as part of the Coalition Government's Industrial Strategy. The objectives of the programme are to:

- Achieve significant progress in developing low carbon propulsion technologies; and,
- Anchor and attract R&D capability in the UK and leverage high value manufacturing opportunities that market exploitation may provide.

The APC involves two main elements:

- **Public and private spending commitments:** The UK Government and the Automotive Council made a commitment to invest £1bn (including £0.5bn in public subsidies) in R&D projects aimed at commercialising low carbon propulsion technologies.
- **Creation of APC UK:** APC UK is an independent body tasked with coordinating R&D activity in the technology area. The role of the body envisaged in the Business Case included maintaining technology roadmaps for the sector, matching products to customers, and catalysing new collaborations. APC UK now brokers, facilitates and validates proposed project consortia, delivers a technology developer mentoring scheme (TDAP), maintains communities focussed around strategic technologies (Spokes network) and co-ordinates relevant international events. A review of these activities is outside of the remit of this study.

2.1.1 Strategic rationale

The Climate Change Act of 2008 places a legal requirement on the UK to reduce its emissions to 80 percent of 1990 levels by 2050. As a key contributor to emissions, the automotive and transportation sector has been identified as a priority area in which transformative low carbon propulsion technologies are needed.[3] The implication is that supply chains centred on the production of conventional internal combustion engines (ICEs) will be replaced by a supply chain focused on the production of new types of low carbon propulsion technology.

[3] There is also a broader strategic case for supporting progression towards low carbon technologies as a route to mitigate the risks associated with dependency on oil reserves (a resource for which the future availability and price are clearly subject to a range of major future uncertainties).

This presents a threat and an opportunity to the sector in the UK owing to its large automotive manufacturing base and legacy in the production of thermal propulsion systems. On the one hand, these changes could diminish the competitiveness of the UK automotive sector if OEMs and the supply chain are unable to respond to these regulatory drivers.[4] On the other, if firms in the UK can acquire a 'first-mover' advantage in the development of the relevant capabilities, there may be opportunities to reverse the 'hollowing-out' of automotive supply chains observed since the 1980s.

2.1.2 Economic rationale

Several arguments were put forward at the outset of the programme to suggest that the private sector will not respond to these challenges in the absence of public intervention:

- **Network externalities:** The widespread adoption of low carbon vehicles may require a network of complementary infrastructure. Technical 'lock-in' will likely arise once a technology standard is reached, making investment in R&D projects inherently risky (e.g. if electric vehicles replace vehicles with internal combustion engines, the required investments in charging infrastructure may make it difficult for an alternative propulsion technologies to compete). Until consensus emerges, it may be privately optimal for manufacturers to postpone significant investment to minimise expenditure on developing technology that will not be adopted on a widespread basis. However, at this point, the opportunity for any form of 'first-mover' advantage may also be lost (providing a rationale for providing grants for R&D investments to de-risk pioneering projects).

- **Transactional frictions:** Development of new forms of propulsion system will require OEMs to build relationships with firms outside traditional automotive supply chains to obtain the required expertise. However, there are a range of market failures that may prevent collaboration emerging, even if the expected returns on investment are sufficiently high. Project success depends on the commitment of all partners involved. However, as effort cannot always be rigorously monitored, there are incentives for partners to 'free-ride' on the efforts made by others. The outcomes of R&D projects are also uncertain and developing contractual frameworks covering all eventualities is challenging. Finally, collaborators will rarely be in equivalent positions leading to potential frictions if one partner brings greater expertise or resources to a project.

- **Knowledge spill-overs:** Classical knowledge spill-overs may also inhibit investment in low carbon vehicles. The inability of producers to internalise the full benefits of R&D will lead to sub-optimal levels of investment. These spill-overs may be enhanced by localised production models resulting from low inventory processes used in the automotive industry. Initial investments in R&D will create external economies of scale such as labour market pooling and local knowledge exchange, boosting the development of the industry in the UK, including attracting foreign direct investment. The presence of these positive externalities provides a rationale for providing public grants to compensate producers and technology developers for those benefits of R&D investment they are unable to capture.

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[4] A number of publications support the role of government in providing subsidies in order to increase the pace of innovation. For example, see Martin & Scott (2000). The nature of innovation market failure and the design of public support for private innovation. Research Policy 29 (2000) 437-447 or Mazzucato (2015). The entrepreneurial state: Debunking public vs. private sector myths. Anthem Press.

- **International competition between governments:** The potential for clusters of expertise to emerge has been recognised by several overseas governments that have also developed similar programmes of support which may lead to concentrations of expertise outside of the UK. If these territories can build comparative advantage, investment may be drawn away from the UK in the long term. Again, publicly funded grants for R&D may help mitigate against these risks.

2.2 Programme context

This subsection presents a summary of the economic, political and technological context in which the programme has been delivered. A more detailed review is provided in Annex A.

2.2.1 Economic context

The UK automotive sector has experienced rapid growth in the last decade but increasingly faces challenges as a result of changing market conditions:

- **Growth since 2008:** Between 2008 and 2017, the output of the UK automotive sector grew by 48 percent from £12bn to £18bn in 2018 prices. The sector outperformed the economy as whole (which grew by 16 percent) and the manufacturing sector, which saw little output growth over the period.[5] The automotive sector also became substantially more productive, with GVA per worker increasing by 25 percent in real terms since 2010 (from £86,000 to £108,000) - again outperforming the manufacturing sector and the economy overall.[6] The UK improved its trade balance in the sector, from a deficit of £27m to a surplus of £5bn in real terms between 2012 and 2016,[7] with the sector exporting over 80 percent of its passenger and light commercial vehicle output in 2018.[8] Finally, the sector saw a rapid growth in investment. Net capital investment in the industry increased from £1.7bn in 2012 to £3.3bn in 2017, while investment in R&D increased from £1.6bn to £3.1bn over same period (with the share of total UK business R&D accounted for by the sector increasing from six to 13 percent).[9]

- **Recent headwinds:** Despite rapid growth following the 2008 financial crisis, the sector faced challenges in recent years. After peaking at £20bn in 2014, automotive sector GVA had fallen to £18bn by 2018, and UK vehicle production decreased between 2017 and 2018 from 1.7m to 1.6m units. Some major OEMs in the UK have made announcements to cease UK production and new vehicle registrations have fallen. This is primarily due to decreased demand for diesel fuel vehicles, which have dominated UK production in recent years.

- **Transition to electrification:** While electrification has become a clear priority for the sector, this transition presents challenges for the UK sector. The UK is a key global producer of BEVs, due to the production of the Nissan Leaf. However, production volumes are dwarfed by those achieved by China and the US. Skills and capability gaps

[5] ONS (2019). *Annual Business Survey 2017 Revised Results.* Release date: 16/05/19.
[6] Ibid.
[7] EUROSTAT data is only provided for these years under the vehicle manufacturing category (NACE2 C29).
[8] IHS (2019). *Passenger and light commercial vehicle production statistics 2005-2018.*
[9] ONS (2019). *Business Expenditure on Research and Development 2017 Results.* Release date: 21/11/18.

in current supply chains present challenges, as UK-based OEMs may have to consider imports while these capabilities are developed domestically.

2.2.2 Political context

Since the launch of the programme, a range of political and regulatory drivers have increased pressure on automotive manufacturers to find low carbon propulsion solutions more rapidly than was anticipated in 2013. These include:

- **Dieselgate and air quality concerns:** The 'dieselgate' scandal of 2015 and increasing public concern in relation to air quality have increased pressure on Government and municipal authorities to support and legislate for a more rapid transition to low emissions vehicles. In the UK, this is reflected in the publication of the 'Road to Zero Strategy'[10] which sets out the Government's ambitions to see at least half of new cars sold in the UK be ultra-low emissions by 2030, and the Air Quality Strategy which sets out plans to end the sale of new conventional petrol and diesel cars and vans by 2040.[11]

- **2050 Target Amendment:** The provisions of the 2008 Climate Change Act were made more ambitious in July 2019, with the Government committing to the UK reaching net zero carbon emissions by 2050.[12]

- **Complementary public funding:** Since the inception of the APC, other public sector commitments have been made to support the development of low carbon propulsion systems and the sector more generally, as summarised in the Automotive Sector Deal.[13] Initiatives include a range of subsidies to lever private investment into R&D of LCV systems and demand side policies to incentivise consumers to purchase LCVs. However, central Government support for capital investment through regional aid schemes has been significantly scaled back with the closure of the Regional Growth Fund to new applicants in 2015.

2.2.3 Technology context

The APC Technology Roadmaps, prepared jointly with the Automotive Council and through consultation with the sector, present a detailed overview of the expected direction of technology development in the short- to long-term. Those interviewed as part of study generally reported that these areas of focus still broadly reflect the expected trajectory of the sector:

- **Electrical energy storage:** The UK has expertise in the early stage development of EV batteries and a key focus for R&D is developing an understanding of how to produce at scale both effectively and efficiently. Beyond the Envision-AESC battery plant in Sunderland (largely supplying the Leaf), the capability of the UK to produce at the required scale and unit cost is limited. Lithium-ion batteries are the technology standard in the short term, although other cell chemistries are in development, such as lithium-sulphur. The UK has a strong academic research base in battery electrochemistry and

[10] HM government (2018). *The Road to Zero - Next steps towards cleaner road transport and delivering our Industrial Strategy.* Available at: https://bit.ly/2DvPWM7. Date accessed: 02/09/19.
[11] DEFRA (2019). *Clean Air Strategy 2019.* Available at: https://bit.ly/2AJ8kNZ. Date accessed: 02/09/19.
[12] HM Government (2019). *The Climate Change Act 2008 (2050 Target Amendment) Order 2019.* Available at: https://bit.ly/2jYhjpl. Date accessed: 02/09/19.
[13] BEIS (2018). *Automotive Sector Deal.* Available at: https://bit.ly/2DsjLNd. Date accessed: 02/09/19.

development of battery cells and modules. Key challenges include securing a sustainable supply of raw materials, the need to upgrade existing pilot production lines, and challenges relating to the safety of systems and toxicity of components, and battery design and integration.

- **Electric machines and power electronics:** A range of power electronics, including stop/start functionality, low cost electronics, accessory electrification, and power electronics to drive motion, are all emerging technologies in the automotive sector. Recent developments in electric machines to convert energy and/or make motors more efficient - also in batteries and power electronics motors and drives, both driven by the move towards LEVs. The power electronics Technology Roadmap is expected to be adapted as a result of developments in adjacent sectors, such as improvements in software and processing power.

- **Internal combustion engines:** ICE development was expected to continue, especially for commercial and off-highway markets, and fuel cell development was also expected due to increased pressures on electricity markets caused by anticipated BEV adoption. While the UK holds strengths in ICE production, especially diesel, it is currently faces capability and capacity constraints in terms of BEV development and production.

- **Thermal Propulsion Systems:** Incremental improvements to the efficiency and emissions control capability of petrol ICE are a key priority for the UK to support the transition to LCVs (especially true for heavy-duty commercial vehicles). ICE development was expected to continue, especially for commercial and off-highway markets, and fuel cell development was also expected due to increased pressures on electricity markets caused by anticipated BEV adoption.

- **Lightweight powertrain structures:** Emissions standards and improved efficiency can also be partly achieved through lightweighting of the powertrain whilst maintaining the required material strength and flexibility. While lightweighting of vehicle shells with novel alloys is common, miniaturisation and downsizing of all vehicle components (including engines, components packaging, power electronics and other drive train components) has been a key trend in recent years. Stakeholders reported future lightweighting would focus on three areas: the design of systems and componentry, the development of new materials and the introduction of new manufacturing processes. The UK has traditionally been a key developer of lightweighting technologies but several challenges remain: implementing lightweighting technologies into mass-produced vehicles that use standardised components and are assembled in different locations is not always possible; adoption of new materials is constrained as existing infrastructure favours processing of steel; and, lightweighting solutions can produce trade-offs that may affect consumer preferences (such as noise).

2.3 Theory of change

This section describes the anticipated processes by which the APC programme is expected to deliver its intended results:

- **Inputs:** The APC involves a ten-year commitment of £1bn of investment activity into low carbon propulsion technologies between 2013 and 2023 (half of which will be supplied by the public sector, with the remainder matched by industry). R&D grant funding is allocated through a competitive application process supported by BEIS and Innovate UK which includes: an assessment of the technical and commercial merits of the applications for funding and their likely value for money, due diligence and contracting processes, and monitoring project delivery to ensure that spending and project delivery are in line with initial plans. Co-ordination, support and monitoring of the programme is supported by APC UK and is funded by a 3.5 percent levy on project costs.

- **Activities:** The activities associated with the funding competitions comprise:
  - **APC UK sector coordination and application support:** APC UK is tasked with coordinating research and development and supply chain activity. It curates the quality of applications by providing guidance to prospective applicants and facilitating the formation of collaborative relationships.
  - **Genesis of R&D projects:** The main activities associated with the APC are the implementation of the R&D projects set out in applications. This largely involve refinement of subsystems and systems in increasingly realistic environments and development of associated manufacturing processes (though some projects may also involve activity at lower TRL levels, such as modelling activity).
- **Outputs:** APC projects deliver a range of outputs over the course of their delivery:
  - **Formation of collaborative links:** The APC is only open to collaborative applications and the availability of subsidies is expected to encourage new – potentially enduring - collaborative relationships between firms, or academic institutions (potentially involving new entrants to the technology area).
  - **Additional R&D expenditure and employment:** The APC may increase R&D expenditure by collaborating partners and create positive short-term employment effects by creating or safeguarding jobs for R&D staff. It may also lead to broader effects in catalysing R&D investment beyond those receiving subsidies (e.g. by demonstrating the technical feasibility of high risk technologies). However, these effects are contingent on subsidies being used to fund marginal R&D projects that would not have been taken forward otherwise (i.e. the funding does not crowd-out private investment or 'leak' into other forms of investment).
  - **Prototype testing and refinement:** Newly developed R&D programmes typically involve testing of individual components in increasingly realistic conditions for durability and other characteristics to understand any specific issues that might be encountered once integrated with other componentry, in production, or to highlight areas in which performance might be optimised.
  - **Refinement of manufacturing processes:** Many components forming the focus of the R&D projects will have only been produced in laboratory setting. Project proposals also describe plans for developing strategies for manufacturing components at scale. However, it is not expected that projects will be ready for low rate production by the end of most APC projects (MRL8/9).
  - **International engagement:** Activities completed by the APC UK Technology Trends and Business Development teams seek to stimulate inward investment. This involves collecting market intelligence to understand global automotive R&D priorities and engagement with international automotive sector firms, which in

turn supports the identification and further development of potential inward investment opportunities.

- **Direct outcomes:** The following outcomes are anticipated as a result of these activities:
  - **Technical progress:** The funding aims to support project consortia in taking R&D projects from TRL5 and MRL4 to TRL8 and (at least) MRL6, meaning that the propulsion system will have been demonstrated to operate effectively in a working vehicle and at least to the point at which a plan for producing the propulsion system as whole has been prepared. This assumes projects overcome technical issues that arise, though R&D in the automotive sector is inherently risky and these outcomes are not assured.
  - **Integration of APC funded technology into new vehicle models:** It is anticipated that APC funded technology will be integrated into new vehicle models (contingent on successful completion of the R&D project). This could occur via the integration of the entire propulsion system, or through the integration of individual components developed into an array of new vehicles.
  - **Increased sales of new vehicles:** Provided new vehicles are commercially successful, sales of vehicles integrating technologies developed with APC support should lead to increased sales for relevant OEMs and the supply chain, and potentially increase exports.
- **Indirect effects:** The programme may also lead to a range of positive and negative outcomes through its indirect effects on producers, workers and consumers, both during and after the delivery of funded R&D projects:
  - **Accumulation of knowledge, skills and IP:** The delivery of APC funded projects may lead to an accumulation of skills and knowledge amongst the R&D workers involved. This could occur through formal training programmes or via the accumulation of tacit knowledge. In turn, this may lead to feedback effects through the genesis of new ideas, continued technology development, or via knowledge exchange. Familiarisation consultations highlighted that the development of skills and capabilities in a workforce is also important to OEMs, who take account of knowledge or skills across the sector in making investment and R&D decisions.
  - **Knowledge spill-overs:** The exchange of skills and knowledge between project participants or movement of workers between firms may lead to productivity gains beyond those involved in APC funded projects where those capabilities find alternative applications. Spill-overs may also arise if competitors can ‘reverse-engineer’ systems in ways that avoid infringement of patent rights.
  - **Attraction of inward and foreign direct investment:** The APC may also lead to direct and indirect effects on inward and foreign investment flows. The grants made available may be attractive to foreign investors - leading to direct effects on FDI. However, if the APC supports an accumulation of scarce knowledge and skills or creates a ‘critical mass’ of demand for specific inputs, domestic or foreign firms may be encouraged to locate in proximity to hubs of skills, expertise or demand. These clustering effects may produce further economic benefits if productivity spill-overs or other external economies arise from increased economic density.

  - **Investment in production capacity:** The exploitation of new technologies may require capital investment to enable production at scale.

- **Economic impacts:** As a result of the above, the competition funding is expected to result in the following economic impacts:

  - **Increases in employment and GVA:** OEMs and component suppliers may need to expand employment and output to satisfy additional demand for vehicles integrating APC technologies. To the degree that systems are manufactured and/or assembled in the UK (or feed into vehicle models assembled in the UK), the programme may lead to net increases in employment and output.

  - **Improved productivity:** The exploitation of technologies developed may also help firms raise productivity by increasing the value of output relative to the inputs employed in the production of vehicles (presuming that consumers will be willing to pay more for more fuel-efficient vehicles).

  - **Reduced import share in OEM purchases:** New UK suppliers may grow or develop as new supply chains emerge and this may be observed in reduced reliance of domestically based OEMs on imported components.

  - **Social and environmental impacts:** Programme funding is also expected to result in several impacts on consumers and society as whole:

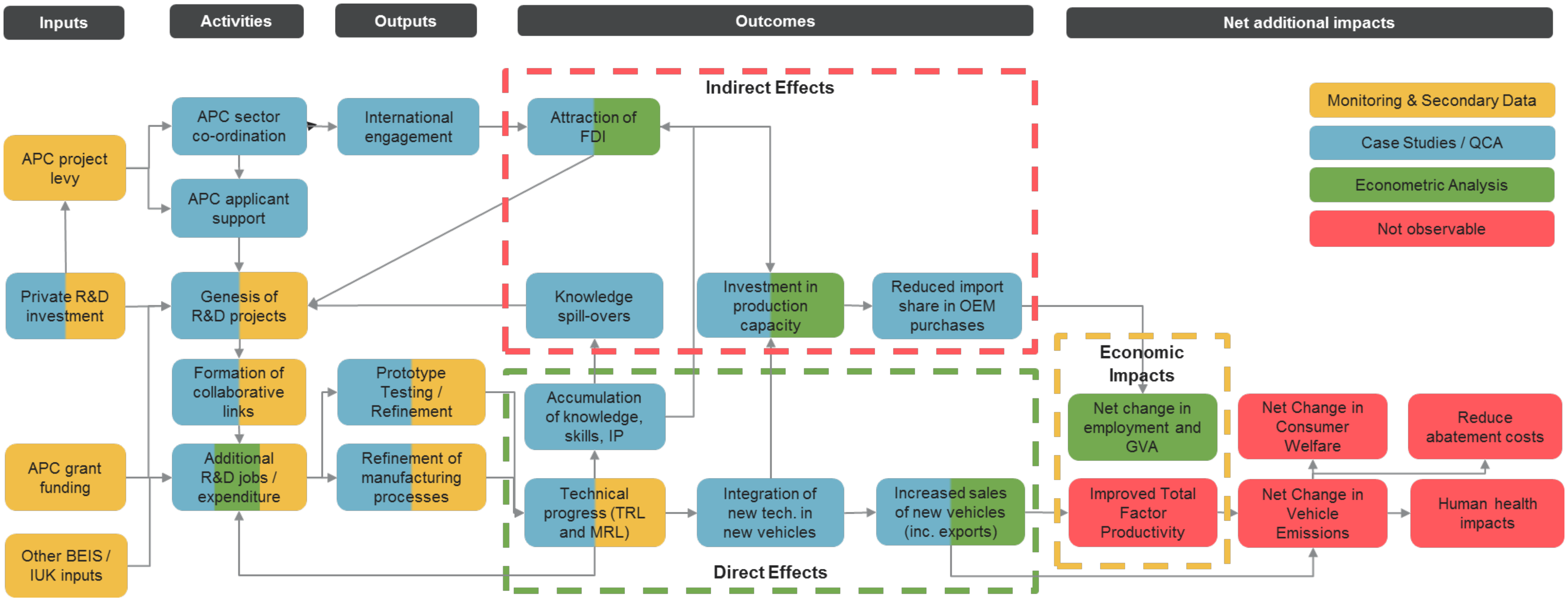
    - **Emissions, noise and health impacts:** Positive externalities may arise in the form of improved fuel efficiency, reduced emissions or noise pollution resulting in reduced abatement costs and risks to the health of public.

    - **Consumer welfare:** There may also be gains in consumer welfare driven by reductions in price or improvements in quality or fuel economy.

2.3.1 Logic Model

The logic model overleaf summarises this depiction of the process, highlighting the range of outputs, outcomes and impacts expected. The methods used to assess these effects are highlighted in the diagram. The extended duration of product development cycles in the automotive sector mean that not all intended effects can be observed at this stage. Longer term outcomes that might only be expected in the future are highlighted.

Figure 2.1: APC logic model



Source: Ipsos MORI (2018). *Developed through a review of programme documents and consultations with the APC and BEIS between October and November 2018.*

3 Project inputs and activities

This section presents an analysis of the portfolio of projects funded through the APC, with a focus on the characteristics of the portfolio and progress in project delivery. The results generated in this section were informed by an analysis of application and monitoring data, views provided by key stakeholders and a comparative analysis of sampled case study projects.

Section 3: Summary of key points
• Thirty-nine projects were funded over the first nine rounds of the APC programme, involving the commitment of £308m in public funds. Many projects built on earlier stage R&D that involved public subsidies. Green Book appraisals of project proposals completed by BEIS indicated that these projects were expected to deliver £1.1bn in net benefits and to have created or safeguarded 15,000 employment years by 2019/20. However, significant commercial exploitation in the form of sales of vehicles integrating APC supported technology was not expected until 2019 and beyond.
• There was a strong alignment between the underlying objectives of projects and the overall objectives of the programme. Most applicants sought to improve their competitiveness and reduce dependence on external suppliers by developing frontier technologies to comply with emissions legislation. More recent competitions saw a growing focus on electrification, aligning with wider trends in the industry.
• Around half of the projects funded have encountered issues with timescales or challenges in spending grants as rapidly as envisaged. There was an average 10 percent underspend amongst projects that have completed.
• The case studies of APC funded projects indicated that most were on course to meet their technical objectives at the time of the research. However, it should be noted that in 6 of 16 cases the projects involved significant rescoping of their objectives and/or exploitation plans – either due to technical challenges encountered or changes in the external context that influenced the commercial context for the project.

3.1 Project inputs and expectations

Eighty-two applications for APC funding were submitted over the first nine competition rounds. Forty were awarded funding – of which one was subsequently withdrawn. This section gives an overview of the 39 remaining projects funded, the benefits anticipated at the start of the projects and project spending to date.

3.1.1 Funding commitments

The allocation of funding to projects can be summarised as follows:[14]

[14] The analysis here is based upon the 39 projects, excluding the withdrawn project (ID 113069).

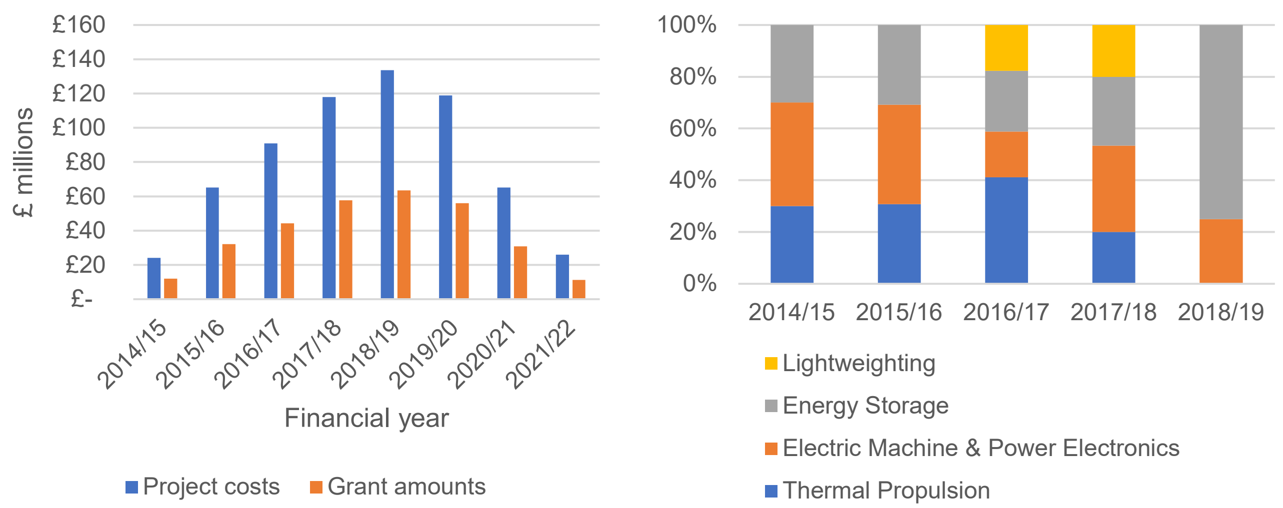
- **Project costs and grant commitments**: The total lifetime costs across the 39 projects were expected to be just over £642m in total. The awards involved a commitment of approximately £308m of public funds (around 48 percent of project costs). The average total cost of approved projects was approximately £16.5m with an average grant per project of just under £7.9m.

- **Commitments over time:** Figure 3.1 below provides an illustration of the annual distribution of project costs and grant commitments, based on a linear spending profile.

- **Technology focus over time:** Figure 3.1 also shows the distribution of projects by technology focus, where projects with a partial focus on more than one technology are double counted. Projects funded through more recent competition rounds had a greater focus on energy storage, and electric machines and power electronics.

- **Commitments by vehicle type**: In total, 69 percent of the grant commitments were for projects with a passenger vehicle focus, with 17 percent focusing on commercial vehicles and 14 percent on off highway vehicles.

Figure 3.1: Project costs, grant commitments and technical focus by year, APC1-9



Source: APC (2019). *APC Monitoring Records: Core Comps Consortia V51.*

3.1.2 Expected benefits

Each application to APC is subject to a Value for Money (VfM) assessment as part of the project appraisal and selection process. These assessments provide a projection of the costs and benefits associated with the project. The value of benefits is estimated using projections of technical performance, vehicle sales, and the creation or safeguarding of jobs provided by the applicant. This is adjusted in light of BEIS' assessment of the risks involved and the likelihood the project would proceed without public intervention. The assessments provide the expectations of the applicant and BEIS regarding the potential impact of the projects funded:

- **Net benefits:** The net lifetime benefits expected by BEIS across the portfolio under review totalled £1.1bn after adjustments for deadweight, displacement effects and risk.[15]

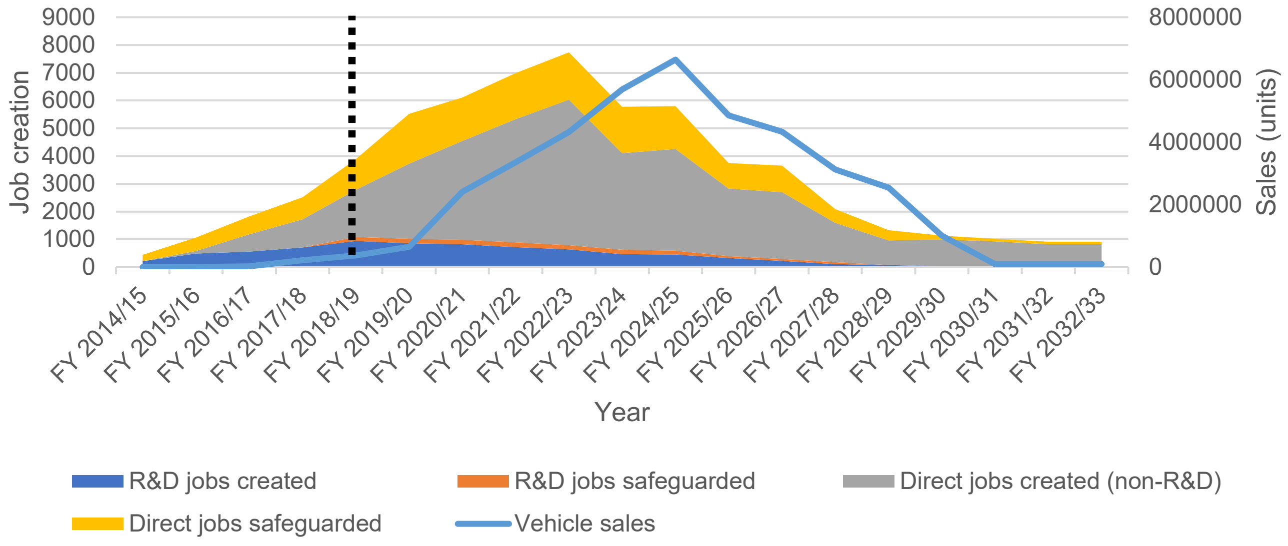
- **Distribution of benefits:** These benefits are distributed across different categories: employment, R&D spill-overs, training and other benefits, the latter of which captures CO2 and other emissions reductions (which account for more than 50 percent of the total net benefits expected, totalling approximately £575m).[16]

- **Vehicle sales:** Applicants also provide projections of sales of vehicles integrating APC funded technology over time. Based on these ex-ante projections, sales were expected to grow more rapidly from 2019/20 before peaking in 2024/25. Limited exploitation was expected to occur in the timeframe of the evaluation (marked by the solid line).

- **Employment:** Applicants also provide projections of the number of R&D and non-R&D jobs (largely production jobs) potentially created and safeguarded. Figure 3.3 indicates that the total employment years expected to be created or safeguarded between the programme's inception and 2019/20 is 15,240, with some 5,520 expected in 2019/20.

- **Technical performance:** Finally, applicants provided expectations regarding the technical performance of the technologies developed in terms of reductions in emissions. Analysis suggested that CO2 emissions measured at the tailpipe were expected to fall by just under 48 percent on average (375 CO2/km).[17] In total, it was estimated that 88.3 million tonnes of carbon dioxide will be saved in gross terms.

Figure 3.2: Time distribution of gross jobs created or safeguarded (employment years) and vehicle sales, APC1-9 and eAPC rounds[18]



Source: BEIS (2019). *VfM assessment forms; Ipsos MORI analysis 2019.*

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15 These are the costs upon which the VfM assessment was based, not the level of grant funding agreed in the Grant Confirmation Letter or subsequent change requests

16 The VfM methodology used changed over time, particularly after APC5 and APC7. This analysis aggregated any wider benefits (e,g, fuel and carbon savings) to allow comparison across the competition rounds.

17 The average is unweighted by vehicle sales.

18 The time horizons over which applicants made these projections differed across VfM assessments (and sometimes across projections for vehicle sales and jobs).

3.2 Project background

This subsection provides an analysis of the background to the APC projects, drawing primarily on project application and monitoring information and project level cases studies.

3.2.1 Prior programmes of R&D

Analysis of the case study findings indicated that 10 of the 16 APC funded projects sampled had their origins in programmes of earlier-stage R&D. Where prior research had been completed, funding was sourced internally or through public subsidies (and case studies did not reveal any examples of projects where the background development work had been taken forward primarily by external organisations). Public funds for precursor projects were typically provided by the APC[19] (where applicants built on technologies that had been commercialised in prior projects) or the Integrated Development Platform. Case study projects that received previous prior support secured an average of £1.9m in public funding before receiving the grant awarded through the APC.

Additionally, 13 universities that received APC funding between rounds one and nine secured over £23m from Innovate UK between 2004 and 2016 (or £1.8m on average) to support the early stage development of low carbon vehicles (LCVs), manufacturing and materials technologies, the results of which, or learning from, may also have fed into the development of APC projects funded in rounds 1 to 9 in some form.

3.2.2 Motivations to apply for funding

Case studies highlighted a range of motivations for applying for APC funding which were closely aligned to the high-level corporate objectives reported by projects partners in relation to the development and commercialisation of LCVs. All APC projects sampled sought to integrate novel technologies or manufacturing processes into new LCV platforms or production lines, especially into passenger and niche vehicles. The rationale for developing new LCVs was driven by the need to comply with changes in carbon emissions legislation and expectations that consumer demand for BEVs and other LCVs will increase in the future:

- **Addressing consumer LCV demand and awareness:** Project teams acknowledged that a key motivation for applying for funding was the expectation that consumer preferences will shift towards BEVs/PHEVs. Meeting consumer demand for LCVs was expected to safeguard vehicle sales in the medium-term, especially given recent decreases in ICE passenger vehicle registrations, and the need to develop a reputation for a positive environmental approach as consumers have become more aware of emissions issues.

- **Maintaining competitiveness:** Large Tier One and OEMs sought funding to develop technologies to 'catch-up' to the technology frontier set by overseas competitors, decreasing their reliance on overseas imports and achieving cost reductions. For SMEs in the automotive supply chain, the motivation to secure funding was underpinned by a need to compete against incumbent LCV component system and subsystem suppliers. APC competition funding provided the opportunity to gain a first mover advantage relative to competitors and increase market share – for example, one case project aimed to manufacture a more fuel- and cost-efficient transmission system that was not

[19] Seven pre-cursor projects were identified across four APC project case studies: Active, Alive 6, Latitude and Transcend.

currently available in UK at the time of application. The project intended to mobilise and strengthen the UK supply chain so that around two-thirds of the transmission system could be sourced from the UK rather than from imports, with the expectation that this will increase the competitiveness of the OEM.

The results indicate a strong alignment between the underlying objectives of proposals and those of the overall programme (as described in Section 2.1).

3.2.3 Role of APC UK in supporting project development

APC UK played a limited role in the initial development of project proposals. The main mechanism through this was achieved was the development of the publicly available Technology Roadmaps, as discussed in Section 2.2.3. However, advisory inputs were provided to encourage applicants to align their proposals with the objectives of the APC:

- **Alignment with project objectives:** Stakeholders reported that the review of project proposals was completed in some cases to validate the extent to which propositions were aligned to the objectives of the programme. In others, project proposals aligned with programme objectives but required adaptation to communicate evidence relating to commercial opportunities and expected benefits more clearly to those involving in assessing the application.

- **Development of Technology Roadmaps:** The evaluation found mixed views on the extent to which the Technology Roadmaps guided the development of novel proposals. Several stakeholders reported that the roadmaps effectively expressed existing OEM plans, but others highlighted they supported the reallocation of private R&D spending to riskier technology development. Analysis of the case studies highlighted one project which argued that the roadmaps had provided validation for the commercial opportunities presented by its technical scope.

3.3 Project delivery

3.3.1 Project spending

As of August 2019, the total level of grant spending by projects funded was £194m (64 percent) of a total £306m committed.[20] Compared to a linear spending profile there is a variance of 24 percent. This reflects the early initial delivery challenges which projects often face. When the analysis is restricted to the first four rounds, the variance against a linear spending profile decreases to 10 percent, indicating projects tend to catch up in the later stages of delivery.

[20] This differs from the £308m reported in records maintained by APC UK and reflected minor differences to grant award amounts between records held by Innovate UK and APC UK.

Table 3.1: Overview of APC project spending

Competition round	Actual spending (£m)	Grant Offered (£m)	% grant spent	Completed projects	Variance against a linear spend profile
Rounds 1-4	£114.4	£130.3	89	15	-10
Rounds 5-9	£79.3	£175.5	51	2	-34
All Rounds	£193.7	£305.9	67	17	-24

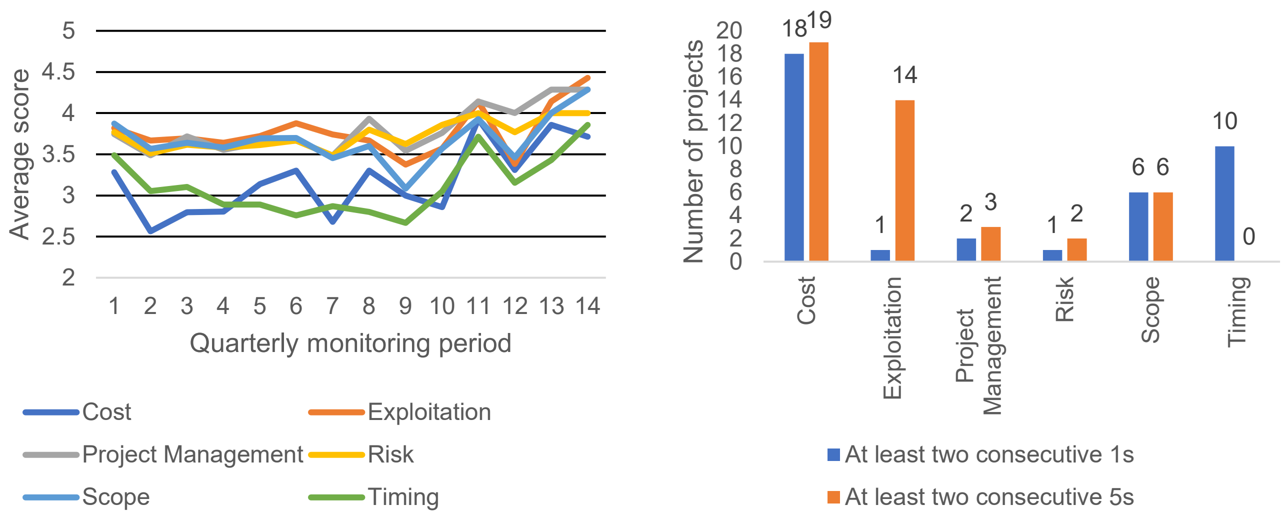
Source: Innovate UK (2019). *Innovate UK Public Grants Database*. Date accessed 02/09/19.

3.3.2 Project performance

Progress in implementing the programmes of R&D set out in the application forms was assessed using Innovate UK's RAG indicators which cover performance in terms of cost, exploitation, project management, risk, scope and timing. Projects are evaluated quarterly, with the Monitoring Officer giving a score ranging from 1 (lowest) to 5 (highest) with a brief supporting commentary. The analysis considered average trends over time and the occurrences where projects score maximum (five) or minimum (one) scores in at least two consecutive monitoring periods.

Figure 3.3 shows that on average projects initially faced issues in relation to cost (i.e. the timely drawdown of funding) and timing, although scores typically improve over time. Analysis also showed considerable progress was made in the areas of exploitation and cost.

Figure 3.3: Average score by RAG category and number of projects recording at least two 1 or 5 scores in a row, by RAG



Source: APC (2019). *Monitoring scores over time for all APC projects*. Last updated: August 2019.

3.3.3 Achievement of technical objectives

The technical aims of projects are translated into a detailed work plan at the start of the project. This specifies a set of technical work packages and milestones which can be used to judge the extent to which the project has been a technical success[21]. Across the 16 APC funded projects sampled:

- Four had met or were on track to meet their original technical objectives. This was defined as having achieved the expected TRL and MRL development across all key technology areas under development.

- Twelve projects partially met their original technical objectives. This was defined as having met the original objectives for some technologies in terms of TRL and MRL development but falling short of these targets in the case of other technologies. Of these projects, six re-scoped their original objectives significantly. These changes were required due to technical or manufacturing challenges, or actual or expected changes in market conditions. In practice these changes in scope included scaling back, narrowing the focus of work packages, and changing proposed exploitation routes.

3.3.4 Determinants of project success

Comparative analysis of project case studies and views provided by stakeholders identified several determinants of success for an APC project:

- **Management of technical challenges:** In several cases, technical challenges required project partners to explore technologies or techniques not envisaged at the outset. This generally resulted in delays or the need to postpone the development of some technologies (requiring further public funding and/or internal investment by the lead organisation). While consortia expected technical challenges, not being able to pinpoint the nature or scale of these made it difficult to set contingency budgets or assess potential timing implications.

- **Responding effectively to external factors**: Examples include problems of access to specialist facilities or supplier/subcontractor issues or the need for rescoping or supplier changes. For example, in one case a supplier was not able to provide the pouch cells for the battery, leading to a change to a supplier which only offered cylindrical cells, with a consequent need for design changes.

- **Effective project management:** Key aspects include: firm strategy, team composition, shared vision, clear ways of working and lines of communication, perseverance to make collaboration work and the importance of an equal voice for all members of consortia.

- **Clear, credible route to exploitation by consortium members:** The business case for one project - which focused on the development of the UK supply chain - was no longer viable, as because exploitation would have necessitated the construction of a new plant, requiring substantial investment for which the necessary resources were not available.

[21] A combination of data sources were used to verify the technical success of active and closed projects, including: close out reports (where available), the most recent quarterly monitoring reports and interviews with APC leads, Monitoring Officers and Project Leads.

4 Impact on R&D activity and collaboration

This section presents an analysis of the effect of APC funding on key R&D and collaboration outputs. Evidence used to develop the findings in this section was compiled from the programme of data-linking and econometrics, an analysis of application and monitoring data, comparative analysis of sampled case studies and the perspectives of key stakeholders.

Section 4: Summary of key points

- Analysis showed that claims made by applicants as to why projects would not have moved forward without APC funding were mostly valid where they related to high levels of technical risk for development and UK supply chain deficiencies (especially in relation high-volume LCV technology manufacturing). However, it was not always clear why large OEMs could not fund the necessary development work, especially given the need to meet legislated emissions targets to maintain competitiveness.

- Case studies exploring the progress made by applicants that were declined APC funding suggested that projects were generally not progressed in a significant way without public support. Applicants tended to made a case that these projects carried excessive commercial and technical risk. Such proposals appeared genuinely marginal in the case of large firms. SMEs were more active in pursuing alternative funding sources, and there were indications that resources could sometimes be obtained to progress further R&D at a smaller scale and reduced speed.

- Econometric analysis exploring the impact of the programme on R&D activity provided evidence that the APC led to an expansion of R&D spending and employment amongst lead applicants. These effects were estimated at 20 percent and 28 percent respectively, though these results were associated with a margin of error. No impacts were observed on the R&D activity of collaborators.

- The findings imply that programme led to an increase in overall R&D spending of between £64m and £482m by 2018. Central findings imply that 68 percent of the £404m in spending on the projects by 2018 would not have happened in the absence of the APC. There was a high estimated likelihood (73 percent) that the programme leveraged additional private R&D spending into low carbon propulsion technologies.

- Levels of collaborative activity amongst APC lead grant beneficiaries does not appear to have been influences by the award of a grant when compared to those lead applicants that were declined funding. Leads that received funding appear to have collaborated more with academics and less with SMEs.

4.1 Impacts on R&D activity

APC funding was expected to increase levels of spending on the development of low carbon propulsion technologies amongst firms receiving grants. This was expected to occur by leveraging additional resources into R&D projects that would not have otherwise been funded (or would not have been delivered at the same scale, over the same timescales, or in the UK). It is important to note, however, that there are a complex range of possible effects. Even if these objectives are met, subsidies could divert private funds from alternative R&D programmes or place pressure on prices (e.g. wages of R&D technicians) leading to reductions in R&D activity elsewhere in the economy. This subsection provides evidence on the impact of the APC on R&D activity at the level of both the projects funded and the firms receiving grants.

4.1.1 Project additionality

A key requirement of the APC funding application is to demonstrate why the project would not go ahead without public support. Those appraising applications make a quantitative judgement as to the likelihood projects would go ahead without public sector support (deadweight). Analysis of these assessments indicated that the ex-ante expectation was that on average, 63 percent of projects funded (or the outcomes associated with those projects) would have gone forward in the absence of funding awards.

The case studies were used to explore the degree to which applicants for funding considered it possible to find alternative means of funding the project had they not secured funding through the APC. Analysis of results suggested that 13 of the 16 APC funded projects sampled would reportedly have been abandoned, scaled back in terms of scope, or completed over a longer timeframe. Such an assessment has limited validity on its own (as respondents have strategic incentives to overstate the impact of the grants and may have not have strategic insights into the relevant decision making context – particularly where such decisions are made by parent companies based overseas). However, the arguments made provide some insight into the relevance of the market and system failures put forward to justify public spending on the APC.

Looking at the additionality claims made in more detail, market and system failures were most prevalent with respect to access to finance and supply chain deficiencies and less severe in all other cases, as summarised in Table 4.1 overleaf.[22] There were challenges in validating claims made around the mobility of R&D projects and the actual collaboration issues that may have occurred in the absence of funding. There was limited evidence of the presence of network externalities problems, as the risks of pursuing EV development have decreased now they are recognised by multiple stakeholders as the successor to traditional ICE vehicles.

Table 4.1: Summary of evidence on additionality arguments made by applications

Additionality argument	Evidence that argument is currently valid
High levels of technical risk and uncertainty	All sampled projects that received funding claimed that, without public support, proposed programmes of R&D would not have gone ahead, or would have been delivered at reduced scope and/or over a longer time horizon. In the case of large OEMs and Tier 1 firms, the proposed R&D was claimed to be too risky to fund internally as it focused on improving ICE technical performance beyond legislative targets and reallocated R&D away from wider strategic priorities where exploitation opportunities were more certain. Niche vehicle OEMs and SMEs with smaller R&D budgets suggested that full proposals could not be funded using internal R&D budgets alone and private finance

[22] Classical knowledge spill-overs is a well evidenced market failure with respect to stimulating science, technology and innovation activity and is not reported here.

Additionality argument	Evidence that argument is currently valid
	was not available due to high levels of risk, and in some cases, limited track records in undertaking such R&D projects. Analysis of private finance flows into the sector since 2010 suggest that only one SME secured private investment to support technology development which may support this view.
Deficiencies in the UK supply chain	Of the 11 sampled projects led by OEMs or Tier Ones, the majority cited deficiencies in the UK supply chain preventing private R&D investment, and four OEMs highlighting concerns that existing suppliers at the point of application could not meet the high-volume and quality requirements to become an approved supplier. This was especially true in the case of power electronics and energy storage componentry. While in-housing of capabilities is an option for large OEMs, for example in areas of testing and validation, the required individual investments in physical infrastructure were not thought to be commercially viable given the associated risks as identified above.
Transactional frictions	Across all sampled projects, it was reported that APC funding enabled OEMs and Tier 1 firms to collaborate with SMEs and academics, for example by funding academic participation or enabling competitor collaboration through setting out terms in a collaborator agreement. However, the evaluation also found that a high proportion of projects were based on previous collaborative partnerships which at least questions claims that transactional frictions are as pronounced as suggested in some applications. Nevertheless, there are cases where these frictions do appear to be valid - for example, three cases highlighted that collaborative frictions appear to be most acute when consortia involve numerous partners, face high levels of competition from overseas suppliers, and exploitation strategies are not completely clear for all partners.
International competition between governments	Four funded cases with overseas parent companies indicated that, without support, their proposed programmes of R&D would have been offshored. In these cases, several other overseas sites were identified with relevant expertise in internal review processes. However, there are challenges in assessing the validity of some of these claims. In one case, an OEM presented evidence of the funding gap that needed to be met by the APC to attract R&D to the UK – although a level of ‘gaming’ could have been involved in preparation of this evidence which is challenging to validate. In another case, R&D activity was reported as geographically mobile but upon review at the VFM stage, only a portion of this activity at risk of offshoring. Nevertheless, stakeholders argued that claims of this type are often valid, reporting that APC funding permitted the UK to compete for geographically-mobile R&D activity, especially when businesses with R&D sites across multiple countries are involved. In one case, the involvement of

Additionality argument	Evidence that argument is currently valid
	an overseas OEM collaborator with an R&D facility in the UK was thought to be crucial in anchoring R&D activity in the UK, especially as the UK had no previous capabilities in the area under development, and the UK subsidiary faced competition from three other overseas plants with comparable capabilities.
Internal competition for R&D funding within international organisations	There were two examples of international lead organisations suggesting that securing APC funding enabled them to retain R&D capacity that would otherwise have been shifted outside of the UK and Europe. The relocation of R&D activities from the UK to areas such as the USA were thought to be key to improving profitability and reducing costs. These lead organisations believed that APC funding was critical to securing UK-based R&D capacity beyond project completion.
Network externalities	Results from the APC External Process Evaluation showed that this particular source of market failure has become less acute since the programme's inception.[23] The evaluation found that there is now much greater confidence that hybrid and pure electric vehicles represent the near term technological solution, and this is reflected in the increasing share of APC projects focused on technologies underpinning the development of electric vehicles (EVs).

Source: Ipsos MORI (2019). *Comparative analysis of sampled case projects; views collected by key stakeholders.*

4.1.2 Outcomes associated with unsuccessful applications for funding

Given the challenges in validating the self-reported accounts of firms receiving APC funding in relation to its impact on their R&D activity, five projects forming the focus of declined applications were sampled as part of the case studies to help understand what occurred in the absence of grant funding. Two of these projects were led by large firms, and the remaining three by niche vehicle producers or SMEs in the supply chain of larger manufacturers. These cases studies showed:

- **Claimed constraints:** Unsuccessful applicants typically made comparable arguments to successful applicants as to why APC funding was needed to take the project forward. In four of the five cases, the applicant argued that the level of commercial or technical risk was too high to secure the commitment of internal funds. This included cases where there was no defined end customer or industrial pull for the project, projects involving major uncertainties regarding the achievability of target manufacturing costs and the associated payback period for the customer, and worries in relation to being too early to market with electrification. Two of the three projects led by SMEs also highlighted the

[23] BEIS (2018). *APC External Process Evaluation BEIS Research Paper 2018: 6.* Available at: https://bit.ly/2lyTOng. Date accessed: 24/10/18.

possible significance of constraints associated with the scale of the R&D project in relation to their retained profits.

- **Attempts to seek alternative funding:** The findings from the case studies indicated differential responses across large firms and SMEs to being declined funding:
  - **Large firms:** No attempt was made to obtain alternative funding in the case of the two projects led by larger companies, with personnel indicating that the firm focussed their efforts on alternative R&D programmes, suggesting these were genuinely marginal projects. In one of these two cases, there were indications that the relevant personnel were absorbed by a parallel project that did obtain APC funding (indicating crowding out). There was no evidence of offshoring. However, both applications were led by UK headquartered producers and there was little evidence of internal competition between sites in these cases.
  - **SMEs:** All three SMEs, by contrast, made active attempts to obtain alternative funding for the project. In two cases, the SME obtained this alternative funding. In one case, the firm was acquired by large company around the time the application was declined, and the acquirer made a commitment to fund the project (though in Canada rather than in the UK). In the second case, the applicant obtained smaller scale funding from Innovate UK to deliver a similar project with a different OEM.
- **Impact on project design:** APC funding appeared to have an impact on the speed and scale of the two projects which were taken forward. In one case, the specification for the project was unchanged, but the firm took a decision to deliver it within its existing resources – requiring it to deliver it more slowly than would have been the case if they had secured APC funding. In the second case, the specification was reduced from developing the entire vehicle platform to elements of the power train and battery.
- **Changes in priorities:** In the one example of offshoring, the project was cancelled following the completion of the first milestone (a largely desk based exercise involving agreeing the specification of the project and making choices regarding key inputs to the design). This was reportedly driven by changes in the priorities of the parent company. As such, only one of the five projects declined funding progressed to R&D activity of any significant scale.

The analysis of the outcomes associated with unsuccessful applications for funding provide some evidence that APC was critical in enabling projects to proceed (either at all, or at the anticipated speed or scope). Qualitative Comparative Analysis (QCA) was also completed by systematically comparing the project characteristics and technical success of the sampled case study projects that were, and were not, funded by the APC, to understand what other factors influenced the technical success of the projects. This approach involved identifying conditions that could affect the achievement of technical objectives and testing how far these influenced the achievement of success in the sampled project cases.[24] The analysis then considered whether different combinations of conditions are required for achieving technical success, as well as how consistent the requirement for different conditions across all sampled cases is.

[24] This approach is discussed in more detail in Annex E.

The following conditions were included in the analysis:

- Timing of APC round: earlier (2014/15 and 2015/15) vs. later (2016/17 and 2017/18)
- Grant size: smaller (<£10k) vs. larger (>£10k)
- Length of delivery: shorter (0-35 months) vs. longer (36+ months)
- Consortium size: smaller (0-5 partners) vs. larger (6+ partners)
- Lead partner type: SME vs. OEM/large company

Most successful projects appeared to have met or were on track to meet technical objectives, and the QCA provided evidence that APC funding on its own was a condition for technical success. In all solutions, APC funding was found to be an important condition associated with the achievement of technical success. Follow-up analyses were conducted looking only at projects that received APC funding (successful projects) to explore these characteristics further. The results suggest that key success factors associated with technical success are projects awarded in later competition rounds, potentially suggesting that the timing of projects is significant, those with longer delivery periods (36+ months) and larger consortia (6+ partners).

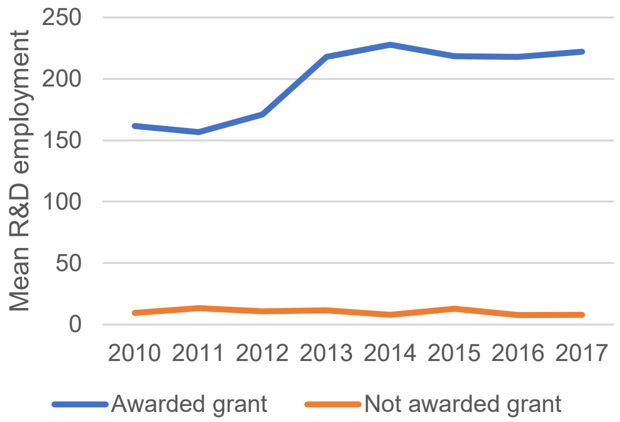
4.1.3 Econometric analysis

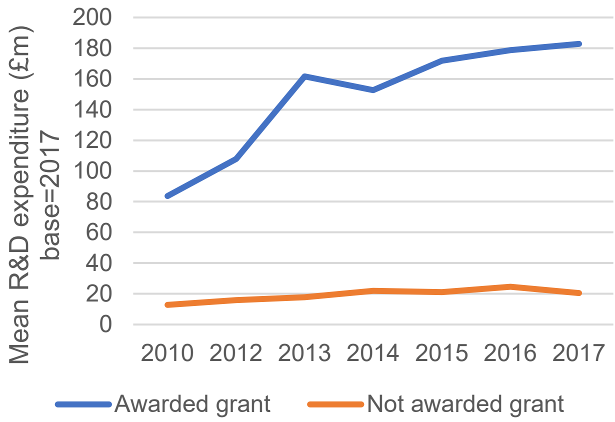
The findings above provide some indications that APC funding influenced the ability of applicants to take forward projects. However, the strength of these findings is limited by the self-reported nature of the qualitative accounts put forward by those receiving funding, the small number of observations from those that applied but were declined funding, and issues regarding the equivalence of funded and non-funded projects (e.g. in terms of levels of commercial and/or technical risk).

A complementary series of econometric analyses were completed to help explore these issues in greater depth and help quantify the magnitude of the effects involved. These involved examining the overall R&D spending and employment of those awarded APC funding relative to a variety of comparison groups (including declined applicants that were awarded high scores and internal comparisons between those awarded funding at an early and later stage). The data driving the analysis was gathered from the ONS Business Expenditure on R&D survey which measures total R&D activity – so while the analyses could explore volume effects, it was not possible to investigate other possible impacts (such as the diversion of R&D into low carbon propulsion technologies from other areas).

The figure below provides an overview of trends in average R&D employment and annual R&D spending across firms that were and were not awarded APC grants. It indicates that the R&D spending of those awarded APC grants expanded substantially after the programme was launched in 2014, while stagnating amongst those firms that applied but were declined. However, the applicants declined funding appear to differ substantially from those receiving grants in terms of their overall levels of R&D activity (raising questions as to how far the patterns shown within the figure are causally related to the programme). It should also be noted that the BERD survey is census of known R&D ‘performers’ and a sample survey of other firms, and the trends observed will be biased to an unknown degree by the presence of very large firms in the population of firms receiving APC funding.

Figure 4.1: Average R&D employment and expenditure between 2010 and 2017, applicants for APC funding (2017 prices)





Source: ONS (2019). *Ipsos MORI analysis of matched records to the Business Expenditure on R&D Survey.*

The econometric analysis completed sought to control as far as possible for both observable and unobservable differences between firms awarded funding and the relevant comparison groups (full details of which are set out in Annex F). Its results are as follows:

- **Effects of on lead partners:** There is some evidence that APC grants resulted in an on-going increase in the overall volume of R&D undertaken by those firms assuming the lead role. The analyses found that each APC grant led to an increase in the R&D employment and annual R&D spending of lead applicants of 20[25] and 28[26] percent respectively. These effects appeared to accumulate one to two years after the grant award was made, though insufficient time had elapsed to fully explore the longer-term persistence of any impacts. These results only came through in the most robust models, and were imprecisely estimated owing to the small sample sizes available. These estimates capture the direct and indirect impacts of the APC grants (for example, if the awards enabled firms to attract follow-on grants for related avenues of inquiry).

- **Effects on collaborators:** There was no evidence that the APC led to increases in R&D investment amongst collaborators, which were typically SMEs or other firms in the supply chains of OEMs.

- **Impact on total R&D spending:** The preferred approach to aggregating these findings to the population of firms awarded APC funding resulted in a central estimate that the programme led to a total increase in R&D spending of £273m by the end of 2018. This is associated with a wide margin of error (with a 95 percent confidence interval of £64m to £482m).[27] These estimates also do not account for the possibility that the programme placed pressure on prices, leading to reductions in R&D activity elsewhere.

- **Leverage of private R&D spending:** Monitoring data indicated that that the total project costs at the end of 2018 was £404m, of which £194m was funded by the public sector. As set out in the following table, central estimates of the impact of the

[25] With a 95 percent confidence interval of 0 to 38 percent.
[26] With a 95 percent confidence interval of 6 to 49 percent.
[27] A specification of the approach adopted is provided in Annex F.

programme on R&D spending suggest that the programme leveraged £0.42 of private R&D spend per £1 of public sector spending, though this could range from -£0.67 (implying a crowding out of private R&D spending) through to £1.49 (implying crowding in of additional resources beyond the costs of the project). Analysis of these statistical uncertainty suggested there was a 73 percent likelihood that the programme leveraged additional – rather than crowded out - private R&D spend.

- **Additionality:** The central results also implied that 68 percent of expenditure on projects funded through the programme would not have happened without the programme. The margin of error associated with this estimate is similarly broad (15 percent to 119 percent).

- **R&D jobs:** The findings imply a central estimate that the programme has supported the creation or safeguarding of perhaps 420 R&D jobs (which compares with a gross figure of 1,080 expected in the BEIS VFM appraisals). This figure is again associated with a wide margin of error, with a 95 percent confidence interval of 10 to 830 R&D jobs.

Table 4.2: Estimated impact on R&D spending by 2018 and associated leverage ratios

Estimate	Estimated impact on total R&D spending by 2018 (£m)	Expenditure of APC grant awards by 2018 (£m)	Implied increase in private R&D spending (£m)	£s of additional private R&D spend per £1 of APC grant spending
Upper bound	482	194	289	1.49
Central	273	194	80	0.41
Lower bound	64	194	-129	-0.67

Source: Ipsos MORI (2019). *Analysis to aggregate R&D effects across the funded portfolio under review.*

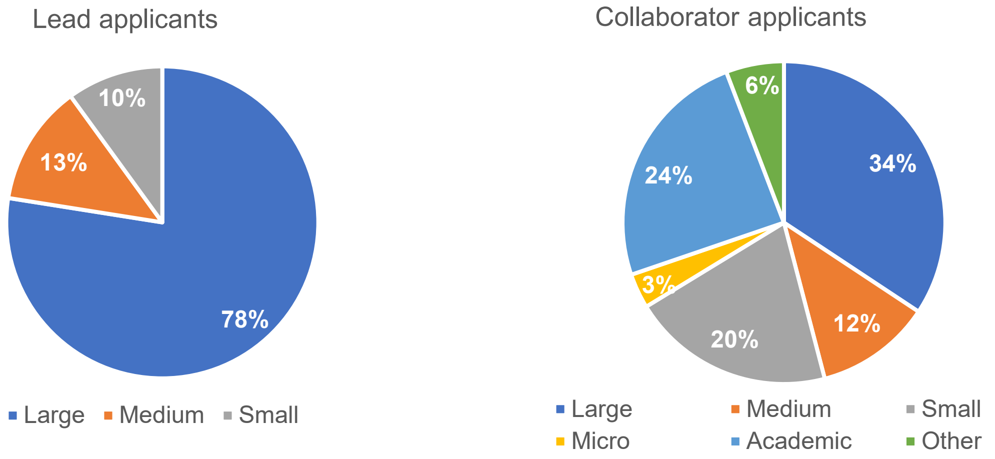
4.2 Impacts on collaboration

All APC projects required collaboration. The eligibility criteria specifically require the involvement of at least one SME and encourage the involvement of firms outside the traditional UK automotive supply chain. This sub-section discusses the collaborations within the APC project portfolio, including the rationale and nature of the collaborative links, and their associated costs and benefits.

4.2.1 Composition of collaborations

A total of 142 individual partners were involved in projects funded over the first nine rounds of the APC. The number of partners involved in projects has ranged from two to 10, with an average of approximately five partners. Most lead partners were large firms (78 percent) while the spread of partner type is more varied among collaborating partners, as seen in the Figure below.

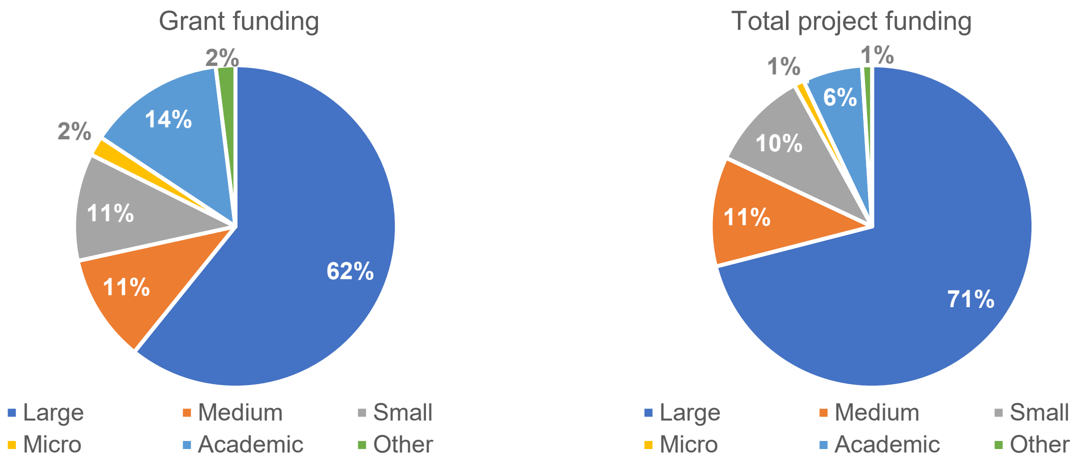
Figure 4.2: Distribution of partner types among lead applicants and collaborators



Source: Innovate UK (2018). *Innovate UK Monitoring Records: Date accessed: October 2018.*

As expected, given most partners were large firms, the figure below indicates that large firms received the largest proportion of grant funding.

Figure 4.3: Distribution of grant and total project funding by partner types (including lead applicants)



Source: Innovate UK (2018). *Innovate UK Monitoring Records: Date accessed: October 2018.*

4.2.2 Rationale for collaboration

The development of consortia typically had three main drivers:

- **Need to engage partners with specific skills, capabilities, expertise and experiences:** Partners generally provided a distinct set of skills, capabilities, expertise and experiences designed to offer the competencies required to maximise the likelihood of securing funding and achieving project outcomes. Project leads looked to engage the most appropriate experts (or specialists/pioneers) in the field or area.

- **Need to access specialist facilities:** In some instances, projects required specialist testing facilities which were often in high demand so finding the right partner with access to such facilities with the capacity, availability and skills to utilise them was key.

- **Development of exploitation routes:** Consortia typically involved vertically integrated partnerships including a large Tier One firm or OEM providing a route to market, although a small number of exceptions were found.

4.2.3 Role of APC UK in support consortia formation

Those engaged in the case studies and stakeholders reported that APC UK has supported the development of collaborative links and project proposals that would not have been created otherwise, although several consortia include longer term partnerships. APC UK support was provided both prior to and during the application stage and, at least in one case, when a project needed to be recast in response to issues which were encountered during the delivery stage. Key areas of added value reported related to:

- **Regular announcement of funding opportunities** – periodic and well communicated funding announcements have made it easier to identify eligible proposals for funding and plan the composition of consortia. Project leads mentioned the need to have sufficient time prior to the submission of applications to the APC to bring together a working consortium, which could take up to six months.

- **Brokered, facilitated & validated consortia relationships** – In several cases, the APC brokered or facilitated relationships that would enhance or strengthen project consortia – often where a technical partner required a manufacturing partner or vice versa. In these cases, the APC either suggested potential partners or project leads asked the APC for assistance in brokering potentially beneficial partnerships. Several project leads indicated that they did not need support from APC but having endorsement from the APC in terms of recognising the quality of consortium partners was still useful.

4.2.4 Costs and benefits of collaboration

The evaluation identified four key benefits of collaboration which directly related to the rationale for collaboration identified in section 4.2.1: gaining access to new knowledge, skills, capabilities and facilities, and the development of new R&D and commercial opportunities:

- **Access to technical expertise:** Most projects reported that access to consortium partners accelerated the resolution of technical challenges - for example, by providing opportunities to troubleshoot with technical expertise and share knowledge from complementary R&D activities or access to specialist facilities. In the case of university collaborations, consortia permitted academics to gain more insight into industry research requirements which informed teaching, provided project opportunities for post-graduates and helped develop students' routes to industrial employment.

- **Access to commercial expertise and opportunities:** Project consortia also created benefits for collaborators by creating new knowledge on the commercial properties and viability of technologies under development. Case studies also pointed to the development of future commercial opportunities between partners in consortia to further develop or exploit technologies. One key example was the opportunity provided to SMEs to gain access to OEM supplier networks.

- **Ability to trial new working relationships**: Collaboration was reported in some cases to have enabled OEMs and Tier 1 firms to trial new working relationships with SMEs and academics, the development of which made was reported to have made future collaboration across the supply chain less costly for these firms.

Box 4.1: Example of collaboration benefits

H1PERBAT: This project enabled the lead applicant to benefit from a Tier One firm's production expertise, while Unipart benefited from the technical expertise in battery design and development offered by WAE. While academic partners provided access to testing facilities and expertise around processes and materials, NCC provided composite expertise, Aspire Engineering provided access to skills and capabilities around managing the lifecycle of batteries, Aston Martin provided knowledge of, and access to, the Rapide-E engine platform in which the technologies would be integrated and an SME provided insights into the market for commercialisation.

The two key costs of collaboration were delays to the delivery of project work packages and, in some cases, the development of inequitable exploitation strategies.[28] The case studies highlighted that these costs occurred as a result of the following factors:

- **Unclear assignment of roles and responsibilities:** Without clearly assigned project roles and responsibilities, management and oversight, projects risked being delivered in a disjointed manner that was not collaborative, or in a way which installed customer-supplier, rather than collaborative, relationships.

- **Unclear lines of communication and management arrangements:** Limited or unclear project management procedures resulted in delays and financial issues as well as challenges in responding to changes in context, which could be internal (such as a change in strategic direction or a merger) or external (such as changes to consumer preferences or market shocks).

- **Personnel changes:** On occasions, personnel changes resulted in delivery challenges, as knowledge of the project was not sufficiently documented in the process. The need to re-establish relationships and complete additional project briefings was said to have caused delays in some projects. Changes in personnel arose from individual employment changes, but also changes in strategic priorities, which were reported to have affected entire teams and divisions as resources were reallocated towards different market opportunities.

- **Differences in academic-industrial culture and objectives:** In some cases, the incentives of academic and industry partners were misaligned, such that academics were not always as concerned with commercial exploitation opportunities as commercial partners, with effects on project timescales.

Box.4.2: Example of project management issues

ALIVE 6: During the early stages of Alive6 the project suffered from changes to personnel. This inhibited a smooth start to the project at the immediate outset. Despite some delays in project delivery, once a permanent project manager was in place, Alive6 progressed well and was viewed successfully.

[28] These issues may of course also arise in R&D projects that are not necessarily collaborative.

4.2.5 Impacts on collaborative activity

To further assess the effect of APC on the collaborative activity of lead applicants, Innovate UK funding records of public funds allocated between 2004 and 2019 were used to compare the collaborative activity of APC lead applicants prior to their first successful or declined APC application, with those awarded since that application.[29]

Table 4.3: Comparison of collaborative activity of lead applicants that received an Innovate UK grant between 2004-2016

Collaboration indicator	Collaborative activity visible in Innovate UK awards prior to first application for APC funding		Collaborative activity visible in Innovate UK awards after first application for APC funding	
	Firms awarded an APC grant	Firms not awarded an APC grant	Firms awarded an APC grant	Firms not awarded an APC grant
Average number of partners	4.5	3.0	5.0	4.3
Average % of projects including an academic	59.0	0	66.3	0
Average % including an SME[30]	83.5	100	62.9	100

Source: Innovate UK (2019) *Innovate UK Public Grants Database. Date accessed 05/09/19.*

Table 4.3 shows that both those firms whose first application was successful and those whose was declined recorded saw an increase in the average number of partners per project. All leads had at least one SME partner over the period. However, analysis suggests that APC leads became more collaborative with academic partners but less so with SMEs. Those lead applicants that were declined funding were highly collaborative with SMEs but not at all with academics – suggesting the programme may have been effective in promoting engagement with the academic base.

[29] For those projects whose start date is not available, this is assumed to be the beginning of the competition year.
[30] SME as such does not exist as a category among the reference group for those who were awarded a grant. The data reported here refers to projects including a 'small' or a 'medium' company.

5 Direct outcomes and impacts

This section presents an analysis of how far APC funding has led directly to changes in technological progress, skills and capabilities and the integration of LCV technology in vehicle platforms. Evidence for this section is taken from the programme of data-linking and econometric analysis, project-level case studies, analysis of monitoring records and views provided by key stakeholders.

Section 5: Summary of key points

- Projects funded through the APC moved more rapidly through the development pathway (as measured through the TRL and MRL scales) than projects that were declined funding. The projects funded were also generally on course to meet their expected reductions in tailpipe emissions.

- Those awarded grants frequently reported they developed new skills and capabilities through delivering projects. These new capabilities were generally reported to have helped support the development of 'in-house' capabilities, reduced reliance on component imports and brought forward productivity gains.

- Projects are generally on course to meet their commercial objectives. However, as few projects are complete, there are limited examples of technologies refined with funding from the APC being integrated into new vehicle platforms. Four of the 10 completed projects had been commercialised at the time of the research, with associated vehicle sales of 1.15m units. 155,000 of those units were associated with significant manufacturing in the UK. Nevertheless, the case studies highlighted four cases in which exploitation of the underlying technologies is likely to occur in the next five years, with a significant share of the manufacturing expected to be taken forward in the UK.

- There is also evidence that the programme has led to impacts on the net capital investment of those awarded grants. Central estimates suggest a possible total effect of between £75m and £98m by 2018. Owing to small sample sizes, these impacts are imprecisely estimated, and allowing for statistical uncertainty, this range could extend from £22m to £161m in total.

- The programme also had a positive effect on the employment and productivity of lead applicants. The programme was estimated to have led to 2,800 to 4,400 jobs created or safeguarded, which appear to be focused on production activities. Each grant awarded was also estimated to have led to an increase in wages of 1.7-2.0 percent. However, these effects were limited to lead applicants and there were some suggestions that collaborators saw negative impacts as a result of their participation in the project. This could suggest that the programme has encouraged insourcing of higher value activities that may have otherwise been externalised.

5.1 Technological progress

The APC provides funding to support R&D activities aiming to accelerate the development of low carbon propulsion technologies. This subsection provides an analysis of the technical objectives and outcomes that have been achieved by APC projects to date. When reading this subsection, it is important to bear in mind that:

- All R&D projects involve a level of technical risk, and there is an expectation that some projects will inevitably not deliver the anticipated improvements in vehicle performance.

- APC projects are complex, often involving the development of several technologies with the potential to be exploited independently. Projects may result in the development of components or sub-systems that can be successfully integrated into other vehicle or engine platforms.

- Success in achieving technological objectives does not necessarily imply that the technology will eventually be commercialised. Firms may face wider barriers in commercialising technologies, such as difficulties in securing the investment to produce the technology at scale.

5.1.1 Technical and Manufacturing Readiness Level progression

The technical progress of R&D projects can be quantified using the Technological and Manufacturing Readiness Level scales (TRL and MRL). These scales describe the progression of technologies through a sequence of tests of increasingly high fidelity prototypes in increasingly realistic environments, and are summarised in Annex D. APC funding was available to projects where the core system under development had reached TRL5 and MRL4, and applicants often provided an assessment of both baseline levels of technical development and expectations with respect to where they expected to finish at the end of the APC project. This provides a framework against which the progress of projects can be assessed.

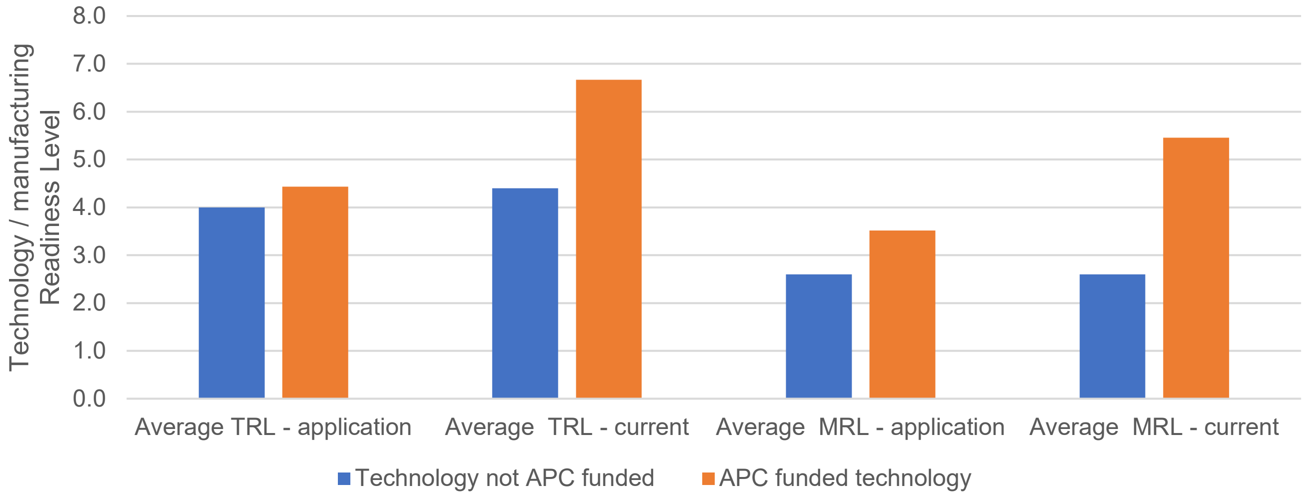
The evaluation team was able to compile records of technical progression from project case studies and annual BEIS monitoring for 27 projects (of which 7 were declined funding, and 16 were completed). These records were validated by reviewing project documentation and clarifying details with project applicants. Where records were provided for more than one technology, an average was taken at the project level. All records used in the analysis focused on a technical system, although in some cases it was not clear whether the reported figured reflected the intricacies of integrating the system into a vehicle. For example, while a standalone engine system may be reported at TRL7, its TRL may be lower when vehicle integration issues are accounted for. In these cases, a conservative approach was taken to assessing progress made by projects to provide a lower bound estimate of any progression.

The results show that more rapid progression was achieved for those technologies that were developed using APC funding:

- **Technology Readiness Levels:** On average, grant recipients progressed technologies under development from TRL4.4 when the application was made to TRL6.7 by the time of the interview. The technologies funded developed more rapidly that those put forward by declined applicants, as shown in Figure 4.1. For completed projects, TRLs for technologies under development were 1.2 levels behind the targets specified at the application stage on average, which suggests that some technical development was halted or not achieved as anticipated.

- **Manufacturing Readiness Levels:** The average manufacturing readiness of APC-funded technologies increased from MRL3.5 to MRL5.5. No material progress was made in terms of manufacturing readiness by applicants that were declined funding. For completed projects, MRL progression was 0.9 levels short of expectations outlined in applications, again highlighting that some development was not taken forward as planned.

Figure 5.1: Progress made in Technology and Manufacturing Readiness Levels reported by applicants



Source: Ipsos MORI (2019). *Compilation of project documents, BEIS annual monitoring and views provided by case study interviewees during fieldwork completed between February and June 2019.*

Stakeholders stated that progression is broadly in line with expectations and argued that some variance was to be expected. Changes in context and residual technical issues have clearly constrained TRL and MRL development in some cases, despite recent R&D investment in the sector as a whole - for example, the significant reduction in market opportunities for hybrid diesel applications limited technical development in related areas.

Projects also sought to achieve technical milestones relating to improvements in technical performance. Information from the VfM assessments shows that 13 of the 16 case studies provided estimates for the expected tailpipe emissions reductions relative to a comparator vehicle. These estimates were examined against figures provided in the most recent BEIS annual monitoring report to assess whether projects are on track to achieve these estimates. When triangulated using data from the case study interviews and other documentation, the evidence suggests that 10 of 13 projects have achieved, or are expected to achieve, their original targets to reduce tailpipe emissions, two will partially achieve these targets and one will not achieve the original targets.

Box 5.1: Examples of technical development

ALIVE6: The main aim of the project was to develop several technologies to TRL8, reducing CO2 emissions by 20 percent on the core volume specification 6-cylinder engine and introducing a mild hybrid 6-cylinder petrol engine into the Jaguar Land Rover product line. The project resulted in a total saving of CO2 emissions equating to 12 percent.

LAtiTuDE: The APC project achieved several successes across the entirety of its work packages. These have ranged from technical achievements to improvements in partners' know-how, capability and processes, these include:

- Second generation Digital Rate Shaping (DRS2) for improved NOx / Soot trade-off. Calibration techniques defined and developed with Bosch and Jaguar Land Rover. The optimisation achieved through DRS2 is perceived as a key technology to address future regulatory targets on emissions and will therefore support Jaguar Land Rover strategy regarding future emissions legislation.

- The addition of 'Twin SCR' to the project enabled a CO2 efficient technology to be trialled and tested for full deployment on all future Jaguar Land Rover diesel engines.

- At close of project, the overall target of 12% CO2 savings had been exceeded and reached 12.7% minimum. Several of the technologies achieved level 8 on the Technology Readiness Scale (TRL) including The Twin SCR and DRS2, as well as key friction rig technologies such as the F-Less Seal.

5.1.2 Knowledge and skills

All sampled projects reportedly resulted in the accumulation of knowledge and skills within project consortia. Skills and knowledge created related to the development and integration of systems into LCV platforms and the development of manufacturing and testing processes (which are likely to mainly benefit lead applicants and academic partners respectively), as summarised in the Table 5.1. These new capabilities were generally reported to help support the development of 'in-house' capabilities, reduce reliance on component imports and ultimately bring forward productivity gains (as discussed further below).

Table 5.1 Examples of new knowledge and skills acquired by grant recipients

Development and integration of systems into LCV platforms (16/16 sampled cases awarded funding)	Development of manufacturing and R&D processes (9/16 sampled cases awarded funding)
Example 1: Integration of new technology into new and / or existing vehicles: For example, understanding how to integrate cylindrical (opposed to pouch) battery cells into a car and downstream design implications, or; gaining knowledge, skills and flexibility around swapping batteries and engines across different vehicle platforms; or skills relating to the development of cryogenic systems for commercial vehicles. **Example 2: Enhanced design architecture and product development:** Gaining a better understanding of the integration and production processes required for new zero or low carbon technologies and feeding this information back into design teams has enhanced vehicle design and development. For example, developing significant knowledge around metrology and tolerance stack ups which was, and will continue to be, essential to informing the design and development of new technology moving forward; or organisational learning around full electrification and the implications for design and production; or the use of 3D sand card printing for prototypes.	**Example 1: Developing new assembly, production and disassembly techniques and approaches:** While many of the techniques and approaches were initially developed for the APC funded projects, such developments have been exploited beyond the project and the R&D teams. For example, exploring different joining techniques and identifying the most effective application of these techniques, such as when to use arc welding and when to use laser welding or; gaining a greater understanding of how materials behave during assembly and / or disassembly which is particularly important for reusing, remanufacturing and recycling batteries. **Example 2: Enhanced testing methods and capability:** For example, to optimise engine performance or to analyse emission levels such as Warwick Manufacturing Group developing new and advanced motor testing capabilities internally and within consortium partners.

Source: Ipsos MORI (2019). *Comparative analysis of case studies.*

However, only a subset of sampled cases were shown to have resulted in the creation of publications which were predominantly authored by academic partners (sometimes with industrial partners as co-authors) or the registration of Intellectual Property Rights, including designs (11 of 16 cases).[31] Comparative analysis highlighted two main reasons for this reticence: the interest in maintaining trade secrets by commercial partners and the costs of registration were deemed to outweigh the benefits of publication and/or registration when technologies development had failed.

5.2 Integration of technologies into new vehicles

The integration of APC funded technologies into new vehicle programmes is the key commercial objective for projects and the principal mechanism through which the programme

[31] The evaluation was also not able to fully validate claims made by interviewees and faced challenges in securing interviews with all case stakeholders as discussed in Section 1.

will realise its expected economic and environmental benefits. This subsection provides an analysis of the extent to which projects achieved, or are on track to achieve, their commercial objectives, including the extent of any commercial exploitation activities.

5.2.1 Achievement of core commercial objectives

The case studies were used to reach a judgement as to how far projects are on track to meet their commercialisation objectives (i.e. to integrate technologies under development into new vehicle platforms). This was completed by comparing any results achieved by projects sampled to the original expectations set out in application forms and Exploitation Plans.

Analysis of sampled cases studies showed that the majority (10 of 16) that received funding have met, or are on track to meet their commercial objectives, of which eight were completed and two are still on-going. Of the remaining six cases, commercial objectives were not met due to weakened opportunities for exploitation opportunities (as a result of the changing market context), insurmountable technical issues or delays with technical development.

The QCA indicated that receiving a comparatively large grant (greater than £10m) was associated with meeting or being on track to meet commercial objectives. Also, being in a consortium led by an OEM or large company (combined with being in a later competition round) showed some limited associations with improved likelihood of achieving commercial success.[32] This may reflect a subset of projects funded in earlier rounds that were responding to market needs that have since become less relevant as electrification has gained greater prominence.

None of the projects sampled that were declined funding were on course to meet their commercial objectives because only one of the cases was taken forward in a meaningful way (and at a reduced scope). Inevitably, the QCA pointed to a causal association between receiving APC funding and the realisation of commercial objectives – i.e. that applicants would not have achieved, or remained on track to achieve, their commercial objectives without receiving funding through the programme.

5.2.2 Product launches

The key programme mechanism for achieving economic impacts is the integration of technologies into new LCVs. The analysis considered projects that were closed by the end of 2018 and attempted to link case study evidence on vehicle integration to records of UK passenger and light vehicle production maintained by IHS Markit.[33] The analysis shows that technology developed in four of the ten projects that were completed by the end of 2018 had been integrated into new vehicle platforms.

This included the integration of a BEV battery into the Nissan Leaf (46,985 units; HEDB), and the integration of an enhanced ICE into the Morgan Aero 8 and Classic (484 vehicles; CO2 divided by 2).[34] In addition, an engine developed in one sampled case was reported to have been integrated into a range of Ford passenger vehicle platforms manufactured in Europe and page China (c.1m units; Active).

The upper bound 2018 production estimate was 1.15m vehicles, of which perhaps 151,000 units were produced in the UK. This amounts to 3.4 times the expected sales reported in the

[32] The QCA approach and results are present in Annex E.
[33] IHS Markit (2019). Passenger and light commercial vehicle production statistics 2005-2018.
[34] Ibid.

relevant BEIS VFM proformas. This indicates that, at this early stage, the commercial outcomes of the programme have exceeded initial expectations and largely reflects the strong commercial performance of two APC projects that led to the introduction of enhanced ICEs to market rapidly following project completion (though note that the available data describes production volumes rather than the underlying value of the technology developed). However, only a small share of the associated production is so far being taken forward in the UK. It is important to note that this apparent success is also driven to a large degree by outliers (as is often typically of innovation programmes).

Finally, analysis of sampled projects indicated that APC funded technologies developed in four projects will be integrated into new vehicles over the next five years, at least some of which are intended to be produced in the UK.

Box 5.2: **Examples of expected future exploitation of APC funded technology**

H1PERBAT: In quarter two 2019, the H1PERAT project consortia successfully developed a high-performance battery for installation in the Aston Martin Rapide-E demonstrator vehicle with APC funding. While the project is still on-going, the lead applicant is piloting battery production in its new facility, with the lead programme being chosen and confirmed by end of March 2020.

SPEED V: This project sought to develop a new powertrain architecture and structures for vehicles produced by a niche vehicle OEM partner that significantly will reduce CO2 emission levels. The main outputs of the project are expected to be integrated into a new model. Several demonstrators have already been produced and a further 22 were being assembled for the second stage of the prototyping at the time of interview. Initial production is due to start in July 2020 with volume ramping up to 5,000-6,000 units a year when rolled out across the OEMs range of products.

5.2.3 Other routes to market

Four of 16 sampled projects resulted in some other form of commercialisation outcome. This included the development of demonstrators which result in commercial R&D contracts for SMEs and the development of software and testing processes.

Box 5.3 Examples of other exploitation routes

ASCENT: One project resulted in the development of a set of digital engineering tools. The delivery of the APC project enabled the lead applicant to allocate resources to the development of these tools. Without the grant opportunity, it was not commercially viable to develop novel tools unless they were attached to a production-focused programme with established exploitation routes. The resulting tools were reported to have reduced the yearly cost of a key system assessment by over $1 million USD, with annual savings expectations of $8M in or before 2025.

ACTIVE: This project sought to apply of a range of advanced engineering concepts to improve the efficiency of a petrol engine in advance of legislative requirements. In addition to the OEM integrating the enhanced engine developed into vehicles, a collaborating partner was also able to develop and commercialise the emissions analyser developed through the project for wider applications.

5.3 Capital investment

5.3.1 Capital spending

A key objective of the APC funding competition is to stimulate additional investment in the UK automotive supply chain. The evidence provided several signals that the delivery of the APC funding competition has, or may result in, increased levels of investment (at least within the collaborations that formed to deliver the projects). Firms within seven of the 16 projects sampled had made – or planned to make – investment in capital equipment to scale up production of the technologies under development.

Box 5.4: Examples of capital spending

DIET: As a result of increased powertrain electrification knowledge generated on the project, one project collaborator has invested in the development of an engineering R&D centre to provide systems engineering services to the major UK & European vehicle and mobile machinery manufacturers in the UK EV supply chain.

BOWSCALE: The lead on the project, which focused on the development of transmissions for hybrid applications, has since invested in its test and development facilities to develop APC research outputs further ‘in-house’ to permit further testing and development with a reduced need to purchase additional R&D services outside of the firm.

HEDB: The project sought to develop enhanced BEV propulsion battery and manufacturing facilities. Its results prompted further investment to convert other production lines to be compatible with the newly developed technology.

Additional investment was commonly a requirement for the technology involved to be fully exploited. OEMs and Tier 1 firms reported that additional investment was, or would be, essential to further develop and exploit the opportunities released through the APC funded project(s), typically through decreasing their reliance on purchases of R&D and componentry. Analysis shows that investment was typically focused on the expansion of R&D facilities, such as those focused on design engineering and systems testing, and manufacturing facilities to test low-volume production set-ups.

The econometric analysis (described in detail in Annex F) examined the effect of the programme on net capital investment drawing on data gathered from the ONS Annual Business Survey (comparing those awarded funding to a variety of comparison groups). This suggested that the magnitude of the effects of the programme on capital investment could be substantial:

- **Estimated effects:** The findings indicate that each APC grant led to an expansion in net capital investment of 33 to 43 percent per annum when compared to the comparators used, with more robust models pointing towards the lower end of this range.[35] Models separating effects between leads and collaborators were insufficiently powered to detect differential impacts, so the degree to which effects varied across subgroups of applicants is unknown at this stage. Owing to small sample sizes, these effects were also imprecisely estimated with 95 percent confidence intervals of +/- 25 percentage points.

- **Total impact on net capital investment:** The preferred approach to grossing up gives an estimated impact on total net capital investment of £75m to £98m based on these central estimates.[36] Allowing for statistical uncertainty in the estimated effects broadens the possible range of effects on net capital investment from £22m to £161m.

5.3.2 Access to external private finance

The inability to access finance at the right level when required was a key additionality argument made by APC applicants. APC grants may affect the ability of firms to secure external private finance, as the delivery of projects potentially de-risks the pay-offs associated with private investment. An analysis linking APC applicant data to financial records in Pitchbook[37] suggests that the award of an APC grant is associated with increased access to private finance to support further R&D and commercial development (based on comparisons between those awarded funding and those that applied but were declined).

In total, 18 firms that were awarded at least one APC grant (of which two thirds were SMEs) had secured £1.6bn in investment over 14 deals between their first application and 2019 (though 70 percent of this relates to the IPO of Aston Martin – again highlighted the skewed nature of returns across the APC portfolio). This amounts to £14m per applicant on average or £4.4m when the IPO deal is removed. In contrast, of those firms that were declined grant funding, only two firms secured £11m in investment over two deals, or just £180,000 on average, since their applications were submitted.

Comparative analysis of the case studies provides some validation of this result, indicating that SMEs partners could secure investment when they were successful in developing technologies beyond a Proof of Concept stage and providing some demonstration to investors of how they could be integrated into a vehicle platform. There is evidence of instances where the skills and capabilities developed as a result of APC projects have provided reassurance to private investors that the teams behind technology development were sufficiently technically capable of finalising the development process.

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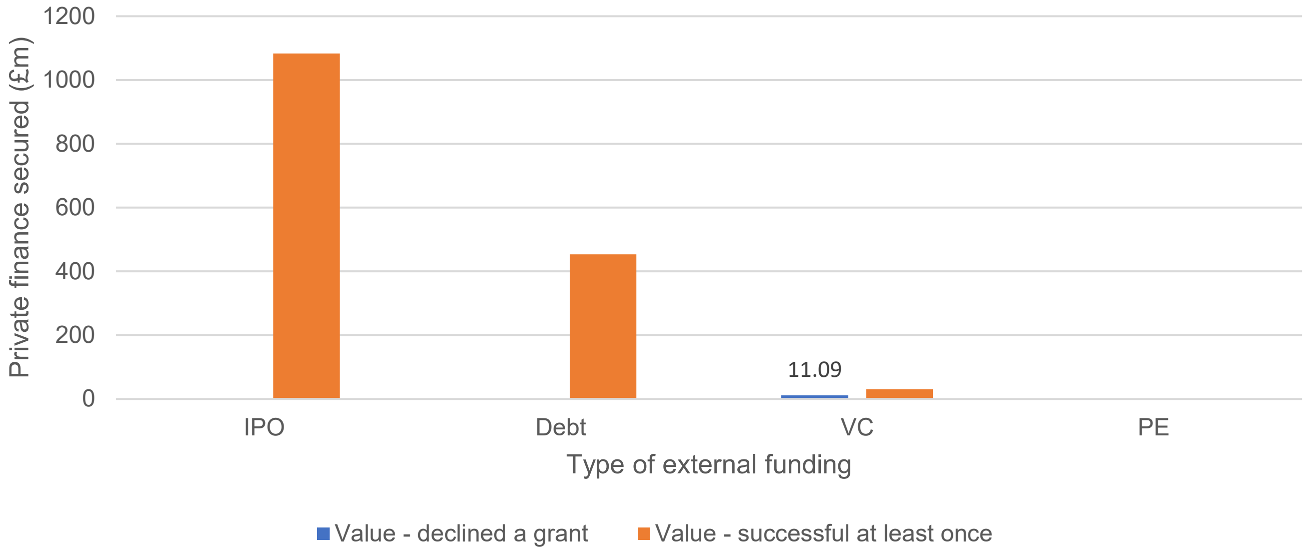
[35]This survey is completed by all large firms and a sample of SMEs in each year. The match rate of APC applicants into this micro-dataset was 82 percent.
[36] A full specification of the approach is provided in Annex F.
[37] 2019 *Ipsos MORI analysis of applicant records linked to the Pitchbook financial data platform.* Pitchbook provides details of disclosed private and public investments.

Figure 5.2: Overview of private finance secured by applicants (£ million, nominal prices)[38]



Source: Pitchbook (2019). *Ipsos MORI analysis of deals secured by APC business applicants. Date accessed 02/09/19. Note that the IPO figures are driven by the floatation of Aston Martin.*

Box 5.5: Example of securing private investment

UK-ABSC: Collaborating partner, Dukosi, received an APC4 grant in competition year 2015/16 to develop battery packs for automotive applications. In 2017 it raised £2 million of Series A venture funding in a deal led by IP Group. Scottish Enterprise and Par Equity also participated in the round. The company intended to use the funds for the final development of its battery semiconductor solution, including extensive multi-industry certification, and the expansion of the team in Edinburgh with new roles in electronics design, software, cell modelling and electrochemistry.

Source: Dukosi (2017). *Dukosi lands £2 million for next generation battery management technology.* Date accessed: https://bit.ly/2lYfRnw. Date accessed: 02/09/19.

5.4 Employment, turnover and GVA

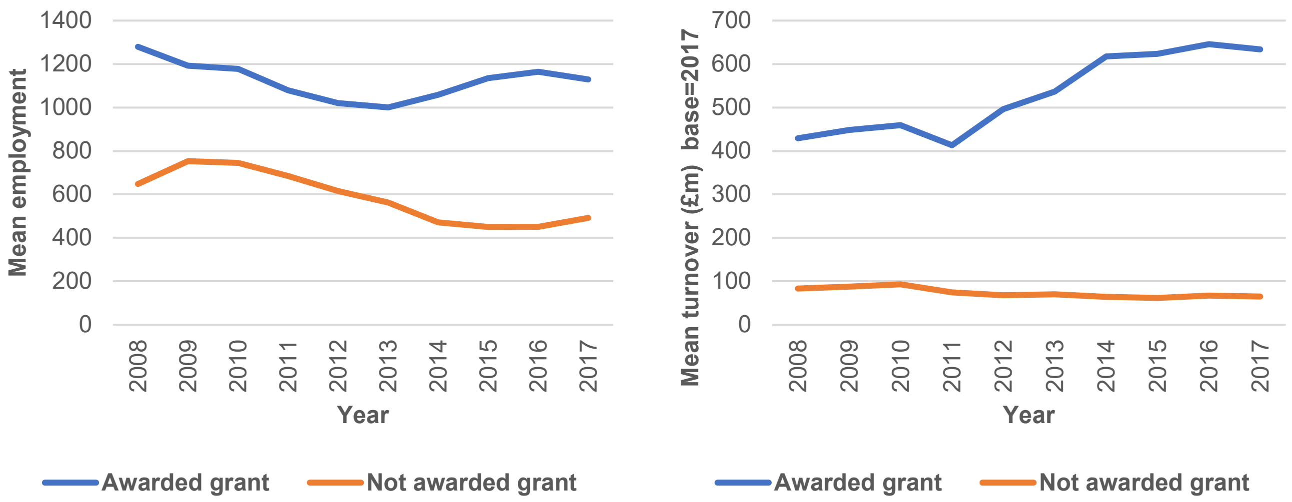
The econometric analysis set out in Annex F provides the primary source of evidence of the impacts of the programme on the expansion of firms (as visible in employment, turnover or GVA). The following figure provides an overview of trends in these measures between 2008 and 2017 for both firms that were awarded grants and the comparison group of unsuccessful applicants. These measures are based on the Business Structure Database, an annual snapshot of the Interdepartmental Business Register that provides yearly observations of employment and turnover of all firms registered for PAYE or VAT.

These figures indicate that those firms awarded grants saw substantial growth in turnover and employment from 2012 and 2013 respectively. However, those whose applications were declined were comparatively stagnant over the period. Again, the analysis highlights the

38 A recent investment made into McLaren was excluded from the analysis as the press release suggested this was focused on the development of professional racing vehicles.

presence of systematic differences between successful and unsuccessful applicants for funding, with the latter group tending to be smaller on average.

Figure 5.2: Employment and turnover of firms applying for APC grants, 2008 to 2017 (2017 prices)



Source: ONS (2019). *Ipsos MORI analysis of APC applicant linked records to the Business Structure Database.*

The findings of the econometric analysis indicate that the programme led to substantial impacts on the growth of lead applicants, though effects on collaborators were ambiguous:

- **Employment impacts:** Each APC grant is estimated to have led to an expansion in employment of the lead applicants of 10 to 16 percent (relative to the comparison group). The preferred approach to aggregating these figures gave estimates of total jobs created or safeguarded of between 2,800 and 4,400.[39] When compared to the effect of the programme on R&D jobs, this indicates that the bulk of these positions are in production occupations. It should be noted that these are gross additional rather than net additional effects, and have not been adjusted for either displacement or crowding out. These estimates can be compared to a total of 5,200 gross jobs expected as projected in application forms.

- **Turnover:** The findings also suggested that each APC grant led to an increase in the turnover of lead applicants of 25 to 30 percent. However, some models indicated that that participation in the programme reduced the turnover of collaborators by 13 to 20 percent. This could indicate that the programme has encouraged 'in-housing' of activities amongst lead applicants and a transfer of output from collaborators to leads, which was the underlying motivation for many projects as described in Section 3.

- **GVA:** The analysis suggested that each grant awarded led to an on-going expansion in the overall output of the firm of 15 to 17 percent.[40] Based on these central estimates, the

[39] This range expands to 700 to 7,000 jobs created or safeguarded once statistical uncertainty is accounted for in the estimate.

[40] These estimated impacts on GVA were significant across the whole population of applicants for funding. The findings were more ambiguous when broken down by leads and collaborators. The most robust model obtained effects on GVA amongst leads of 20.9 percent though this was only significant at the 90 percent level of confidence.

programme led to an estimated increase in GVA of £329m to £372m by 2018[41]. This does not allow for displacement effects or crowding out.

Analysis of the case studies highlights that most project partners expanded their workforce to deliver the APC projects, recruited new production staff as a result of the new technologies developed on the project, and/or benefitted from its effects in safeguarding existing employment:

- **Review of outsourcing policies**: While many projects had planned to increase employment, the delivery of projects also facilitated internal reviews regarding outsourcing policies. For some organisations that would ordinarily outsource production overseas, the project provided an opportunity to assess whether expanding the size of their internal team within the UK was a viable alternative. Without APC funding, production within the UK and the expansion of the UK workforce would not have occurred.

- **Safeguarding existing employment**: By expanding and developing the skills and capabilities of existing employees, this helped ensure these skills could be deployed or transferred into key areas such as electrification. Several organisations indicated that engineers had expanded their knowledge and skills in relation to the technology under development, with those involved subsequently being transferred or redeployed to continue to support technological development. This is particularly important as priorities move towards zero carbon alternatives and away from internal combustion engines. For example, in the case of TRANSCEND, although this project had been wound down, skills acquired from developing a hybrid transmission enabled engineers to be to redeployed to the electrification team.

Box 5.6: Example of increased employment levels

SPEED V: As a result of participation in an APC project, funded in competition year 2016/17, the consortium of this project expects to create 85 full time equivalent person-years jobs and safeguard a further 215 up in the years up to 2022 as a result of expanded R&D and commercial operations.

5.5 Productivity

The econometric analysis explored the impact of the programme on a range of indicators of productivity – including the wages of the workers employed by those receiving grants, turnover per worker (which approximates changes in productivity provided the firms' relative consumption of goods and services is not altered by the programme), and GVA per worker (though sample sizes for these analyses were small). These findings indicated:

- **Wage effects:** The most robust results were visible in the impact of the programme on the hourly earnings of workers employed by lead applicants, which were estimated to have risen by 2.0 to 2.3 percent per grant awarded. This could suggest an improvement in productivity levels. However, it is also possible that this may reflect a 'grant-sharing' effect (i.e. the firm rewards its employees for securing a grant) or that the programme

[41] Based on 95 percent confidence intervals associated with the estimated impacts, this range could extend to £98m to £610m.

pushed up equilibrium wage levels. There were also differences across leads and collaborators – while each grant was estimated to have increased to the hourly earnings of workers employed by lead applicants (by 1.7 to 2.0), some models suggested that the impact of the programme had negative effects on the hourly earnings of workers employed by collaborators.

- **Turnover per worker:** The econometric analysis did not provide substantial evidence that the programme led to increases in turnover per worker. Positive effects on turnover per worker of 14 percent came through only in those analyses focused on lead applicants and this estimate was only statistically significant at the 90 percent level. Again, there were suggestions that the programme had a negative effect on the productivity of collaborators in some models, with an estimated reduction in turnover per worker of 20 percent.

- **GVA per worker:** Finally, the estimated effects of the programme on employment above were consistently smaller than the estimated effects on GVA, suggesting enhanced efficiency. The findings implied an effect on GVA per worker of 3 to 8 percent – though, the models did not find a statistically significant effect on GVA per worker when direct observations of productivity were used.

These results were used to estimate the overall impact of the programme on GVA arising from productivity gains:

- **Wage based estimates:** Wage based estimates were generated by applying the estimated effect on hourly earnings to the number of workers employed by firms before the programme was launched. This provides a conservative measure of the net economic benefit of the programme, that is less sensitive to possible issues regarding displacement and crowding out[42]. An assumption was made that changes in wages will be broadly reflected in changes in GVA per worker. On this basis, the additional GVA arising from productivity gains was estimated at between £36m and £60m by 2018.

- **GVA per worker estimates:** There were also signals in the results that the estimated effects on wages may understate the impact of the programme on GVA per worker. If the results are grossed up using the increase in GVA per worker implied by the estimated the programmes effects on employment and GVA (3 to 8 percent), then this implies a range for the additional GVA arising from productivity gains by 2018 of between £70m and £275m.

- **Persistence:** The lifetime economic benefits of the programme will arguably largely be determined by how far these productivity gains persist in the longer term. There are significant uncertainties in relation to the durability of these impacts and this evaluation could only explore short term effects.

The case study research highlighted that productivity gains could have emerged through two key channels:

- **Improvements in human capital:** The allocation of a grant made resources available for investment in human capital, resulting in the recruitment of skilled workers or the

[42] This decomposes the overall gain in output (GVA) into a component driven by its expansion or volume and a component driven by productivity gains.

development of in-house staff though training programmes. In addition, workers that delivered APC projects had better access to development opportunities within consortia organisations and were able to apply the skills learnt in a more productive manner. As highlighted above, engineers involved in one APC project developed new skills, which resulted in some transferring to different teams to deliver adjacent programmes of R&D.

- **Better application of skills and capabilities** Several project teams reported improvements in in-house expertise. These improvements manifested in different ways – for example, some firms were able to manufacture componentry in house which decreased development costs and delivery timescales. In other cases, APC projects resulted in the development of new business processes, such as those relating to R&D and manufacturing which made partner operations more efficient. For example, in one project, a partner developed one tool required for a new manufacturing process that previously require three separate tools and processes to implement.

Box 5.7: Example of productivity gains made

Bowscale: The formation of one project encouraged the lead applicant to make the case for internal investment in skilled workers based in the UK, rather than relying on inputs from an overseas company site. The award of the grant was indicated to have made investment in human capital in the UK more appealing to the parent company. At the time of application, the lead employed five staff whilst, at the time of interview, they employed 80.

6 Indirect outcomes and impacts

A key justification for the public funding for R&D made available through the APC is the expectation that projects will lead to benefits for third parties that were not awarded funding through the programme. This section presents early evidence of these 'spill-over' effects resulting from the APC funding competitions. A framework of potential spill-over effects of the programme is summarised in Appendix B. Evidence used in this section came from the programme of data-linking and econometric analysis, project level case studies and stakeholder consultations.

It should be noted that the absence of monitoring of the knowledge based outputs of the programme (e.g. academic publications or patents) has limited attempts to systematise the analysis of possible knowledge spill-overs through analysis of citation patterns. For the purposes of future evaluation, it is recommended that BEIS and Innovate UK seek to collect details of these documents in on-going monitoring of the projects funded.

Section 6: Summary of key points

- Case studies indicated that APC grants were associated with local clustering effects. There were examples of collaborators seeking to reduce the costs of developing R&D and commercial opportunities with OEM and Tier 1 firms and/or gain access to specialist facilities or expertise by relocating or opening new facilities in proximity.
- These results were validated by an econometric analysis exploring the impacts of the programme on the economic performance of areas in proximity to those awarded grants. These effects were largest in the output areas in which grant recipients were; amounting to an 11 percent effect on the number of firms located in area, a 17 to 18 percent effect on local employment levels, a 22 to 24 percent effect on the turnover of local firms, and a 6 percent effect on productivity (turnover per worker).
- The evaluation found some evidence to suggest the programme resulted in an increase in FDI flows, with investment mainly driven by OEMs headquartered overseas but with existing UK operations.
- The evaluation found evidence that technical and economic knowledge spillovers were realised within collaborating organisations and across project consortia, but at this stage there was only limited evidence of the replication of technologies outside of project consortia to support external R&D or commercial activities.
- Other spill-over effects were present but less pronounced at this stage. Potential technology applications with the potentially for spill-overs most frequently reported in relation to the aerospace sector but other sector examples were also cited. The evaluation also found evidence that the programme had produced de-risking/demonstration spill-over effects but limited evidence of other non-spatial spill-over effects at this stage.

6.1 Clustering effects

The R&D grants awarded through the APC were expected to result in clustering effects in which the skills, capabilities, and 'first-mover' advantages developed by those awarded grants produce incentives for third parties to locate related economic activities in proximity. These incentives could stem from the exploitation of the technologies funded through the programme, where the resultant expansion in demand encourages suppliers (or potential suppliers) to locate new production facilities in proximity to those awarded grants. Several studies have also shown that knowledge spill-overs are often spatially concentrated, potentially creating further incentives to locate in proximity to hubs of expertise.

6.1.1 Local clustering effects

The evidence from the case studies provided several examples in which projects led to these types of clustering effects. Analysis of the results gave evidence of local agglomeration effects in 3 of 16 cases, driven by two key mechanisms:

- **Reducing the cost of collaboration:** Clustering was driven mainly by the set-up of new collaborator operations in areas in which the lead was located. Location in proximity to lead applicants was viewed as desirable because it reduced the cost of current and future R&D and maintaining commercial relationships, both related and unrelated to the APC project being delivered. In some cases, project partners and other firms had secured contracts with an OEM or Tier 1 and co-located to establish the partnership and capitalise on potential future opportunities.

Box 6.1: Example of local clustering – reduced collaboration costs

H1PERBAT: As a result of a joint investment in a new manufacturing facility, a collaborating partner has since moved some of its operation to this new facility to continue further R&D and exploitation of the battery technology under development. In the absence of funding, the opportunity to secure an OEM contract and develop a new manufacturing facility as a result would not have arisen.

- **Access to skills, capabilities and infrastructure:** Firms, both inside and outside of APC project consortia, were found to locate in proximity to reduce the costs of exploiting spatially concentrated skills, capabilities and infrastructure – for example, testing facilities and assembly/production lines located at, or near, APC project partners' sites. A key example cited was the development of the centres of automotive excellence at the Universities of Warwick and Bath which have attracted firms to surrounding areas seeking to exploit the skills and infrastructure offered by the centres. APC funding permitted these universities to develop industrially focused skills in research groups in advanced propulsion systems – case interviewees reported this development would not have occurred on the same scale in the absence of APC funding.

Box 6.2: Example of local clustering – Access to skills capabilities and infrastructure

DIET: To take advantage of an OEM located in the North East of England, one project collaborator invested in the development of an engineering R&D centre to provide systems engineering services to OEMs that were increasingly focused on the development of LCVs, especially BEVs. The APC project enabled the collaborator to develop key skills in powertrain electrification which resulted in further capital investment in the technical area. Co-locating was expected to reduce the costs of securing commercial contracts with the

6.1.2 Foreign direct investment

The case studies found limited evidence of overseas firms establishing new production locations or R&D facilities in the UK as a consequence of APC funding. However, the evaluation did find evidence of OEMs with an existing presence in the UK investing to expand or upgrade current operations in the UK. That said, two of the project case studies highlighted OEMs with operations based in the UK that were reducing their levels of investment into the UK in response to profitability challenges or changes in technical priorities.

Box 6.3: Examples of FDI secured

Bowscale: The APC funded project supported the development of a completely new generation of technically advanced driveline modules offering significantly improved CO2 figures for high performance vehicles. As a result of the project, the lead applicant, whose headquarters is located overseas, has since invested in upgrading its UK-based testing facilities in order to develop prototypes on site without the need for external purchases.

HEDB: As a result of the development of manufacturing facilities that have successfully enabled the integration of battery technology into a vehicle platform, the lead OEM has invested in upgrading other production lines in the UK, drawing on the insights into manufacturing processes gained through the APC funded project.

T-REX: The overseas owned lead OEM has since invested in the development of electrification teams at a UK facility after the completion of an APC project which focused on the development of knowledge and capabilities relating to PHEV light-commercial vehicles and electrification more generally. This has helped in the wider transition of the OEM's UK engineering focus from ICE engines to electrified powertrains and commercial vehicle development.

6.1.3 Results from econometric analysis

These effects were given more systematic quantitative treatment through a series of econometric analysis exploring the effects of grants awarded through the APC on the economic performance of small areas up to 10km from the location of those firms receiving funding through the programme. Effects were identified by comparing the economic performance of areas proximate to successful and unsuccessful applicants and areas benefiting from funding at different points in time. Further details of the analysis are set out in Annex F, and the findings are summarised in Figure 5.1.

Overall, the findings indicated that the programme had a positive net impact on the local economies in which firms benefitting from APC were located:

- **Clustering:** The results suggested that the grant awards had a positive effect on the number of firms located in areas in proximate to those awarded grants. These effects were largest in the output area[43] in which the firms receiving grants were located (11 percent). The median number of firms located in the output area of the lead applicants was 67 (suggesting that the grants encouraged 7 firms on average to collocate with the lead applicant). The estimated effects were positive, though significantly smaller, at larger distances. In absolute terms, these effects were comparatively trivial as the density of firms beyond 1km of the applicant was substantially lower (a median of 5 per Output Area). This indicates that APC grants have worked to produce clustering effects at the very local level, with no evidence of net displacement effects within 10km.

- **Local economic performance:** The evidence indicated that APC grants had a positive net economic impact on local economic growth and productivity. The impacts included:

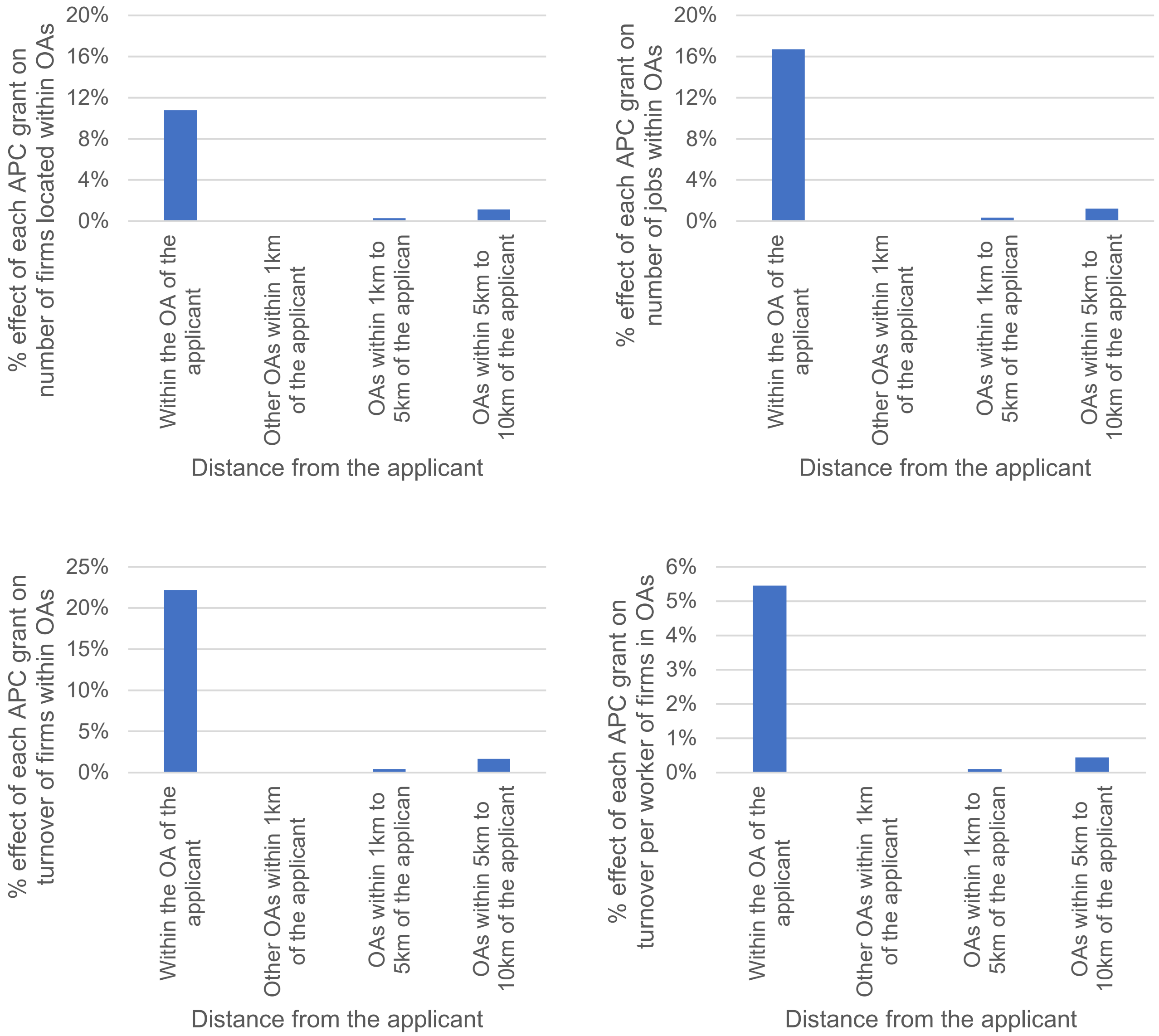
    - Localised effects: The models indicated that each grant led to a 17 to 18 percent increase in the number of jobs in the OA in which the applicant was located, and a 22 to 24 percent increase in the turnover of firms based in the area. The turnover per worker of firms (used a proxy measure of productivity) in the area also rose by an average of 5.5 to 5.8 percent in response to the grants awarded. It should be noted that the lead applicant tended to account for a high share of economic activity within the Output Area (more than 50 percent on average), and these impacts are broadly comparable to those observed amongst those applying for funding. As such, a large share of these impacts will relate to the direct effects of the APC rather than indirect effects mediated by spillovers. However, there was little suggestion of displacement or crowding out at the very local level.

    - Effects within 10km: There were also positive economic impacts at distances of 1km to 10km from those awarded funding. The econometric models indicated that each APC award led to an increase in the total number of jobs in these OAs by 0.3 to 1.5 percent and the turnover of firms located in these OAs by 0.4 to 1.7 percent. The turnover per worker of firms located in these areas rose by 0.1 to 0.5 percent. Larger effects were observed at distances of 5km to 10km than between 1km and 5km. There was no evidence of net displacement or crowding-out effects locally (which would have been visible in negative impacts at some distances).

These findings indicate that the APC has produced positive spill-over effects for local economies. Given the evidence on firm relocations, it is assumed that these effects have arisen largely from the attraction of higher value activities to the area, potentially from other areas of the UK. It should be noted that there will likely be corresponding negative effects on the local economies from which those activities were relocated. Additionally, the econometric analysis did not explicitly control for other economic policies at the local or sub-regional levels and the estimated impacts may not be fully attributable to the APC.

[43] A small geographical area defined by the Office for National Statistics for the purposes of reporting Census statistics, consisting of around 10-12 postcodes.

Figure 6.1 Impacts of APC grants on the number of firms, employment, turnover, and turnover per worker of output areas within 10km of firms receiving funding



Source: ONS (2019). *Analysis of linked APC applicant records to the Business Structure database.*

6.2 Knowledge spill-overs

As highlighted in Section 2, grant recipients may create new skills, knowledge or intellectual property that could be adapted and/or applied in other projects, define new programmes of R&D or make use of other commercial activities. The case studies were used to identify possible knowledge spill-over effects of the following types:

- Internal spill-overs in which the knowledge developed through the project is applied to adjacent or unrelated areas of the applicants' operations
- Within consortia spill-overs in which knowledge exchange between partners facilitates exploitation in adjacent or unrelated operational areas.

- External spill-overs where third parties external to the consortia receiving funding have exploited the knowledge and skills developed through the project.

The evaluation defined spill-overs as those relating to the application of new knowledge or skills to support the development of adjacent programme of R&D (technical), or those that have supported the creation and/or improvement of exploitation opportunities. Overall, the study found evidence that technical and economic knowledge spillovers were realised within collaborating organisations and across project consortia. However, there was only limited evidence of external imitation or replication of technologies.

Table 6.1: Prevalence of knowledge spill-overs among sampled project case studies

Spill-over type	Within a collaborating organisation	Across project collaborators	External to the project consortia
Technical	8/16	5/16	0/16
Economic	3/16	3/16	1/16

Source: Ipsos MORI (2019). *Comparative case analysis.*

As shown in the table above, the main source of knowledge spill-overs was the application of learning to adjacent programmes of R&D, both within and across consortia. In the case of economic spill-overs, the delivery of APC projects enabled firms to gain access to new commercial contracts and opportunities (such as OEM and Tier 1 supplier lists) by developing a track record of working with larger firms in the supply chain, as well as providing evidence of relevant skills and capabilities. At this stage, claims regarding spill-overs accruing to organisations outside of project consortia related to the confirmation of new or expanded commercial contracts as a result of the integration of APC technologies within vehicle platforms produced at high volumes. However, it was not possible to validate these claims with other members of the supply chain so the result should be taken with some caution.

Box 6.3: Examples of knowledge spill-overs

TRANSCEND: As a result of the project, the Jaguar Land Rover Limited gained a greater understanding of how to assess issues related to the development of transmission systems, such as transfer, vibration and noise, using virtual design and testing facilities. Based on the prototypes and demonstrators developed in the course of the project, Jaguar Land Rover reported it was able to apply these R&D processes to other R&D related programmes.

ACTIVE: As a result of the success of the enhanced ICE developed through the project, other members of the supply chain associated with the development of the OEM vehicle platforms have benefitted from increased componentry sales. Some supply chain members, external to the consortia, also suggested that a proportion of the benefits may have also leaked overseas as some of the vehicle platforms embodying the technology have been produced in plants outside the UK. Although the project developed skills and capabilities for the development of advanced ICE engines which remains rooted in the UK.

The research indicates that there were three main mechanisms through which knowledge spillovers arose from APC funding competitions:

- **Industry to academia:** Universities in project consortia developed a better understanding of industry requirements and translated this into university teaching and applied research programmes. For example, a network of APC grant recipient universities was launched in collaboration with the APC to share knowledge on best practice for working with industry, which included information on academic requirements for working with industry and an overview of processes and tools used to deliver industrial R&D projects.

- **Academia to industry:** Industry also generated an understanding of the latest testing and validation approaches developed by university research groups and implemented these across their R&D portfolios – for example, the development of innovative tests that could take transient rather than static measurements.

- **OEMs to SMEs:** SMEs benefited from knowledge shared by OEMs, specifically on suitable reporting structures to use for research outputs, robustness test concepts, the use of OEM tools, techniques and software and how to register IP.

In addition to the delivery of APC projects, stakeholders reported that knowledge spill-overs were also likely to result from complementary activities delivered by APC UK – for example, the management of Spokes communities and delivery of relevant events, such as the annual Low Carbon Vehicle show and the 'Future of Tech' event series, have enabled the potential formation of project consortia for future competition rounds.

6.2.1 Cross sector-spill-overs

APC grant recipients may also generate new R&D and/or commercial opportunities outside the automotive sector.

Aerospace

The case studies suggested the aerospace sector has particularly benefited from the APC funded projects, which in turn has enabled APC funded projects to further exploit the technologies and capacities developed:

- Organisations that specialise in the development of tools, equipment and manufacturing processes tend to work across sectors, transferring knowledge, skills and feeding learnings into a range of projects across sectors. For example, NCC, WMG and Coventry University, which are involved in several projects, have developed a range of processes and tools that have been used, and/or are currently being refined for use, within the aerospace sector.

- There are examples where components/systems/sub-systems designed during the APC funded projects are now being sold into the aerospace sector (such as the motors designed by iNetic as part of the Gryodrive project).

- Some projects have indicated that discussions with companies such as Airbus are ongoing, and others are pursuing multiple partnerships.

Other sectors

Applications were also reported in the military, energy storage, infrastructure, marine and shipping, and construction sectors, as shown in the table overleaf.

Table 6.2: Illustrations of cross-sector spill-overs

Sector	Key examples reported in the evaluation
Energy	The outputs of one project were being applied in static battery storage systems; a new project working with a UK energy supplier to deploy static storage batteries into social housing in the UK also resulted. Whilst still at an early stage, if technically successful, this project is expected to result in economic benefits to the local energy storage sector and benefits for consumers, as well as CO2 savings.
Military	One project developed an energy storage technology which has since been demonstrated to domestic and overseas military departments for a potential application in micro grid management and weaponisation, although at the time of interview the technology had not been pursued for this application.
Emergency Services	One project has resulted in the deployment of fuel cell scooters for use by Blue Light services, especially the Metropolitan Police.

Source: Ipsos MORI (2019). *Comparative analysis of sampled project case studies and views collected from key stakeholders.*

6.2.2 Other spill-over effects

A range of other potential spill-over effects were identified at the outset of the evaluation and are thought to be of some potential significance:

- **De-risking and demonstration spill-overs:** The delivery of an APC project potentially reduces the levels of risk and uncertainty associated with a technology under development such that other organisations may be incentivised to also invest R&D efforts in the same, or similar, technology areas.

- **Demand aggregation and other non-spatial effects:** Organisations may benefit from locating near grant recipient in terms of technology or exploitation decisions - for example, other organisations may generate economies of scale through targeting similar technology areas or exploitation strategies to APC grant recipients. In these cases, reallocation of resources to different activities rather than the geographical relocation of activity may be involved.

The evaluation found evidence to suggest that the delivery of APC projects did result in some demonstration and de-risking spill-overs. This was primarily achieved through the production of test results presented in academic and industry journals and conference proceedings, and the development of demonstrators (at varying stages of technical and manufacturing readiness):

- **Test-results:** In one project, a new calibration method for application in the development of electrical control units resulted in a c.50 percent reduction in calibration time, which resulted in further development in similar applications.

- **Demonstrators:** The development of demonstrators was shown to result in further internal investment into associated technologies as a result of APC funding. For example, the development of a PHEV demonstrator resulted in additional development by an OEM partner to develop a set of refined PHEV prototypes, based on technical results produced by the APC project.

However, the evaluation found limited evidence to suggest that the programme has resulted in non-spatial spill-overs at this stage – for example investments in adjacent technology areas to the APC portfolio, aggregating demand for subcomponents to realise economies of scale and/or attracting inward investment into the UK supply chain. However, it is acknowledged that case study and stakeholder interviewees may just not be aware of such effects, or it may be too early in the stage of delivery of the portfolio for these to be observed – a key limitation of any interim programme evaluation.

7 Conclusions and recommendations

This section presents the conclusions of the APC Interim Impact Evaluation.

7.1 Meeting programme objectives

At this interim stage of programme delivery, BEIS is seeking to understand the extent to which the programme is on track to meet its objectives relating to expanding and anchoring high-value LCV R&D and manufacturing activity in the UK:

- **Developing low carbon propulsion technologies:** Over competition rounds 1-9, the APC funded projects focused on a variety of LCV applications - some of which were continuations of previous programmes of R&D and some in direct response to APC funding calls. At this stage of delivery, most projects met, or were on track to meet, their technical objectives. However, a subset of projects were halted or re-scoped in response to insurmountable technical challenges or changes in the economic context. Falling demand for diesel engines was a key inhibiting factor in projects developing hybrid technologies. Furthermore, analysis shows that the technical development of funded projects in terms of TRL and MRL development was larger than that achieved by unsuccessful comparators and resulted in the creation of new knowledge and capabilities which led on to new programmes of LCV R&D activity.

- **Anchoring R&D and manufacturing activity in the UK:** It was not possible to fully validate some of the additionality claims made by applicants. However, the evaluation produced strong evidence that the award of a grant resulted in the expansion of R&D activity among lead applicants. These results are associated with a degree of uncertainty and should be revisited in later evaluation work. The results also provide some signals that a subset of closed projects have integrated APC funded technology into vehicle platforms, a key mechanism through which economic impacts are expected to arise. However, while projects under delivery have promising exploitation strategies, commercialisation for most projects is only expected from the end of 2019 and beyond. However, given the evidence of productivity gains (derived from three different sources), indirect clustering effects and signals of increased private investment flows, the evaluation provides reasonable evidence to suggest that the programme has helped anchor R&D activity in the UK and may result in increased levels of manufacturing activity as more projects are completed.

7.2 Answering Key Evaluation Questions

The key evaluation questions set out in the ITT, and presented in Section 1, relate to the extent to which a range of project, organisational and sector outcomes have been achieved as a result of APC funding.

1) How far has APC funding leveraged additional (direct) expenditure on new vehicle design and manufacturing technologies, both amongst beneficiaries of APC funded R&D projects and their suppliers? To what extent would any leveraged expenditure have occurred at all, at a slower rate, at higher risk and/or outside the UK in the absence of APC funding?

Econometric analysis exploring the impact of the programme on R&D activity provided evidence that the APC led to a 20 percent expansion of R&D spending and a 28 percent increase in R&D employment amongst lead applicants. No impacts were observed on the R&D activity of collaborators. The findings imply that programme led to an increase in overall R&D spending of between £64m and £482m by 2018. Central findings imply that 68 percent of the £404m in spending on the projects by 2018 would not have happened in the absence of the APC. There was a comparatively high estimated likelihood (73 percent) that the programme leveraged additional private R&D spending into low carbon propulsion technologies.

The case study research indicated that claims made by applicants as to why projects would not have moved forward without APC funding were mostly valid where they related to high levels of technical risk especially in relation high-volume LCV technology manufacturing. Case studies of projects put forward by applicants that were declined APC funding suggested that projects were not generally progressed without public support due to excess commercial and technical risk. Project proposals appeared genuinely marginal in the case of large firms (though it was not always clear why large OEMs would not fund the necessary development work, given the need to meet legislated emissions targets to maintain competitiveness). SMEs were more active in pursuing alternative funding sources, and there were indications that resources could sometimes be obtained to progress further R&D at a smaller scale and reduced speed.

2) How far has APC accelerated the development of new vehicle design and manufacturing technologies funded through the projects (i.e. progress through Technology Readiness Levels)?

Projects funded through the APC have moved more rapidly through the development pathway (as measured through the TRL and MRL scales) than projects that were declined funding. The projects funded are also generally on course to meet their expected reductions in tailpipe emissions. However, most projects had only partially met their project technical objectives. As noted, several projects were re-scoped in response to changing commercial opportunities and technical challenges – though the latter is to be expected in any innovation subsidy programme.

As few projects are complete, there are limited examples of technologies refined with funding from the APC being integrated into new vehicle platforms. Four of the ten completed projects had been commercialised at the time of the research, with associated vehicle sales of 1.15m units. However, it was estimated that 155,000 of those units were associated with significant manufacturing in the UK. Nevertheless, the case studies highlighted four cases in which exploitation of the underlying technologies is likely to occur in the next five years, with a significant share of the manufacturing expected to be taken forward in the UK.

3) How far has APC influenced patterns of collaboration (or introduced new ones), including increasing the volume and strength of collaborative relationships both between firms in the automotive supply chain, and with academic institutions?

All APC projects required collaboration including requirements to involvement at least one SME. A total of 142 individual partners were involved in projects funded over the first nine rounds of the APC. Case studies showed that collaboration was sought to gain access to specialist skills and capabilities whilst attempting to increase the likelihood of future R&D and/or commercial opportunities. However, the collaborative activity of leads of funded projects does not appear to have been affected by the award of a grant when compared to those lead applicants that were declined funding. Leads that received funding appear to have collaborated more with academics and less with SMEs relative to those declined funding.

Econometric analysis also suggested that the positive impacts of the programme were largely confined to the lead applicant. There was little evidence that the underlying performance of collaborators improved as a result of their participation in the programme, and some models indicated that collaborators saw negative impacts. This could suggest that the programme has encouraged insourcing of higher value activities that may have otherwise been externalised.

4) How far has the availability of APC funding led to – or encouraged - the initiation of new R&D projects in new design and manufacturing automotive technologies (i.e. projects that would not have come to fruition in the absence of APC funding)?

Case studies of projects highlighted several instances where project consortia developed new programmes of R&D that were linked to the results of an APC project. Technical outputs were also shown to spill-over into adjacent R&D programmes both within and across project consortia. Without the development of skills, capabilities, test results and demonstrators as part of APC projects, case study respondents and other stakeholders indicated that the development of new avenues of R&D would not have occurred at the same rate.

5) How far has the APC led to an improvement in the infrastructure such as machinery, equipment and tooling which is used to undertake R&D and helped to secure/create high wage employment in both R&D and the longer term manufacturing during production?

There was evidence that the programme has led to impacts on the net capital investment of those awarded grants. Central estimates suggest a possible total effect of between £75m and £98m by 2018. Owing to small sample sizes, these impacts are imprecisely estimated, and allowing for statistical uncertainty, this range could extend from £22m to £161m in total. The cases studies provided examples of the internal investments by OEMs to enhance or expand existing facilities, the development of new facilities as a direct result of project outputs, or wider investment in human capital, to build up supply chain capabilities in relation to electrification and BEVs and alternative propulsions systems, transmissions and ICEs.

The econometric analysis also showed that the programme has led to the expansion of lead partners awarded APC funding in terms of:

- **Employment** – each grant award led to an increase in employment of 10 to 16 percent with a total impact of 2,800 to 4,400 jobs created or safeguarded, much of which appear to be focused on production activities.

- **GVA** – each grant award led to an increase in GVA of 15 to 17 percent with a total increase in the output of lead applicants awarded funding of £329m to £372m by 2018.

- **Productivity** – there were also signals of productivity gains. APC grants were estimated to lead to an increase in the wages of workers employed by lead applicants by 1.7 to 2.0 percent. There were also signals that the programme raised GVA per worker (by a range of 3 to 8 percent). The additional GVA arising from productivity gains by 2018 is estimated at between £36m and £275m.

The lifetime economic benefits of the programme will arguably largely be determined by how these productivity gains persist in the longer term. There are significant uncertainties in relation to the durability of these impacts and this evaluation could only explore short term effects.

6) How far is APC expected to deliver spillover benefits based on evidence on the nature and extent of collaborations/supply chain outputs?

The strongest evidence of spill-over effects from the APC programme were in the form of agglomeration and local clustering impacts. Econometric analysis was completed to examine the impact of the programme on the economic performance of the areas in which grant recipients were located and adjacent areas. These results indicated that the APC encouraged other firms to relocate to those areas as well as producing spill-over benefits in the form of the growth and efficiency of local firms. The estimated effects were strongest in the areas in which grant recipients were located (though these effects will conflate both the direct and indirect effects of the grant):

- 11 percent effect on the number of firms,
- a 17 to 18 percent effect on total employment,
- a 22 to 24 percent effect on total turnover; and,
- a six percent effect on productivity (turnover per worker).

The case studies indicated that this may occurred where collaborators sought to reduce the costs of developing R&D and commercial opportunities with OEM and Tier 1 firms and/or gain access to specialist facilities or expertise. Knowledge spillovers were realised across organisations collaborating in the delivery of APC projects, though at this stage there was limited evidence of the imitation or replication of technologies outside of project consortia.

7) What broader technological and policy developments have emerged since the APC programme was created (including the emergence of a preferred technological standards), and how are these likely to influence the impact of the scheme?

The broad technical areas identified in the Technology Roadmaps are thought to accurately describe the anticipated trajectory of technical development in the sector. The development of energy storage and power electronics have become increasingly important as the sector accepts BEVs as the technical standard in the medium-term. This has had knock-on effects on other areas – for example the increased need for lightweighting to accommodate battery development and the decreased focus on PHEV and diesel engine development. Qualitative views provided by case study participants and stakeholders highlight that recent changes to emissions targets, an increasing focus by Government and consumers on air quality and environmental issues, and complementary demand and supply-side polices to support EV development and up-take, have also increased pressure on the sector to invest in zero-emissions propulsion technologies.

8) Has APC leveraged additional inward investment spend from supported businesses as a result of the funding, and influenced their decisions to invest in the UK in any way?

As discussed above, APC grants attracted increased investment into grant recipient firms. This includes internal investment allocated by OEMs to enhance or expand existing facilities, the development of new facilities as a direct result of project outputs, or wider investment in human capital, to build supply chain capabilities in relation to electrification and BEVs and alternative propulsions systems, transmissions and ICEs.

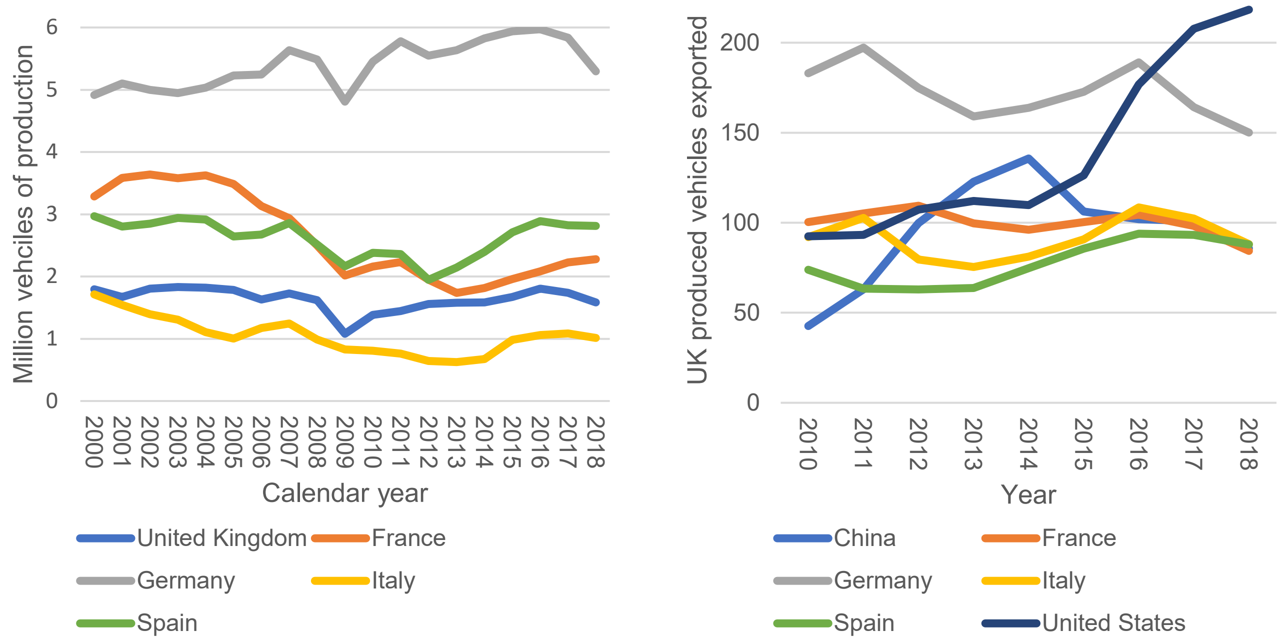
Appendix A: Context Review

A.1 Economic context

The UK automotive sector produced 1.6m passenger and light commercial vehicles in 2018, ranking fourth in the EU after Germany (5.3m), Spain (2.8m) and France (2.3m), as shown in Figure A.1.

In the years following the 2008 Financial Crisis, the UK sector experienced rapid growth which subsided from 2014 onwards, as shown in Figure A.2. GVA and employment in the sector have increased by 11 and 9 percent in real terms respectively since the inception of the programme in 2013. Productivity (GVA per worker) in the sector grew by around 25 percent in real terms since 2010, from £86,000 to £108,000. This performance was substantially stronger than that of the manufacturing sector as a whole in which productivity remained stable at around £67,000 in the same period. The on-going growth of the sector has been supported by a rapid expansion in investment. Net capital investment expanded from £1.7 billion in 2012 to £3.3 billion in 2017, while investment in R&D rose from £1.6 billion to £3.1 billion over same period (with the share of overall UK R&D accounted for by the automotive sector rising from 6 to 13 percent). The UK also substantially improved its trade balance in the sector from a deficit of £27 million to a surplus £4.8bn in real terms between 2012 and 2016.[44]. Eighty-two percent of the total vehicles produced in the UK were exported in 2018, with 14 percent exported to the United States and 9.5 percent exported to Germany.[45]

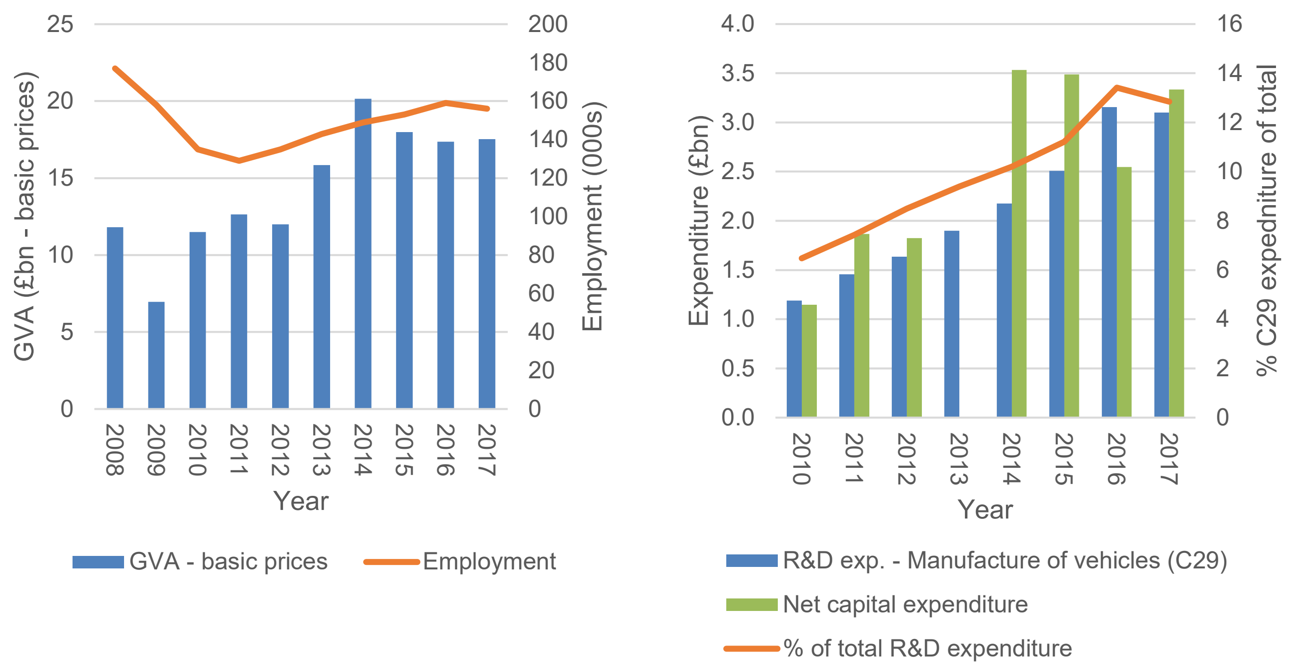
Figure A.1: European passenger and light vehicle production and exports



Source: IHS (2019).

[44] EUROSTAT data is only provided for these years under the vehicle manufacturing category (NACE2 C29).
[45] IHS Markit (2019). Passenger and light commercial vehicle production statistics 2005-2018.

Figure A.2: Output, employment and investment in UK automotive manufacturing sector (2018 prices)



Source: ONS (2019). *Annual Business Survey 2017 Revised Results. Release date: 16/05/19*; ONS (2019). *Business Expenditure on Research and Development 2017 Results. Release date: 21/11/18.* N.B. Records for 2013 net capital expenditure were suppressed to avoid disclosure by the ONS.

However, the sector now faces major challenges:

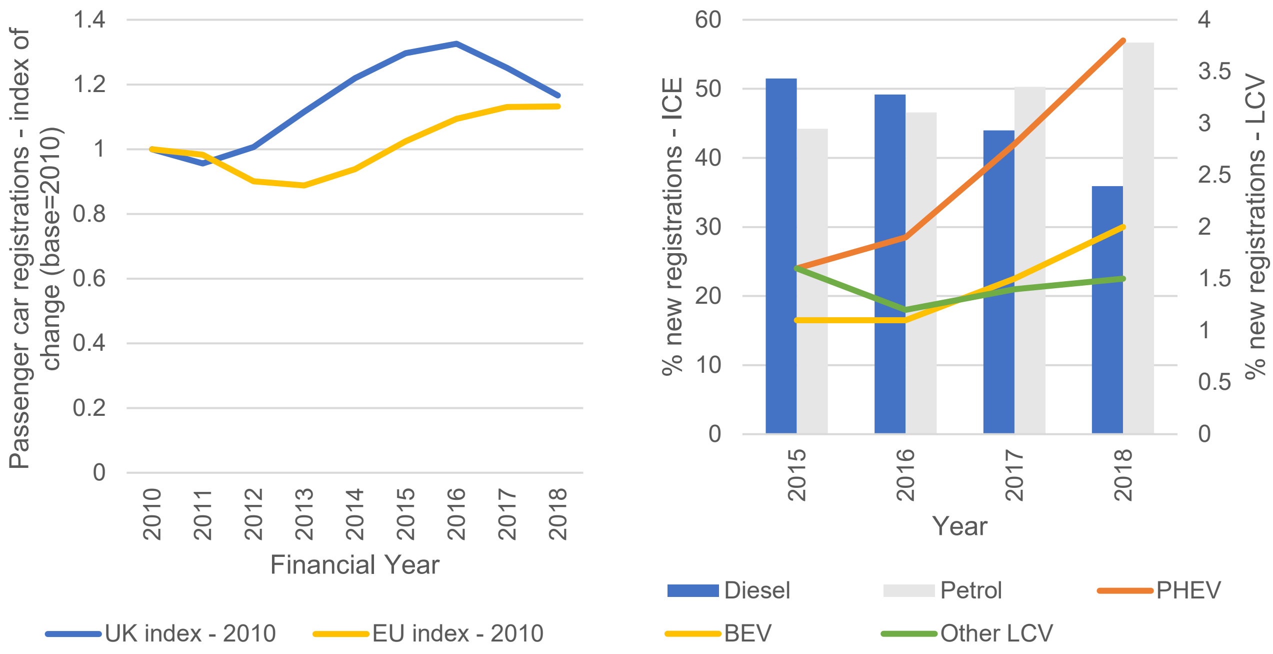
- **Decreasing production activity:** As Figure A.1 shows, production in 2018 fell from 1.7 million units in 2017. Key UK-based OEMs have announced plans to reduce or halt production activity in the UK, for example: the scheduled 2021 closure of the Honda car manufacturing plant in Swindon[46], Nissan's announcement it will cease production of certain platforms at its Sunderland plant[47], the planned closure of Ford's Bridgend engine plant and production halts at a number plants as a result of political uncertainties.[48] The future of Vauxhall Astra production in the UK is also uncertain. The underlying problems facing the sector include both falling UK car sales and waning demand in important overseas markets. Deteriorating market conditions have also impacted on European competitors, all of which - with major exception of France – have seen declines or stagnation in automotive sector output since 2015 as shown in Figure A.1.

- **Reduced demand for diesel vehicles:** A key indicator of business performance in the automotive sector is new vehicle registrations. Analysis of registrations of passenger cars over time shows that UK registrations decreased from 2016 onwards, as shown in

[46] Honda EU (2019). *Honda announced proposal to cease production at its Swindon factory in 2021. February 2019*. Available at: https://bit.ly/2kdNjGc. Date accessed: 02/09/19.
[47] UK Parliament (2019). *Statement following announcement of Nissan's Sunderland decision. February 2019.* Available at: https://bit.ly/2jZMoce. Date accessed: 02/09/19.
[48] BBC (2019). *Jaguar Land Rover starts Brexit shutdown*. Available at: https://bbc.in/2FR0SSo. Date accessed: 02/09/19.

Figure 2.4. With EU registrations slowing too, European OEMs performance may be affected which could have implications for R&D activity. The composition of new registrations has also changed, with consumers favouring new petrol over diesel vehicles from 2017 onwards. This decrease was shown to have affected the profitability of key UK- based OEMs that were reliant on diesel vehicle sales such as Jaguar Land Rover, which reported a decrease in pre-tax profits between 2017 and 2018 for quarter one from £676 million to £364 million in nominal terms.[49] Stakeholders consulted as part of the evaluation indicated this may have had implications for automotive firm R&D budgets which are typically set as a percentage of expected firm revenue.

Figure A.3: Total new passenger vehicle registrations and proportion by fuel type in EU



Source: ACEA (2019).

While the UK can be considered a leading global developer and producer of EVs, production activity is small compared to market leaders, China, and a number of barriers currently exist that prevent mass adoption consumers:

- **EV production:** UK vehicle production is dominated by diesel which peaked at 74 percent of total UK production in 2016 before decreasing to 64 percent by 2018, while the proportion of total petrol vehicle production increased from a quarter to just over a third in the same period. UK production of electric vehicles began in 2013. Volumes doubled between 2017 and 2018, primarily due to expanded production of the Nissan Leaf, but still represent less than one percent of total passenger car output. Whilst the UK is one of the world's largest manufacturers of BEVs, its production is dwarfed by that of China which manufactured 595,000 units in 2017, compared to just under 17,000 produced by the UK. Other key producer nations include the US and Germany - with BMW is the third largest BEV manufacturer globally, after Tesla and the Chinese global leader BYD.

[49] Financial Times (2018). *Jaguar Land Rover profits skid on falling diesel demand.* Available at: https://on.ft.com/2jVfcm9. Date accessed: 02/09/19.

- **Demand for electric vehicles:** Figure 2.4 summarises the demand for passenger LCVs well, in that demand for BEVs and other LCVs has increased in recent years but fundamentally ICE vehicle registrations still dominate. Recent consumer research has highlighted several barriers to the adoption of EVs which include: unclear or insufficiently attractive government financial incentives, limited choice of available EV models and negative perceptions relating to the costs and range of EVs, and the availability of EV charging and maintenance infrastructure.[50]

A.2 Political context

Since the launch of the programme, a range of political and regulatory drivers have increased pressure on automotive manufacturers to find low carbon propulsion solutions more rapidly than was anticipated in 2013. These include:

- **The UK's Departure from the European Union:** The UK's departure from the European Union has created uncertainties for the sector, especially given the high volume of foreign-owned firms in the supply chain based in the UK. However, it is currently not clear what the net effect in terms of business performance will be. While the decision presents exchange rate risks which affect factor input prices and availability, it may present opportunities for increased export activity and reorganisation of the supply chain to minimise costs and decrease exposure to risk. One example of the latter is BMW-Jaguar Land Rover EV manufacturing partnership – a commitment made in 2019 to share resources and take advantage of economies of scale to jointly develop electric drive units and other EV systems.[51]

- **Dieselgate and air quality concerns:** The 'dieselgate' scandal of 2015 in which the United States Environmental Protection Agency (EPA) formally accused the Volkswagen group and other OEMs of violating US emission standards by falsifying tailpipe emissions tests[52] – alongside increasing public concern in relation to the long-term public health impacts associated with breaches of legal limits in relation to nitrogen oxide and particulate matter (emissions of which are elevated in diesel vehicles) – have increased pressure on both Government and municipal authorities to find and legislate for a more rapid transition to low emissions vehicles. In the UK, this is reflected in the publication of the 'Road to Zero Strategy'[53] which sets out the Government's ambitions to see at least half of new cars sold in the UK be ultra-low emission by 2030, and the Air Quality Strategy which sets out plans to end the sale of new conventional petrol and diesel cars and vans by 2040.[54]

- **The Climate Change Act of 2008 (2050 Target Amendment):** In addition, the provisions of the 2008 Climate Change Act were made more ambitious in July 2019, with the Government committing to the UK reaching net zero carbon emissions by

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[50] For example, see YouGov (2019). *Why is the UK's electric car adoption so sluggish?* Available at: https://bit.ly/2kqSF0L. Date accessed: 02/09/19.
[51] BMW Group (2019). *BMW Group and Jaguar Land Rover announce collaboration for next-generation electrification technology.* Available at: https://bit.ly/2KGygQF. Date accessed: 02/09/19.
[52] EPA. *Learn About Volkswagen Violations*. EPA webpage, available at: https://bit.ly/1WNL4D9. Date accessed: 02/09/19.
[53] HM government (2018). *The Road to Zero - Next steps towards cleaner road transport and delivering our Industrial Strategy.* Available at: https://bit.ly/2DvPWM7. Date accessed: 02/09/19.
[54] DEFRA (2019). *Clean Air Strategy 2019.* Available at: https://bit.ly/2AJ8kNZ. Date accessed: 02/09/19.

2050.[55] This was introduced after much of the research underpinning this report was completed and as such, the influence of these commitments will not be captured in the evidence gathered for the study. However, this will likely to place additional pressure on the sector to decarbonise moving forwards, exacerbating some of the issues noted in this section.

- **Complementary public funding support:** Since the inception of the APC funding competition, other public sector commitments have been made to support the development of low carbon propulsion systems and the sector more generally, as summarised in the UK 'Automotive Sector Deal'.[56] Initiatives include: the launch of Industrial Strategy Challenge Funds (ISCFs) relating to the development of batteries, and electric powertrains, and the inception of a programme to enhance supply chain productivity and investment in connected and autonomous vehicles. Demand-side policies have also been implemented to create incentives for the adoption of LCVs, especially for BEVs. These included OLEV funding to expand EV infrastructure in the UK[57] and the availability of consumer subsidies for eligible low-emission vehicles and EV home charging infrastructure, although both the availability and size of the grant was restricted from 2018 onwards.[58] Finally, it is noted that, while there is enhanced availability of public funds to support industrial R&D, central Government support for capital investment through regional aid schemes has been significantly scaled back with the closure of the Regional Growth Fund to new applicants in 2015.

A.3 Technology context

The APC Technology Roadmaps present a detailed overview of the sector over the short- to long-term by technology area and vehicle application.[59] Table 2.1 below presents stakeholder and case interviewee views on key trends since the publication of the roadmaps. The consensus view was that in the short-term, the development of battery electric vehicle platforms is likely to remain a dominant feature of most OEMs plans, though exploration of alternative low emission propulsion systems has not entirely fallen off the agenda:

- **Electrical energy storage:** The UK has expertise in the early stage development of EV batteries and a key focus for R&D is developing an understanding of how to produce at scale both effectively and efficiently. Beyond the Envision-AESC battery plant in Sunderland (largely supplying the Leaf), the capability of the UK to produce at the required scale and unit cost is limited. Lithium-ion batteries are the technology standard in the short term for batteries as the main source of propulsion in BEVs, although other cell chemistries are in development, such as lithium-sulphur. The UK has a strong academic research base in battery electrochemistry and development of battery cells and modules. Key challenges include securing a sustainable supply of raw materials,

[55] HM Government (2019). *The Climate Change Act 2008 (2050 Target Amendment) Order 2019.* Available at: https://bit.ly/2jYhjpl. Date accessed: 02/09/19.
[56] BEIS (2018). *Automotive Sector Deal.* Available at: https://bit.ly/2DsjLNd. Date accessed: 02/09/19.
[57] OLEV (2019). *Making the Connection - The Plug-In Vehicle Infrastructure Strategy.* Available at: https://bit.ly/2kqe4Hd. Date accessed: 02/09/19.
[58] HM Government. *Changes to the Plug-in Car Grant.* Webpage, available at https://bit.ly/2koWofg. Date accessed: 02/09/19.
[59] APC (2019). *The Roadmap Report - Towards 2040: A Guide to Automotive Propulsion Technologies.* Available at: https://bit.ly/2KOSsfT. Date accessed: 02/09/19.

the need to upgrade existing pilot production lines, and technical challenges relating to the safety of systems and toxicity of components, and battery design and integration.

- **Electric machines and power electronics:** A range of power electronics, including stop/start functionality, low cost electronics, accessory electrification, and power electronics to drive motion, are all emerging technologies in the automotive sector. Recent developments in electric machines to convert energy and/or make motors more efficient - also in batteries and power electronics motors and drives, both driven by the move towards LEVs. The power electronics Technology Roadmap is expected to be adapted as a result of developments in adjacent sectors, such as improvements in software and processing power.

- **Internal combustion engines:** ICE development was expected to continue, especially for commercial and off-highway markets, and fuel cell development was also expected due to increased pressures on electricity markets caused by anticipated BEV adoption. While the UK holds strengths in ICE production, especially diesel, it is currently faces capability and capacity constraints in terms of BEV development and production.

- **Thermal Propulsion Systems:** Incremental improvements to the efficiency and emissions control capability of petrol ICE are a key priority for the UK to support the transition to LCVs (especially true for heavy-duty commercial vehicles). ICE development was expected to continue, especially for commercial and off-highway markets, and fuel cell development was also expected due to increased pressures on electricity markets caused by anticipated BEV adoption. While the UK holds strengths in ICE production, especially diesel, it is currently faces capability and capacity constraints in terms of BEV development.

- **Lightweight powertrain structures:** Emissions standards and improved efficiency can also be partly achieved through continual lightweighting of the powertrain whilst maintaining the required material strength and flexibility. While lightweighting of vehicle shells through the development of novel alloys is common, miniaturisation and downsizing of all vehicle components (including engines, components packaging, power electronics and other drive train components) has been a key technological trend in recent years. Stakeholders reported future lightweighting would focus on three areas: the design of systems and componentry, the development of new materials and the introduction of new manufacturing processes. The UK has traditionally been a key developer of lightweighting technologies but several challenges remain: implementing lightweighting technologies into mass-produced vehicles that use standardised components and are assembled in different locations is not always possible; developing new materials is constrained as existing infrastructure favours the processing of steel; and, lightweighting solutions can produce trade-offs that may affect consumer preferences (such as noise).

Appendix B: Spill-over framework

Table B.1: Overview of spill-over effects relevant to the APC programme

Spill-over	Description
Spatial agglomeration effects	Exploitation of a technology will have encouraged other businesses to make complementary investments (e.g. making inward investments) in areas in proximate locations to grant funding recipients. This may be in order to exploit skills or capabilities developed, or capital investments made, through the projects. This could include inward investment decisions of overseas subcontractors or the relocation of domestic firms to geographic areas with access to particular capabilities or infrastructure.
Internal knowledge spill-overs	Where project delivery may have resulted in knock-on changes to decision-making with respect to project partners R&D spending and/or business investment. For example, capabilities developed on an APC project may influence the future R&D agenda of a business, or software developed in an APC project may be adopted by other parts of the business.
Classical knowledge spill-overs	In this case, businesses that have not received APC funding may have replicated or imitated APC funded research outputs to guide their own R&D activity or investment decisions. Here the focus is on directly repurposing APC research outputs for economic benefit. Whereas de-risking and demonstration spill-overs focus on the ability of organisations to reallocate resources to complete R&D that builds on APC research outputs created.
Spill-overs into other sectors	In this case, project partners, may have been able to sell a developed technology into other sectors. They may also have been able to create collaborative links with other businesses to develop technologies to sell into those sectors, as a result of capabilities developed during APC projects.
De-risking or demonstration effects	The completion of an APC project may have marginally reduced levels of risk and uncertainty associated with a technology under development, such that other organisations are incentivised to also invest R&D efforts in the same, or similar technology areas. In other words, the risk and uncertainty associated with the expected return on investment of a technology have decreased, resulting in increased R&D spending by the sector.
Demand aggregation and other non-spatial effects	Organisations can also benefit from locating in close proximity to grant recipient in terms of technology or exploitation decisions. Through the development of technologies as part of the programme, other organisations can generate economies of scale through targeting similar technology areas or exploitation strategies. In these cases, reallocation of resources to different activities would be observed rather than geographical relocation of activity.

Appendix C: Overview of BEIS annual economic monitoring forms received by Ipsos MORI

BEIS economic monitoring reports should be collected on an annual basis (Q4, Q8, Q12) at a project level and at close out at a partner level. If close out falls within six months of the final annual monitoring point, no annual monitoring is performed and data is collected at close out only. Information provided in the monitoring reports is self-reported. The evaluation team received across 16 projects, as shown overleaf including 12 Q4 reports, ten Q8 reports (four of which relate to one project at partner level) and one Q12 report. Close out reports were provided by 15 partners across seven projects: six projects had a close out report from one partner and one project had close out reports from nine partners.

The analysis includes projects with at least one annual economic monitoring report (Q4, Q8, Q12) at project level to understand changes since the original VfM assessments. This includes 15 projects, as detailed in the table below, and excludes one project with a Q8 report provided at partner rather than project level. The analysis uses the latest annual report available. The analysis does not include close out reports completed at partner level due to missing reports from the majority of partners.

Table C.1: BEIS annual economic monitoring reports included in analysis

Project ID	Project name	Project duration (quarters)	Number of annual reports	Q4	Q8	Q12
102082	HVEMS-UK	12	1		X	
113057	ZERE	15.3	2		X	X
113059	ASCENT	12	1		X	
113061	TRANSCEND	10	1	X		
113066	HEDB	8	1	X		
113067	CO2by2	12	2	X	X	
113068	UK-ABSC	12	2	X	X	
113070	LAtiTuDE	12	2	X	X	
113114	Breathe	15	1	X		
113115	CEMZEP	10	1	X		
113116	ACE-DC	14	1	X		
113117	SPEED V	14	1	X		
113123	DIET	10.3	1	X		
113124	Superlight Twin	10	1	X		
113150	HP-LiSD	12.7	1	X		

Source: BEIS (2018). *BEIS annual economic monitoring forms submitted by grant recipients.*

Appendix D: Technology and Manufacturing Readiness Levels

Table D.1: TRL Scale

TRL	TRL Summary
1	Basic principles have been observed and/or formulated
2	Developing hypothesis and experimental designs
3	Specifying and developing an experimental Proof of concept (PoC)
4	Proof of concept (PoC) demonstrated in test site/initial evaluation of costs and efficiency produced
5	Technology/process validated in relevant environment
6	Technology/process validated in operational environment
7	System complete and qualified
8	Product/technology in manufacture/process being implemented
9	Product/service on commercial release/process deployed

Source: UK Gov (2018). *Guidance on Technology Readiness Levels, available at: https://bit.ly/2kFO0bp. Date accessed: Nov. 2018.*

Table D.2: MRL Scale

MRL	MRL Summary
0	Basic manufacturing implications identified.
1	Manufacturing concepts identified.
2	Manufacturing proof of concept developed.
3	Capability to produce the technology in a laboratory environment.
4	Capability to produce prototype components in a production relevant environment.
5	Capability to produce a prototype system or subsystem in a production relevant environment.
6	Capability to produce systems, subsystems or components in a production representative environment.
7	Pilot line capability demonstrated. Ready to begin low rate production.
8	Low rate production demonstrated. Capability in place to begin Full Rate Production.
9	Full rate production demonstrated and lean production practices in place.

Source: DOD (2011). *Manufacturing Readiness Level Deskbook.*

Appendix E: Econometric analysis

This Appendix sets out an analysis of the impacts of the Advanced Propulsion Centre between 2013 and 2017. It explores the impact of the programme on firms receiving grants in Rounds 1-9 of the APC funding competitions using a variety of econometric methods. The analysis uses APC project monitoring records and administrative data on firm performance made available by the Office of National Statistics through the Secure Research Service (SRS).[60]

E.1 Key results

The results of the analysis suggest that:

- **R&D activity:** The results gave some evidence that APC grants resulted in an on-going increase in the overall volume of R&D undertaken by those firms leading projects. The analyses found that each APC grant led to an increase in the R&D employment and annual R&D spending of lead applicants of 20 and 28 percent respectively. These effects appeared to accumulate one to two years after the grant award was made, though insufficient time has elapsed to fully explore the longer-term persistence of any impacts. It should be noted that these findings did not come through in all models and were based on relatively small samples sizes, and there is uncertainty regarding the size of any effects. There was no robust evidence that the APC led to increases in R&D investment amongst collaborators, who were typically SMEs or other firms in the supply chains of OEMs (suggesting that the programme may have crowded out parallel activities). Finally, it should be noted that the data available did not capture R&D activities that were taken forward by academic collaborators, which may have been relatively important given the frontier nature of the technologies being explored.

- **Employment, turnover and GVA:** The grants awarded through the APC appear to have stimulated growth amongst lead applicants – raising employment by 9 to 15 percent, turnover by 15 to 30 percent, and GVA by 15 to 20 percent. Again, in broad terms, no effects were observed amongst collaborators, though some models appeared to indicate that participation in the programme reduced their turnover by around 20 percent. This could indicate that the programme has encouraged ‘in-housing’ of activities amongst lead applicants.

- **Capital investment:** Evidence on the impacts of the programme on the capital investment of those awarded grants appears to support this hypothesis. The findings indicated that the programme had large impacts on the net capital investment of those applying for grants (of 33 to 43 percent), which would be consistent with the increases in output and employment observed.

- **Productivity:** The findings also provided a range of indicators that the programme has raised the productivity of lead applicants, though there is uncertainty regarding the magnitude of these effects. Grants awarded through the APC raised the hourly earnings

2 [60] These figures are based upon the firms which were successfully linked to ONS held records at the SRS. Care was taken to clean the company reference numbers throughout APC applications, however it was not possible to successfully link every firm. Further details on the linking and the data available for analysis can be found in the data section of this Appendix.

of workers employed by leads of (1.7 to 2.0 percent), turnover per worker (of 14 percent) and the estimated effects on employment were consistently smaller than the estimated effects on GVA (with an implied effect on GVA per worker of 3 to 8 percent), although the models did not find a statistically significant effect on GVA per worker when observed directly. There were suggestions that the programme had a negative effect on the productivity of collaborators in some models. Again, this is suggestive that the programme encouraged insourcing of higher value activities that may have otherwise been externalised.

- **Uncertainties:** Although the findings provide an indication that the programme has been successful in meeting its objectives, there are several uncertainties as the findings were not always consistent across modelling approaches and the estimated magnitude of effects varied. The analyses were based on comparatively small sample sizes, and revisiting the analysis at later stages will offer an opportunity to provide more robust quantification of the programme's effects and investigate further important issues, such as their persistence over time. Additionally, it should be noted that the data available only ran to 2017, and the effect of external factors that may have influenced the performance of the automotive sector between 2017 and 2019 will not yet be visible in this data.

E.2 Key hypotheses

The APC funding competition has the potential to result in greater levels of economic activity through the following mechanisms:

- **R&D activity:** In the short to medium term, grants awarded through the programme could be expected to lead to increased levels of R&D spending. This assumes funding is not used to either fund activity that the private sector would have funded anyway (deadweight), or encourage the diversion of resources from parallel programmes of development activity (crowding out). Greater spending on R&D may induce some firms to increase their employment of workers, potentially those in R&D roles. However, greater R&D expenditure will not necessarily feed through to the recruitment of new workers to the extent that the additional spending is placed with subcontractors. In these cases, the impact of additional spending on employment might be anticipated within the supply chain rather than at the level of firms applying for grant funding (known as multiplier effects).

- **Crowding out:** Greater demand for the required inputs to the R&D process - such as skilled labour - could place pressure on wages and other prices. This would have offsetting effects elsewhere in the economy by reducing demand for labour and other inputs amongst other firms. In a closed economy operating at full employment, any expansion in employment amongst firms receiving grants will be neutralised by these types of effect. However, employment may still rise in net terms if firms are able overcome labour supply constraints by attracting workers from overseas or if higher wages encourage the economically inactive to enter the labour market.

- **Exploitation:** In the long term, firms successfully developing their technologies may move into an exploitation phase in which they seek to commercialise the underlying technologies refined through the R&D process. The typical expectation is that APC funded technology will be integrated into new vehicle models. This could occur via the integration of the entire propulsion system or the integration of individual components into new vehicles. However, other R&D outputs could be exploited by recipients, such as the development of new manufacturing processes or software. To commercialise any R&D outputs, it is expected that firms will need to scale-up their operations to manufacture at scale. This may require additional funds from the firm or an external investor. Assuming firms can successfully launch new innovations to market, this would be expected to result in increases in sales or turnover, and employment and output (GVA). The productivity of the firm will also potentially rise as it moves from investment in R&D to productive activities.

However, several factors make this process complex:

- **Product development timescales:** Product development timescales are long term in nature. While this evaluation covers a group of firms that received grants between 2013 and 2017, the timescales involved with bringing new automotive technologies to market are extensive. As such, it may be too early in the development process to expect significant commercialisation effects at this interim stage.

- **Resource requirements:** Completing the product development process may require a level of resources that cannot be brought to the project by an SME. SMEs may be well placed to develop a prototype power electronics component but will likely not have access to the resources and infrastructure needed to manufacture it in the required volumes for additional testing and validation. As such, the firms leading the initial development of the product may seek to license the technology to (or enter some other form of collaboration agreement with) a large OEM or Tier 1 firm with deeper resources to take forward development. Alternatively, the firm may seek to achieve an exit to such a company. In these cases, long term economic outcomes may be difficult to trace as production of the underlying technology will be taken forward by another firm.

- **Displacement and crowding out:** Where firms do successfully commercialise a new product, there are also offsetting effects that need to be accounted for. If firms claim market share from domestic competitors that produce alternatives, there may be corresponding loss of revenues, output and employment elsewhere in the UK. Even where sales are taken from overseas competitors, additional demand for labour and other inputs may put pressure on wages and other prices, encouraging other firms to reduce their production. These effects need to be considered to develop an understanding of the net economic impacts involved.

E.3 Data

To explore the causal effects of the programme, records of firms applying for APC funding were linked to several administrative and secondary datasets (summarised in the table overleaf), accessed through the ONS Secure Research Service (SRS) as part of the ONS Approved Researcher Scheme. This was achieved by linking the Companies House Reference numbers (CRNs) of firms associated with applications to the programme to the Interdepartmental Business Register (IDBR). A total of 225 firms applying for APC funding were linked to the IDBR from a population of 237 (a 95 percent match rate). Several these firms appeared in the sample more than once. In total, 173 unique firms were included in the sample, of which 114 were awarded funding at least once (66 percent), and 41 were lead applicants at least once (25 percent).

Administrative records were processed to create panel datasets providing annual observations over the periods specified in the table below. Except in the case of the BSD, the data sources used were survey based comprising a census of large firms and random samples of SMEs. While this sampling results in unbalanced panels, attrition in the data is random (i.e. produced by the sampling process) and is not expected to bias the results reported below, though findings will be skewed to larger firms. The matching rate to each dataset is shown in the table below.

When firms have more than one geographic location, the data in the BSD and ABS gives records of employment for each site. In these cases, these site level observations were aggregated to give data at the level of the overall enterprise. Finally, all financial variables were deflated using the GDP deflator to provide financial measures in 2017 prices.

Table E.1 Overview of datasets used for the analysis

Dataset	Analysis Period	Match rate (%)
Business Expenditure on Research & Development (BERD): This is an annual survey that comprises a longitudinal panel of known R&D performers and their expenditure on research activities by type and sector.	2010-17	82
Annual Survey of Hours and Earnings (ASHE): This survey gives data on the levels, distribution and make-up or earnings and hours worked for UK employees and can be linked to business level data. The data includes a panel dataset of workers whose wages are tracked each year.	2010-17	42
Business Structure Database (BSD): This dataset provides longitudinal records of employment and turnover for all firms registered for VAT or PAYE and offers an annual snapshot of the Inter-Departmental Business Register. Data is provided with different lags and are recorded as and when it arrives. These types of issue are more acute for evaluations considering short time horizons, and given the longer time frame under consideration in this evaluation (2013 to 2017), the extent of these types of bias may be less significant.	2008-17	86

E.3.1 Outcome Variables

The econometric analysis examined the impact of the APC funding competition on the key outcomes specified in table E.2. The baseline values reported show that there are significant differences across between firms awarded and declined funding that need to be accounted for in the analysis (as described in subsection 1.5 below). It should also be noted that the underlying distribution of these variables were highly skewed, owing to the presence of numerous large firms (for example, the largest UK automotive producer accounts for more than half of overall R&D spending in the entire sector). This creates substantial challenges in reaching an estimate of the overall impact of the programme (rather than its average effects) as discussed below.

Table E.2 Overview of key outcomes and 2013 baseline averages (2017 prices)

Outcome	Description	Mean baseline values	
		Awarded grant	Declined grant
BERD			
R&D employment	Employment of FTE scientists and technicians	218	11
Total R&D expenditure	In-house and external R&D purchases for performing R&D (£000)	161,658	17,777
ASHE			
Earnings	Average hourly earnings (£)	18.64	18.16
Hours worked	Average total paid hours worked during the reference period	40	39
ABS			
Employment	Reported employment	2,371	2,509
Turnover	Reported turnover (£000)	1,451,659	324,524
Turnover per worker	Turnover divided by employment (£000)	380	251
GVA	Gross value added (£000)	362,984	77,484
GVA per worker	GVA divided by employment (£000)	85	58

Outcome	Description	Mean baseline values	
Net capital expenditure	Net capital expenditure - sum of disposals and acquisitions (£000)	-2,675	18,245
BSD			
Employment	Employment from the Interdepartmental Business Register (IDBR)	1000	562
Turnover	Turnover from IDBR (£000)	536,233	69,849
Productivity	Turnover divided by employment (£000)	246	208

Source: ONS (2019). Analysis of microdata matched to APC records.

E.3.2 Control variables

Several control variables were included in the model as outlined in the list below:

- **Application score:** The score awarded to a project application as a result of the independent assessment process, which provides a means to control for the quality of the project that forms the focus of the application.
- **Foreign ownership:** This defines whether a business is owned by a parent business that is registered overseas.
- **Region:** This defines which region in the UK applicants (and their R&D activities) are located.
- **Business size:** This defines the size of applicants and uses the European Commission definition based on number of employees in any given reporting year.

E.4 Econometric analysis

This section provides the results of a series of econometric analyses seeking to provide estimates of the impact of the grants on these metrics of firm performance.

E.4.1 Selection bias

To assess the impact of grant funding in a credible way, the analysis requires a comparison group of firms that did not get the grant but were otherwise equivalent to those that did. As grants were allocated on a non-random basis, there are likely to be systematic differences between those firms awarded grants and any group of firms that were not, which could be correlated with the key outcomes of interest and bias findings. In the case of the APC, selection bias is potentially introduced at three stages: self-selection, the Innovate UK independent assessment process and the BEIS VfM assessment:

- **Self-selection:** Applicants 'self-select' into the programme by submitting an application for APC competition funding. Applicants can be assumed to differ systematically from other businesses in ways that would influence comparisons. For example, non-applicants may not be exposed to the same financial constraints as those applying for funding, which could reflect unobserved characteristics of the applicant or project - such as the risk associated with technologies under development, anticipated profits levels, or managerial qualities. In this example, comparing non-applicant firms to those benefitting from APC funding would understate the effect of public support, as the former would - under normal conditions - be expected to outperform the latter. Alternatively, non-applicants may not have developed their own programme of R&D activity, meaning the comparison may overstate the effects of public support.

- **Independent assessment process:** Applications are judged through an independent assessment process, considering their scientific merits, technical feasibility, the quality of the team, and the strength of the commercial opportunity. If these judgements are made effectively, it may be expected that in the absence of the programme, firms awarded grants would outperform firms that applied but were declined funding.

- **Value for Money Assessment:** Applications are also scrutinised on the extent to which they provide good value for money. This assessment is driven by expected changes in employment, skills and training, R&D spill-overs, commercial and environmental benefits, discounted for measures of additionality and risk. Again, providing these assessments are accurate, it would also be plausible to expect that in the absence of the programme, firms awarded grants would outperform those that did not secure funding.

E.4.2 Counterfactual selection

To address the issues identified in Section 1.2.1, two counterfactual groups were used:

- **Applicants that did not secure funding:** This involved selecting a counterfactual from the group of applicants that did not receive funding. It is assumed that this approach addresses self-selection issues, as both treatment and comparison groups can be assumed to share similar characteristics motivating their application. As highlighted, this approach leaves residual issues in terms of differences between both groups and the influence they may have over the outcomes of interest. To increase the robustness of results, a further set of analyses were completed by restricting the focus to those applicants that did not secure funding that submitted the highest scoring applications.[61] This assumes that the score reflects the underlying merits of the project proposal rather than solely the ability to develop high scoring applications.

- **Pipeline design (early vs late):** As highlighted above, there were substantial observable differences between applicant that were and were not awarded funding (e.g. in terms of R&D employment and spending). To address concerns that this may reflect unobserved differences between the two groups, a second approach used applicants that received funding in later years as a counterfactual for applicants that received funding in earlier years (on the assumption that the effects of APC grants should be

3 [61] Defined as those scoring at least 60 in the independent assessment process; the lowest scoring successful applications was 61.8.

visible amongst the latter group first). Restricting comparisons to only those firms that were awarded funding should mitigate against the risk of bias driven by systematic differences between early and late applicants. This approach will provide an unbiased estimate of the impacts if there are no systematic differences between firms that made applications for funding at different points in time. A review of firm size and other characteristics of firms awarded grants in each year highlights that there are no significant differences across rounds, as shown in Appendix A.

These approaches help address some of the problems outlined above, but leaves potential concerns that differences between treatment and comparison groups that may be driven by differences in their underlying characteristics rather than the grants themselves. The following section describes the analytical strategy employed to mitigate these concerns.

E4.3 Econometric model

The following econometric model was adopted to estimate the causal effects of the APC programme on the outcomes of interest:

$$Y_{it} = \alpha_i + \beta T_{it} + \gamma t + \delta X_{i,t} + \alpha^i + \alpha^t + \varepsilon_{it}$$

In this model, the performance firm i in period t (Y_{it}, representing the outcomes of interest identified in Table 1.2) is determined by its exposure to the APC funding (βT_{it})[62], and the parameter β gives an estimate of the effect of interest (representing the long-term effect of the grant on the outcome of interest). The model also allows for general trends affecting all firms in the sample (t) as well as firm characteristics including their size, the region in which they were located and whether they are foreign owned ($X_{i,t}$). As noted above, estimates of the impact of the programme have the potential to be biased by differences between treatment and comparison groups. The following approaches were taken to address this problem, exploiting the longitudinal nature of the data:

- **Fixed effects:** The model was augmented to allow for unobserved differences between firms that do not change with time (α^i). This captures the effect of any unchanging qualities of the firm that may have influenced both its success in the application process and its performance – this could represent the effectiveness of its commercial management team, the strength of its underlying intellectual property, or its business model (although results could still potentially be biased to the degree that these factors change over time).

- **Time-specific shocks:** The model also allows for any unobserved but time specific shocks affecting all firms in the sample (α^t). Examples of this might be changes in diesel prices in 2015, or the effects of the EU Referendum in 2016.

These models did not control for receipt of other public funding for R&D. This will not bias estimates of impact unless the receipt of other public funding was correlated with the receipt of APC funding (i.e. if applicants tended to receive APC funding at the same time they were awarded other grants). There is also an issue that the programme may also increase the ability of those awarded funding to secure additional grants from the public sector (e.g. by generating

4 [62] This variable takes the value of 0 in the years before a firm receives a grant, and the cumulative number of grants received in the following years. For firms forming the comparison group, this variable takes the value of 0 in all years.

additional lines on inquiry). These additional grants may also contribute to the outcomes of interest, and the models above will conflate these two effects. These issues could merit more detailed exploration in the final analysis (for example, by linking records of APC applicants to details of Innovate UK awards published through their transparency data).

E.4.3 Model specifications

The following model specifications implemented in the analysis:

- **Model 1:** This benchmark model applies a simple OLS model exploring the relationship between receipt of the grant and the outcomes of interest, with outcomes transformed into log values. The coefficients provide an estimate of the percentage effect of the grant on the outcomes of interest.

- **Model 2:** This model implements the specification in 1.6.2 which includes firm fixed effects (which account for unobserved differences between firms which do not change over time) and year fixed effects (which account for any unobserved time specific shocks).

- **Model 3:** These regressions repeat those in Model 2 but the analysis is restricted to include firms awarded funding and firms associated with declined applications that scored at least 60 in the independent assessment process.

- **Model 4:** This model restricts the specification in Model 2 to include only firms awarded funding (implementing the pipeline design described above).

- **Models 5-7:** These models repeat Model 2 (all applicants), Model 3 (restricting to comparison group firms scoring at least 60) and Model 3 (restricting to treatment firms only) but allows for differential effects across lead and collaborator, and SME and large applicants by restricting the samples to the relevant groups.

E.5 Effects on R&D activity

This subsection explores the extent to which grants resulted in an expansion of R&D activity amongst firms awarded grants.

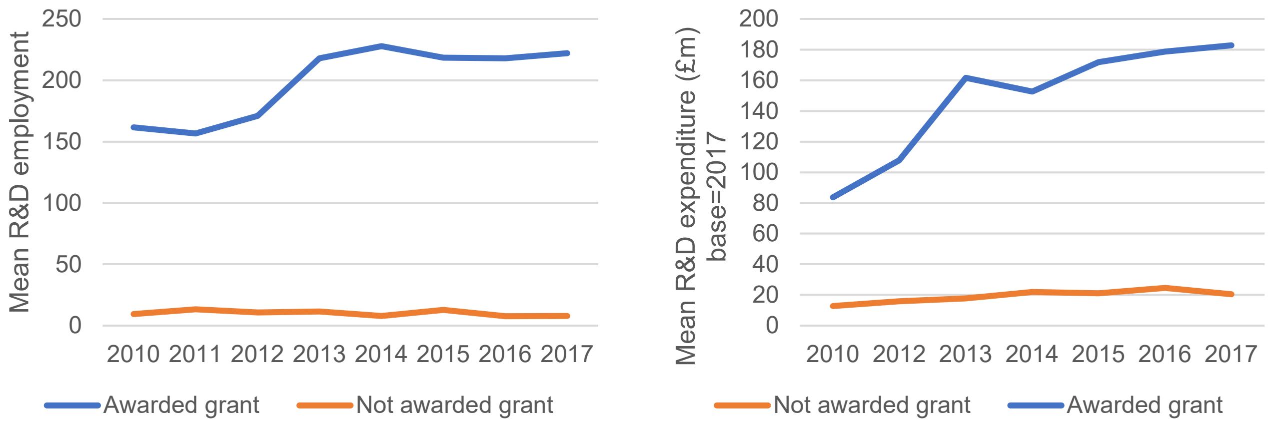
E.5.1 Key trends

Using the measures of R&D activity described above, figure 1.1 below shows that that firms that secured a grant saw their R&D employment and annual expenditure increase, while remaining stable amongst firms that did not secure a grant. Those that secured grants were also more R&D active than the comparator group, suggesting there may be systematic differences between the two groups:

- **R&D employment:** Firms securing APC grants saw R&D employment increase by 37 percent (from 160 to 220) between 2010 and 2017. R&D employment for firms that did not receive grants decreased from 9 to 8 on average over the same period.

- **Total R&D expenditure:** Total R&D expenditure rose consistently between 2010 and 2017 for firms that received APC grants (from £84m to £183m), in comparison to growth of £13m to £20m amongst unsuccessful applicants.

Figure E.1 Mean R&D employment and expenditure between 2010 and 2017



Source: Business Enterprise R&D Survey (2019). Ipsos MORI analysis.

E.5.2 Ongoing effects on R&D activity

At the overall level, the application of the modelling approach described above did not find that grants awarded through the APC had any causal effects on R&D employment or R&D expenditure (with significant results only coming through in relation to R&D spending in the least robust models that do not account for unobserved differences between firms).

Table E.3 Estimated effect of grants on R&D activity of all firms

	Model 1		Model 2		Model 3		Model 4	
Firms included	All		All		Applicants scoring >60		Firms awarded grants	
Model	OLS		Fixed Effects		Fixed Effects		Fixed Effects	
Dependent variable	Log transformed		Log transformed		Log transformed		Log transformed	
Year Fixed Effects	No		Yes		Yes		Yes	
Number of observations	444		444		430		396	
Outcome	**Coeff.**	**R2**	**Coeff.**	**R2**	**Coeff.**	**R2**	**Coeff.**	**R2**
R&D employment	0.253*	0.559	0.0793	0.053	0.0841	0.055	0.125	0.060

	Model 1		Model 2		Model 3		Model 4	
Total R&D expenditure	0.350**	0.639	0.0288	0.061	0.0541	0.060	0.0793	0.061

Source: Business Expenditure on R&D (2019), APC Competition Application Information, Ipsos MORI analysis. ***, **, and * indicate that the estimated coefficient was significant at the 99%, 95%, and 90% level of confidence respectively.

However, when the sample is broken down between leads and collaborators, the findings appeared indicated APC grants had `a positive effect on the R&D employment and spending of those firms leading the project (of 19.6 percent and 27.9 percent respectively). This result should be treated cautiously, as significant results only came through in those models that restricted comparisons to applicants awarded funding, and will need to be revisited at a later stage when it will be possible to gather more data and estimate effects with more precision.

No effects were observed amongst collaborators in any model. Collaborators were more likely to be SMEs in the supply chains of (or potential suppliers to) the large firms that tended to take the leading role. This could be an indicator that the firms concerned may have struggled (or were unwilling to) to scale up their R&D operations to accommodate additional activity, leading to crowding out of parallel activity. This pattern is also observed in other studies investigating the impacts of collaborative R&D grants (e.g. the evaluation of the Biomedical Catalyst)[63].

Table E.4 Estimated effect of grants on R&D activity by role

	Model 5		Model 6		Model 7	
Firms included	All		Applicants scoring >60		Firms awarded grants	
Model	Fixed Effects		Fixed Effects		Fixed Effects	
Dependent variable	Log transformed		Log transformed		Log transformed	
Year Fixed Effects	Yes		Yes		Yes	
Number of lead obs.	140		135		118	
Number collaborator obs.	354		344		298	
Outcome	**Coeff.**	**R2**	**Coeff.**	**R2**	**Coeff.**	**R2**

5 [63] Biomedical Catalyst Impact Evaluation (2019) Innovate UK

	Model 5		Model 6		Model 7	
Leads						
R&D employment	0.135	0.126	0.125	0.133	0.196**	0.145
R&D expenditure	0.140	0.135	0.164	0.165	0.279**	0.188
Collaborators						
R&D employment	-0.197	0.063	-0.209	0.071	-0.0695	0.071
R&D expenditure	-0.181	0.076	-0.184	0.078	-0.107	0.076

Source: Business Expenditure on R&D (2019), APC Competition Application Information, Ipsos MORI analysis. ***, **, and * indicate that the estimated coefficient was significant at the 99%, 95%, and 90% level of confidence respectively.

E.5.3 Temporary effects on R&D activity

Grants awarded through the APC are time limited, and may have temporary – rather than permanent – effects on R&D spending. To test this, the analysis was also completed using an alternative model specified as follows:

$$Y_{it} = \alpha_i + \beta T_{it} + \beta T_{it-1} + \beta T_{it-2} + \beta T_{it-3} + \gamma t + \delta X_{i,t} + \alpha^i + \alpha^t + \varepsilon_{it}$$

This model is identical to the one described above, except the treatment variable (T_{it}) is redefined to equal 1 in the year the grant was awarded and 0 otherwise. The co-efficient (β) now captures the effect of the grant in the year it was awarded, with lagged values included to capture effects up to three years later.

The results of these analyses were inconclusive. These findings appeared to show that the grants led to growing effects on R&D spending and employment that emerged one year after the award and stabilised after two years. However, the estimated effects were only weakly significant and were not sufficiently conclusive to draw definitive inferences regarding the persistence of the effects of the scheme. Again, it will be possible to investigate this in more detail at later stages once longer time series are available for analysis.

E.6 Wages and hours worked

The subsection explores the extent to which grants resulted in any changes in earnings of employees and their hours worked.

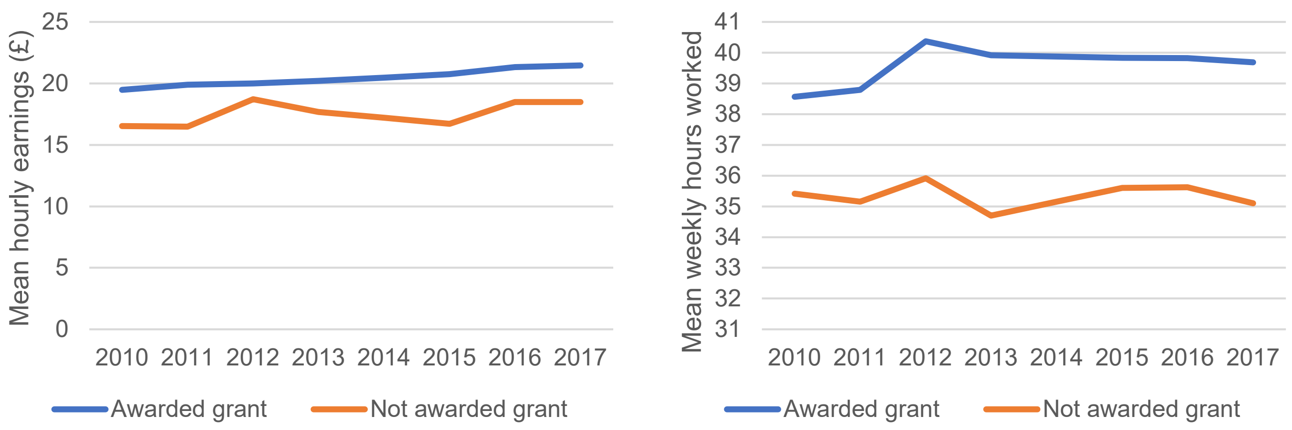
E.6.1 Key trends

The figure below shows provides an overview of trends in the hourly earnings and hours worked by workers employed by firms applying for APC grants:

- **Hourly earnings:** Workers employed by firms that secured a grant saw real hourly earnings increase by 16 percent between 2010 and 2017 (from £18.65 to £21.66) while the hourly earnings of firms that did not secure grant increased by 22 percent (from £15.65 to £19.06).

- **Weekly hours worked:** In terms of weekly hours worked, staff employed by grant funded firms increased their weekly working hours from 39 to 40 between 2010 and 2017, while staff at firms not awarded funding saw their hours worked remain stable at around 35 per week.

Figure E.2 Mean hourly earnings and hours worked, workers employed by APC applicants 2010 and 2017



Source: Annual Survey of Hours and Earnings (2019). Ipsos MORI analysis.

E.6.2 Permanent effects on wages and hours worked

The results of the analysis showed that APC grants had a positive effect on hourly earnings of 2.0 to 2.3 percent), though there were no significant effect on hours worked. This could be interpreted as a signal of productivity gains (as in competitive labour markets, a marginal increase in labour productivity should be reflected in a marginal increase in the wage). However, it may be that additional demand for workers has produced wage inflation (which is more difficult to interpret as a productivity effect).

Table E.5 Estimated effect of grants on wages and hours of workers - all firms

	Model 1		Model 2		Model 3		Model 4	
Firms included	All		All		Applicants scoring >60		Firms awarded grants	
Model	OLS		Fixed Effects		Fixed Effects		Fixed Effects	
Dependent variable	Log transformed		Log transformed		Log transformed		Log transformed	
Year Fixed Effects	No		Yes		Yes		Yes	
Number of observations								
Av. Hourly earnings	7334		7334		7122		6369	
Av. Total paid hours worked	7335		7335		7123		6369	
Av. Hourly earnings	7334		7334		7122		6369	
Outcome	**Coeff.**	**R2**	**Coeff.**	**R2**	**Coeff.**	**R2**	**Coeff.**	**R2**
Av. hourly earnings	0.0488 ***	0.507	0.0208 ***	0.253	0.0199 ***	0.271	0.0233 ***	0.203
Av. total paid hours worked	0.00226	0.464	0.00163	0.239	0.0008	0.229	0.00185	0.284

Source: Annual Survey Hours and Earnings (2019), APC Competition Application Information, Ipsos MORI analysis. ***, **, and * indicate that the estimated coefficient was significant at the 99%, 95%, and 90% level of confidence respectively.

There were variable effects across leads and collaborators. The impact of grants on the hourly earnings of workers lead firms was estimated at between 1.7 to 2.0 percent. while the effect on earnings amongst collaborators was negative in some models.

Estimated effect of grants on wages and hours by role

Table E.6 Estimated effect of grants on R&D activity by role

	Model 5		Model 6		Model 7	
Firms included	All		Applicants scoring >60		Firms awarded grants	
Model	Fixed Effects		Fixed Effects		Fixed Effects	
Dependent variable	Log transformed		Log transformed		Log transformed	
Year Fixed Effects	Yes		Yes		Yes	
Number of observations						
Av. Hourly earnings	7334		7122		6369	
Av. Total paid hours worked	7335		7123		6369	
Outcome	**Coeff.**	**R2**	**Coeff.**	**R2**	**Coeff.**	**R2**
Leads						
Av. Hourly earnings	0.0182***	0.095	0.0167***	0.275	0.0196***	0.286
Av. Total paid hours worked	0.0202	0.239	0.00128	0.229	0.00222	0.203
Collaborators						
Av. Hourly earnings	-0.0142*	0.095	-0.0202***	0.275	-0.00988	0.286
Av. Total paid hours worked	0.00668	0.239	0.00731	0.229	0.00519	0.203

Source: Annual Survey Hours and Earnings (2019), APC Competition Application Information, Ipsos MORI analysis. ***, **, and * indicate that the estimated coefficient was significant at the 99%, 95%, and 90% level of confidence respectively.

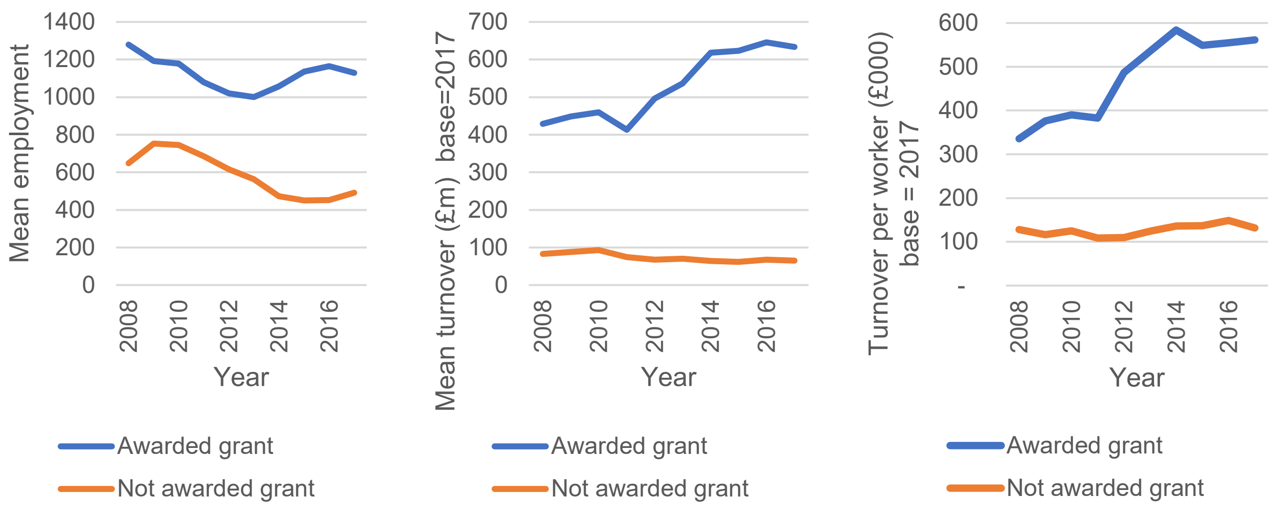
E.7 Impacts on business performance

The subsection explores to how far APC grants led to increases in the growth and efficiency if firms awarded funding.

E.7.1 Key trends

The following figure shows that those firms that were awarded grants grew and became more efficient from 2011 onwards, in marked contrast to those that were not awarded grants. The figure also show that firms awarded grants differ in systematic ways to applicants that did not receive funding although these figures may be being distorted by outliers.

Figure E.3 Employment, turnover and turnover per worker between 2008 and 2017



Source: Business Structure Database (2019). Ipsos MORI analysis.

E.7.2 Effects on employment, turnover, and turnover per worker using the Business Structure Database

The econometric analysis indicated that at the overall level, each grant awarded through the APC had a statistically significant effect on the number of workers employed by recipient firms (in more robust specifications) of between 4.7 and 5.9 percent. However, there were no statistically significant effects on turnover or turnover per worker.

Table E.7 Estimated effect of grants on business performance of all firms

	Model 1		Model 2		Model 3		Model 4	
Firms included	All		All		Applicants scoring >60		Firms awarded grants	
Model	OLS		Fixed Effects		Fixed Effects		Fixed Effects	
Dependent variable	Log transformed		Log transformed		Log transformed		Log transformed	
Year Fixed Effects	No		Yes		Yes		Yes	
Number of observations	1262		1262		1236		936	
Outcome	Coeff.	R2	Coeff.	R2	Coeff.	R2	R2	Coeff.
Employment	0.0553	0.900	0.0477 **	0.638	0.0477 **	0.638	0.900	0.0362
Turnover	0.0766	0.770	0.0154	0.272	0.0154	0.272	0.770	0.00235
Turnover per worker	-0.0874	0.098	-0.0959	0.098	-0.202**	0.143	-0.0874	0.098

Source: Business Structure Database (2019). APC Competition Application Information, Ipsos MORI analysis. ***, **, and * indicate that the estimated coefficient was significant at the 99%, 95%, and 90% level of confidence respectively.

There were differential effects across leads and collaborators:

- **Lead applicants:** Grants awarded through the APC appeared to have large effects on the employment of lead partners of 10 to 16 percent. Additionally, the pipeline model (which is robust to time varying unobserved differences between successful and unsuccessful applicants), also showed that the grants had a significant effect on turnover[64] (of 30 percent), and an effect in raising turnover per worker by 13.8 percent that was weakly significant (i.e. at the 90 percent level of confidence).

6 [64] It should be noted that the income received from the APC grants will typically be accounted for in turnover figures, so this may partly capture the direct financial benefit of the award.

Table E.8 Estimated effect of grants on business performance by role

	Model 5		Model 6		Model 7	
Firms included	All		Applicants scoring >60		Firms awarded grants	
Model	Fixed Effects		Fixed Effects		Fixed Effects	
Dependent variable	Log transformed		Log transformed		Log transformed	
Year Fixed Effects	Yes		Yes		Yes	
Number of lead obs.	279		274		182	
Number collaborator obs.	1054		1032		732	
Outcome	**Coeff.**	**R2**	**Coeff.**	**R2**	**Coeff.**	**R2**
Leads						
Employment	0.0987***	0.682	0.117***	0.686	0.159***	0.627
Turnover	0.112	0.267	0.136	0.252	0.297***	0.360
Turnover per worker	0.0137	0.104	0.0190	0.095	0.138*	0.205
Collaborators						
Employment	-0.0407	0.637	-0.0324	0.635	-0.0103	0.678
Turnover	-0.128**	0.333	-0.128**	0.326	-0.212**	0.344
Turnover per worker	-0.0874	0.098	-0.0959	0.098	-0.202**	0.143

Source: Business Structure Database (2019). APC Competition Application Information, Ipsos MORI analysis. ***, **, and * indicate that the estimated coefficient was significant at the 99%, 95%, and 90% level of confidence respectively.

- **Collaborators:** By contrast, the analysis appeared to indicate that the grants appeared to have no impact on employment and a negative impact on the turnover of collaborators (of between 13 and 21 percent) with reductions in turnover per worker of 20 percent in the most robust models. This would be consistent with a pattern in which the grants awarded by APC encourage 'in-housing' of more advanced or higher value activities by lead applicants, leading to displacement of some of these activities from the collaborating parties (who were often suppliers to OEMs). This is also consistent with the findings presented above on the effect of the programme on wages.

E.7.3 Permanent effects on business performance using the Annual Business Survey

The Annual Business Survey (ABS) was used to provide direct estimates of the impact of the programme on output (GVA), productivity (GVA per worker), and net capital investment – and provide validation of the findings set out above using data gathered from the BSD. The ABS is a mandatory census of large firms and a sample survey of SME, and does not involve the same issues of 'lags' in the observations associated with the BSD. However, as it does not provide as comprehensive coverage of the firms of interest, there were fewer observations available for these analyses and the effects less precisely estimated.

Table E.9 below provides the overall results of findings from these analyses:

- **Employment, turnover and GVA:** At the overall level, the APC was estimated to have led to an expansion in the employment, turnover and GVA of firms receiving grants (of 10, 15 and 18 percent respectively in the robust models). These effects were larger than estimated using the BSD, though were broadly consistent with those estimated for lead applicants. This may reflect the relatively greater coverage of larger firms in the ABS (which tended to take the leading roles). However, significant effects did not appear in every specification of the model and there is a degree of uncertainty regarding the magnitude of any effects.

- **Productivity:** The estimated effect of the programme on GVA (11 to 17 percent) was larger than its estimated effect on employment (9 to 10 percent). These findings would be consistent with an increase in productivity of 3 to 8 percent. However, the estimated effect of the programme on GVA per worker was not statistically significant. Given the findings elsewhere on wages and turnover per worker, it is thought likely that the analyses did not have sufficient power to detect the effects of the programme on GVA per worker.

- **Net capital investment:** The results also appeared to indicate that the programme had relatively large impacts on capital investment (of 33 to 43 percent). This would again be consistent with a view that the programme has encouraged in-housing of activity that would have otherwise been externalised (assuming this effect is again contained to lead applicants).

Table E.9 Estimated Effect of Grants on Business Performance of All Firms – ABS

	Model 1		Model 2		Model 3		Model 4	
Firms included	All		All		Applicants scoring >60		Firms awarded grants	
Model	OLS		Fixed Effects		Fixed Effects		Fixed Effects	
Dependent variable	Log transformed		Log transformed		Log transformed		Log transformed	
Year Fixed Effects	No		Yes		Yes		Yes	
Number of observations	482		482		468		401	
Outcome	Coeff.	R2	Coeff.	R2	Outcome	Coeff.	R2	Coeff.
Employment	0.111	0.750	0.0892***	0.393	0.101***	0.400	0.0952***	0.304
Turnover	0.136	0.663	0.0868	0.149	0.102*	0.145	0.155***	0.184
Turnover per worker	0.0248	0.225	-0.00242	0.141	0.000648	0.141	0.0595	0.241
GVA	0.249**	0.641	0.114*	0.289	0.153**	0.290	0.173***	0.269
GVA per worker	0.0912	0.179	0.0280	0.278	0.0562	0.278	0.0819	0.317
Net capital expenditure	0.464***	0.529	0.382***	0.102	0.433***	0.105	0.333***	0.121

Source: Annual Business Survey (2019), APC Competition Application Information, Ipsos MORI analysis. ***, **, and * indicate that the estimated coefficient was significant at the 99%, 95%, and 90% level of confidence respectively.

The table below separates the effect of the programme by lead applicants and collaborating parties. The findings are broadly consistent with those set out elsewhere, although the estimated effects of the programme on the GVA and capital investment of lead applicants were only weakly significant (and no effects were observed amongst collaborators).

Table E.10 Estimated effect of grants on business performance by role – ABS

	Model 5		Model 6		Model 7	
Firms included	All		Applicants scoring >60		Firms awarded grants	
Model	Fixed Effects		Fixed Effects		Fixed Effects	
Dependent variable	Log transformed		Log transformed		Log transformed	
Year Fixed Effects	Yes		Yes		Yes	
Number of lead obs.	279		274		182	
Number collaborator obs.	1054		1032		732	
Outcome	**Coeff.**	**R2**	**Coeff.**	**R2**	**Coeff.**	**R2**
Leads						
Employment	0.0968**	0.551	0.114***	0.554	0.122***	0.378
Turnover	0.0597	0.187	0.0718	0.179	0.244**	0.219
Turnover per worker	-0.0371	0.104	-0.0423	0.106	0.122	0.156
GVA	0.139	0.481	0.173	0.472	0.209*	0.392
GVA per worker	0.0214	0.332	0.0362	0.317	0.0450	0.313
Net capital expenditure	0.312	0.183	0.360*	0.554	0.256	0.178

	Model 5		Model 6		Model 7	
Collaborators						
Employment	0.0178	0.277	0.0168	0.285	0.0470	0.269
Turnover	-0.0190	0.223	-0.0233	0.214	0.0518	0.165
Turnover per worker	-0.0368	0.305	-0.0400	0.301	0.00479	0.304
GVA	-0.0726	0.265	-0.0516	0.265	0.0593	0.251
GVA per worker	-0.0796	0.318	-0.0555	0.319	0.0123	0.358
Net capital expenditure	0.0963	0.082	0.108	0.077	0.0266	0.093

Source: Annual Business Survey (2019), APC Competition Application Information, Ipsos MORI analysis. ***, **, and * indicate that the estimated coefficient was significant at the 99%, 95%, and 90% level of confidence respectively.

E.8 Indirect effects

As an extension to the above direct analyses, consideration was also given to the extent to which an APC grant resulted in greater levels of economic activity within the local area.

E.8.1 Key hypothesis

These effects are expected to occur through:

- **Knowledge spill-overs:** The case for public intervention is partly underpinned by the likelihood that firms will only be able to partly capture the benefits of their investments in R&D. A range of processes, such as learning by imitation and circulation of workers in the labour market will have enabled other firms to ‘free-ride’ on the investments in R&D made by beneficiary firms, potentially resulting in productivity gains and growth beyond the pool of firms receiving funding. These effects can be expected to be mediated by proximity, with past studies showing that knowledge spill-overs tend to be more prevalent at the local level as the costs associated with collaboration and knowledge exchange tend to fall with distance. As such, these types of spill-over effects will have been expected to be more prevalent amongst neighbouring firms than over larger distances.

- **Agglomeration effects:** Firms may be attracted to areas surrounding successful applicants should they seek to benefit from potential knowledge spill overs or to benefit from other efficiencies such as locating near to a growing customer. There may, however, also be a possibility that this could force rents in the area up and push less productive firms out. Whilst this would represent a positive effect for the local area, it would have no net effect at the national level.

E.8.2 Data

The analysis was prepared using a variety of administrative datasets that provided (or were aggregated to provide) annual measures of employment, unemployment and productivity at a small area level - Census Output Areas (representing 10 to 12 postcodes – of which there are 234,735 in the UK). This dataset was linked to records of the locations associated with the leads and collaborators applying for APC funding.

E.8.3 Approach

A non-parametric[65] approach to modelling these effects was adopted, following the general methodology developed in Gibbons (2018)[66]. In this model, the economic performance of each Output Area in the UK is determined by four separate 'treatment effects' as follows:

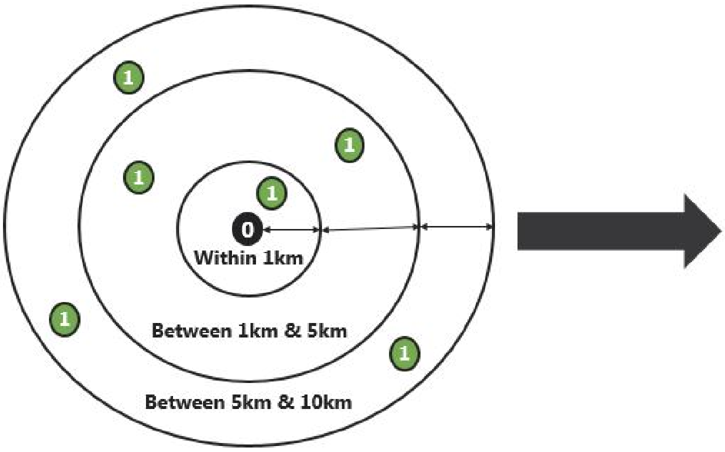
- The cumulative number of grants awarded to firms located within its boundaries;
- The cumulative number of grants awarded to firms located in other Output Areas within 1km
- The cumulative number of grants awarded to firms located in Output Areas located 1km to 5km away; and,
- The cumulative number of grants awarded to firms located in Output Areas located 5km to 10km away

These bands were selected arbitrarily, and effects beyond 10km were not explored owing to the intensive nature of computations required to generate the calculate the distance between Output Area pairs. The approach is illustrated in the hypothetical example in Figure 1.1 This shows a hypothetical Output Area which is not 'treated' by any grants awarded to firms located within its boundaries, but is treated by one grant to firms based within 1km, two grants to firms located within 1km and 5km, and three grants to firms located between 5km and 10km.

Figure E.4 Illustration of data processing of Innovate UK grant award records

7 [65] I.e. an approach that does not impose a specific relationship between distance and

8 [66] Gibbons (2018) The Local Economic Impact of Regeneration Projects: Evidence from UK's Single Regeneration Budget, Spatial Economics Research Centre Discussion Paper 218.



	Number
Awards in OA	0
Awards within 1km of OA	1
Awards within 1km and 10km of OA	2
Awards between 5km and 10km of OA	3

E.8.4 Counterfactual

To assess the impact of grant funding in a credible way, a comparison group is necessary to estimate what would have happened in the absence of funding. As grants were allocated on a non-random basis, there are likely to be systematic differences between those firms awarded grants and any group of firms that were not awarded grants. These differences are also likely to extend to the wider areas in which firms are located. For example, firms located in more diversified and dense regional innovation systems may have relative greater access to resources (e.g. externally produced knowledge or skilled labour) that are both likely to determine the success of their application and the longer term economic growth of the area. In line with the econometric approaches adopted elsewhere in this evaluation, two comparator areas were used to identify the spatial impacts of the grants:

- **Output areas within 10km of unsuccessful applicants:** The first approach involved restricting the analysis to Output Areas that were located within 10km of a firm applying for an APC grant. This mitigates against possible issues of bias arising from differences in the local economic characteristics that do and do not contain firms that have applied for funding. In this specification, impacts are identified from comparisons between areas housing successful and unsuccessful applicants for funding, and variability in the timing of grants awarded. However, there may still be systematic differences between the areas near to unsuccessful applicants and those near to successful applicants, particularly if clusters containing more productive firms are more likely to receive awards than less productive clusters.

- **Pipeline design:** Further robustness checks made use of a second approach limiting the sample to just those areas within 10km of successful applicants for funding (replicating the pipeline design set out elsewhere). This approach is likely to produce the most robust evidence of impact and exploits the fact that some areas received awards earlier than others and that these areas should share more similar characteristics.

E.8.5 Econometric set-up

The following model specification was established to estimate the causal effects of APC grant awards on the outcomes of interest

$$Y_{it} = \alpha_i + \gamma_t + \beta_1 T_{it} + \beta_2 T_{1km_{it}} + \beta_3 T_{1to5km_{it}} + \beta_4 T_{5to10km_{it}} + \delta_1 X_{it} + \varepsilon_{it}$$

In the model above, the outcome for area i in period t (Y_{it}) is determined by the cumulative number of APC awards in the output area (T_{it}), within 1km of the output area ($T_{1km_{it}}$), 1 to 5km away from the output area ($T_{1to5km_{it}}$) and 5 to 10km away ($T_{5to10km_{it}}$). The coefficients β_1, β_2, β_3 and β_4 give the estimate of the effects of interest across these bands (representing the long-term effect of the grant on the outcome). The vector X_{it} includes a set of control variables at the local authority level.

Finally, to mitigate potential bias, the following adaptations were applied, exploiting the longitudinal nature of the data:

- **Fixed effects:** The model was augmented to allow for unobserved differences between output areas that do not change with time (α_i). This captures the effect of any unchanging qualities of the output area that may have influenced both the number of awards in the area and its performance – this could represent the degree of clustering or inherent commercial strength of the business located there (although results could still potentially be biased to the degree that these factors change over time).

- **Time-specific shocks:** The model also allows for any unobserved but time specific shocks affecting all areas in the sample (γ_t).

E.8.6 Results

The results of the analysis are set out in table E.11:

- **Clustering:** The results show that the grant awards had a positive effect on the number of firms located in areas in proximate to those awarded grants. These effects were largest in the output area[67] in which the firms receiving grants were located (11 percent) but were positive though smaller at greater distances. This indicates that APC grants have worked to produce clustering effects at the local level, with no evidence of net displacement effects within 10km.

- **Local economic performance:** The evidence indicated that APC grants had a positive net economic impact on local economic growth and productivity. The impacts included:
    - The models indicated that each grant led to a 17 to 18 percent increase in the number of jobs in the OA in which the applicant was located, and a 22 to 24 percent increase in the turnover of firms based in the area. The turnover per worker of firms (used a proxy measure of productivity) in the area also rose by an average of 5.5 to 5.8 percent in response to the grants awarded. These impacts are broadly comparable to those observed amongst those applying for funding, suggesting that any displacement or crowding out effects at the very local level were negligible.
    - There were also positive economic impacts at distances of 1km to 10km from those awarded funding. The econometric models indicated that each APC award led to an increase in the number of jobs in these OAs by 0.3 to 1.5 percent and

9 [67] A small geographical area defined by the Office for National Statistics for the purposes of reporting Census statistics, consisting of around 10-12 postcodes.

the turnover of firms located in these OAs by 0.4 to 1.7 percent. The turnover per worker of firms located in these areas rose by 0.1 to 0.5 percent. Larger effects were observed at distances of 5km to 10km than between 1km and 5km, and there was no evidence of net displacement or crowding-out effects locally.

These findings indicate that the APC has produced positive spill-over effects for local economies. Given the evidence on firm relocations, it is assumed that these effects have arisen largely from the attraction of higher value activities to the area. It should be noted that there will likely be corresponding negative effects on the local economies from which those activities were relocated.

Table E.11 Estimated indirect effect of APC grant awards

	Comparisons between Output Areas within 10km of successful and unsuccessful applicants				
Outcome	In OA	Within 1km	1km to 5km	5km to 10km	No. of observations
Number of firms (%)	0.114***	0.00687**	0.00411***	0.0137***	478,410
Employment (%)	0.178***	0.00781	0.00479***	0.0149***	478,410
Turnover (%)	0.235***	0.0144**	0.00623***	0.0202***	478,410
Turnover per worker (%)	0.0576**	0.00661**	0.00145**	0.00529***	478,410

	Comparisons restricted to Output Areas within 10km of successful applicants only				
Outcome	In OA	Within 1km	1km to 5km	5km to 10km	No. of observations
Number of firms (%)	0.108***	0.00417	0.00292***	0.0114***	336,233
Employment (%)	0.167***	0.00339	0.00332***	0.0122***	336,233
Turnover (%)	0.222***	0.00908	0.00436***	0.0166***	336,233
Turnover per worker (%)	0.0545**	0.00570*	0.00104*	0.00440***	336,233

Source: Ipsos MORI analysis. ***, **, and * indicate that the estimated coefficient was significant at the 99%, 95%, and 90% level of confidence respectively. All models were estimated with fixed effects and unobserved time specific shocks.

E.9 Estimates of total impact

The findings above provide estimates of the average effects of with the grants awarded through the APC. This section outlines estimates of the overall impacts of the programme. This is achieved by applying estimates of the average effect (e.g. the percentage impact on employment) to population averages prior to the launch of the programme (e.g. average employment of firms receiving APC grants). This involves some challenges due to the following factors:

- The firms involved are highly diverse in terms of their size and R&D intensity. Key averages are highly skewed by the presence of very large firms that account for meaningful shares of automotive sector R&D and output.

- There are differential effects across subgroups and owing to sample size restrictions, it was not possible to fully unpack these effects across the role of the firm in the project and across different size bands. As such, grossing up the estimated average treatment effects to the population based on average measures of size may produce biased results (for example, if the effects on the largest firms are materially smaller or larger than those on smaller firms).

- The BERD and ABS surveys comprise a census of larger firms and random samples of smaller firms. Average measures of R&D spending and employment, capital investment, and GVA are skewed towards larger firms – and applying estimates of the average effect of the grant to these measures of central tendency will produce an overstatement of the overall impact.

- These issues introduce some uncertainties regarding the optimal approach to aggregating the findings to the population of firms awarded grants. This following sections highlight some of these issues, and some assumptions and judgement have been required in reaching a preferred result.

E.9.1 R&D expenditure

The pipeline models described above indicated that each APC grant produced a permanent increase in overall R&D spending of 27.9 percent amongst lead applicants only. The average R&D spending of lead applicants in 2013 as reported in the BERD survey was £51m (based on a trimmed mean excluding the 20 percent smallest and largest observations), implying an average effect on annual R&D spending of £14.3m. When this is grossed up to the 38 lead applicants awarded grants through the programme (as illustrated in Table 1.12), this produces an estimated total additional R&D spending attributable to the APC of £1.5bn. Allowing for public sector spending of £193.6m, this gives a leverage ratio of £6.76 of private investment in R&D per £1 of public sector spending[68].

This result is possibly unrealistically high. Ipsos MORI is not aware of any prior study that has demonstrated that grants for R&D have resulted in such large leverage effects. As noted, the BERD survey is made up of a census of known R&D performers and a random sample of other firms. As such, this average will be biased upwards by the presence of large firms with significant annual R&D spending, including Nissan and Ford (both spending more than £400m on R&D) and JLR (with annual R&D spending exceeding £1bn)[69]. Alternative estimates were developed by:

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10 [68] I.e. (£1502 - £194) / £194.

11 [69] These values are based on public account filings.

- Taking the average annual R&D spending of large firms and SMEs awarded APC grants (£12.2m and £0.4m respectively), and weighting these values by the share of large firms and SMEs leading APC projects (76 and 24 percent respectively).

- This gives a lower estimate of the average pre-programme annual R&D spending of lead applicants of £9.4m, and an estimated average (on-going) impact on annual R&D spending of £2.6m per annum and a 95 percent confidence interval of £0.6m to £4.6m.

- Grossing these estimates up to the population of firms awarded grants produces a more plausible estimate of the overall impact of the programme on R&D spending of £273m by the end of 2018 (a 95 percent confidence interval of £64m to £482m).

This more conservative result gives a central leverage ratio of additional private R&D spending per £1 of public sector expenditure of £0.41[70] (a 95 percent of confidence interval of -£0.67 and £1.49), which is more consistent with other evidence on the effectiveness of financial incentives for R&D activity. The central result would imply that around 68 percent of the gross costs incurred by applicants by 2018 in the delivery of projects (an estimated £404m) would not have been incurred in the absence of the programme. However, the high margin of error associated with these results means that it is not possible to rule out either much higher leverage ratios or the possibility that the programme crowded out private R&D spending[71].

Table E.12 Estimated impact of APC grants on R&D spending to 2018

	Average effect (£m)	2014	2015	2016	2017	2018	Total
Cumulative number of leads awarded grants	-	5	10	20	32	38	
Upper bound estimate (£m)	14.3	71.6	143.1	286.3	458.0	543.9	1,502.8
Lower bound estimate (£m)	2.6	13.0	26.0	52.0	83.3	98.9	273.3

Source: Ipsos MORI analysis

12 [70] I.e. (£273.3m - £193.6m) / £193.6m.

13 [71] Based on this grossing up approach, there was a 73 percent likelihood that the programmes effects on overall R&D spending exceeded public expenditure on the programme.

E.9.2 Capital investment

The findings suggested that the programme also led to a permanent effect on net capital investment of 33 to 43 percent per annum, which was observed across all applicants for funding (though clear signals did not appear when the sample was broken down by leads and partners). Analysis of the ABS suggested that the average net capital spending of firms supported by the APC in 2013 was £3.7m. However, this average is biased towards large firms, and was adjusted downwards based on the ratio of employment across all firms awarded grants (68 employees, based on the BSD) and those appearing in the ABS (512 employees). This gave an adjusted estimate of net capital investment spending of £504,000. Applying this to the estimated effects of the programme gives an estimated average impact on annual net capital investment spending of £168,000 to £218,000.

A similar procedure to that outlined above was used to estimate the total impact of the APC on capital investment spending by 2018 – with the difference that the average effects were applied to all firms awarded grants rather than just the lead applicants. The findings gave an estimated range for the total impact on net capital investment spending of £75.4m to £98.0m by 2018. There is a 95 percent confidence interval associated with this range of £22.4m to £160.8m.

Table E.13 Estimated impact of APC grants on net capital investment spending to 2018

	Average effect (£m)	2014	2015	2016	2017	2018	Total
Cumulative number of grants awarded	-	26	46	86	135	156	
Upper bound estimate (£m)	0.2	5.7	10.0	18.8	29.5	34.1	98.0
Lower bound estimate (£m)	0.2	4.4	7.7	14.4	22.7	26.2	75.4

E.9.3 GVA impacts

The findings of the analysis suggested that the programme had an on-going effect of raising the overall output (GVA) of firms awarded grants by 15.3 to 17.3 percent. Based on an analysis of the ABS, firms awarded grants produced an average of £35.8m in GVA in 2013. However, this figure will be biased upwards due to the relative coverage of large firms and SMEs in the ABS. This average was again adjusted downwards using the ratio of average employment across all firms awarded grants to the average employment of firms appearing in the ABS. This gave an adjusted estimate of the average GVA of firms awarded grants of £4.7m, and a range for the average impact on GVA per grant awarded of £732,000 to £828,000.

Grossing these results on the same basis as capital investment impacts gave a range for the total cumulative impact on GVA (not allowing for displacement and crowding out) of £329m to £373m. Allowing for statistical uncertainty (based on the 95 percent confidence intervals associated with the estimated impacts) widens this range from £98m to £610m.

Table E.14 Estimated impact of APC grants on GVA to 2018

	Average effect (£m)	2014	2015	2016	2017	2018	Total
Cumulative number of grants awarded	-	26	46	86	135	156	
Upper bound estimate (£m)	0.8	21.5	38.1	71.2	111.8	129.2	372.0
Lower bound estimate (£m)	0.7	19.0	33.7	63.0	98.9	114.3	329.0

Source: Ipsos MORI analysis

E.9.4 GVA impacts from productivity gains

The econometric analysis explored the impact of the programme on a range of indicators of productivity – including the wages of the workers employed by those receiving grants, turnover per worker (which approximates changes in productivity provided firms relative consumption of goods and services is not altered by the programme), and GVA per worker (though sample sizes for these analyses were small). There were a range of signals that the programme led to improvements in productivity, though there was uncertainty regarding the magnitude of those effects:

- **Wage effects:** The most robust results were visible in the impact of the programme on the hourly earnings of workers employed by lead applicants, which were estimated to have risen by 2.0 to 2.3 percent per grant awarded. This could suggest an improvement in productivity levels, though it is also possible that this may reflect a ‘grant-sharing’ effect (i.e. the firm rewards its employees for securing a grant) or that the programme pushed up equilibrium wage levels. There were also differences across leads and collaborators – while each grant was estimated to have increased to the hourly earnings of workers employed by lead applicants (by 1.7 to 2.0), some models suggested that the impact of the programme had negative effects on the hourly earnings of collaborators.

- **Turnover per worker:** The econometric analysis did not provide substantial evidence that the programme led to increases in turnover per worker. Positive effects on turnover per worker of 14 percent came through only in those analyses focused on lead applicants and the estimate was only statistically significant at the 90 percent level.

Again, there were suggestions that the programme had a negative effect on the productivity of collaborators in some models, with an estimated reduction in turnover per worker of 20 percent

- **GVA per worker:** Finally, the estimated effects of the programme on employment above were consistently smaller than the estimated effects on GVA. The findings implied an effect on GVA per worker of 3 to 8 percent – though, the models did not find a statistically significant effect on GVA per worker when observed directly.

E.9.5 Wage based estimates

As the wage effects of the programme were estimated most robustly, the primary measure of the GVA impacts of the programme arising from productivity gains were estimated on this basis. Estimates of the average annual impact per grant on wages were estimated by applying the estimated impact on hourly earnings to the average number of hours worked per week (40) and average hourly earnings (£18.65). This was applied to the average number of workers employed by the firm in 2013 – as while the firms may have expanded over this period due to the programme, there is a risk that this expansion was achieved either by claiming market share from competitors (displacement), or by crowding-out other firms by placing pressure on equilibrium wages. These estimates also allowed for differential effects across leads and collaborators.

Table E.15 Estimated average annual impact of APC grants on wages

	Average employment in 2013	Average number of hours worked per week	Average hourly earnings in 2013 (£)	Average effects on wages per APC grant (%)	Total effect on wages per grant per annum (£m)
Leads					
Upper bound estimate	736	40	18.65	2.0	0.57
Lower bound estimate	736	40	18.65	1.7	0.49
Collaborators					
Upper bound estimate	56	40	18.65	0	0.00
Lower bound estimate	56	40	18.65	-0.02	-0.04

Source: Ipsos MORI analysis

These estimates were used to provide wage based estimates of the overall impact of the APC on GVA via productivity gains as illustrated in the table below. The overall impact of the programme on earnings was estimated at £36m to £60m.

Table E.16 Wage based estimates of the impact of APC grants on GVA via productivity gains to 2018

	Average effect (£m)	2014	2015	2016	2017	2018	Total
Leads							
Cumulative number of leads awarded grants	-	5	10	20	32	38	
Upper bound estimate (£m)	0.5	2.9	5.7	11.4	18.3	21.7	60.0
Lower bound estimate (£m)	0.6	2.4	4.9	9.7	15.5	18.5	51.0
Collaborators							
Cumulative number of collaborators awarded grants		21	36	66	103	118	
Upper bound estimate (£m)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lower bound estimate (£m)	-0.0	-0.9	-1.6	-2.8	-4.4	-5.1	-14.8
Net effects							

	Average effect (£m)	2014	2015	2016	2017	2018	Total
Upper bound estimate (£m)		1.5	3.3	6.9	11.1	13.4	36.2
Lower bound estimate (£m)		2.9	5.7	11.4	18.3	21.7	60.0

Source: Ipsos MORI analysis

E.9.6 GVA per worker based estimates

Estimates of the total productivity gains associated with the programme were also generated with estimates of the effect of the programme on GVA per worker implied by differences in its effects on employment and GVA. Estimates of the average annual impact of the grants on GVA via increases in GVA per worker were developed in the same way as for wages, as illustrated in the table below.

Estimated annual impact of APC grants on GVA via increases in GVA per worker

Table E.17 Estimated average annual impact of APC grants on GVA via GVA per worker

	Average employment in 2013	GVA per worker in 2013 (2018 prices)	Average effects on GVA per worker per APC grant (%)	Total effect on GVA per grant per annum (£m)
Leads	68	109.8	8.2	0.61
Upper bound estimate	68	109.8	2.8	0.21

Source: Ipsos MORI analysis

Estimates of the total impact of the APC on GVA via increases in GVA per worker are set out in the table below. The findings gave an overall range for the impact of the programme on GVA of £70m to £275m.

Table E.18 GVA per worker based estimates of the impact of APC grants on GVA via productivity gains to 2018

	Average effect (£m)	2014	2015	2016	2017	2018	Total
Cumulative number of grants awarded	-	26	46	86	135	156	
Lower bound estimate (£m)	0.2	15.9	28.1	52.6	82.6	95.4	274.6
Upper bound estimate (£m)	0.6	4.0	7.1	13.4	21.1	24.5	70.2

Source: Ipsos MORI analysis

E.9.7 Job impacts

Finally, the results also enabled an assessment of the net effect of the APC on the number of R&D and total workers employed by the firms awarded grants. These effects were estimated by applying the estimated percentage effect of the grants to average employment in 2013 and scaled-up by the number of grants awarded, as illustrated in the following table (note that the estimated employment effects were confined to lead applicants).

Table E.19 Estimated impact of APC on R&D and overall employment

	Average employment in 2013	Average number of hours worked per week	Average hourly earnings in 2013 (£)	Average effects on wages per APC grant (%)	Total effect on wages per grant per annum (£m)
Leads					
Upper bound estimate	185[72]	19.6	36	38	1,377
Lower bound estimate	56[73]	19.6	11	38	421
Collaborators					
Upper bound estimate	736	15.9	117	38	4,449
Lower bound estimate	736	9.9	73	38	2,762

Source: Ipsos MORI analysis

[72] Median R&D employment amongst lead applicants.

[73] Weighted average across large and small firms.

Appendix F: QCA

This Annex sets out the approach and results of the Qualitative Comparative Analysis undertaken to determine under which conditions the funding awarded through the APC had a causal role in producing technical or commercial success and how project characteristics affected these results. The analysis uses APC project monitoring records and qualitative evidence from case studies with firms receiving grants from the APC funding competitions.

Methods

Qualitative Comparative Analysis (QCA) bridges qualitative and quantitative analysis. It provides a systematic approach for establishing causality using qualitative case study data where there is variability between cases and complex causation or equifinality, i.e. there is more than one way in which an outcome can happen[74]. These represent different causal pathways or different configurations of causal conditions that are capable of generating the same outcome. As such, QCA involves identifying conditions within and across cases to examine cross-case patterns and examines configurations of multiple causal conditions, not just single causes.

"QCA's examination of cross-case patterns respects the diversity of cases and their heterogeneity with regard to their different causally relevant conditions and contexts by comparing cases as configurations."[75]

The following steps were undertaken to conduct the QCA:

Step 1: Identify outcomes of interest

The logic model depicted in Figure 2.1 in the main evaluation report shows multiple outcomes that were anticipated to occur as a result of receiving APC funding. The QCA prioritised an examination of the presence/absence of two key outcomes:

technical success (e.g. TRL and MRL change, achievement of technical milestones) and

commercial success (exploitation and commercialisation of technology, typically through integration).

Step 2: Case study selection

Table 4.1 in the Evaluation Plan provided project details for 23 selected case studies. This included:

- 7 'light touch' case studies with projects receiving APC funding and included in the previous process evaluation[76];

16 [74] Equifinal can mean: 1. Different conditions can produce the same outcome and 2. The same conditions can produce different outcomes.

17 [75] http://eprints.ncrm.ac.uk/250/1/What_is_QCA.pdf

18 [76] https://www.gov.uk/government/publications/advanced-propulsion-centre-external-process-evaluation

- 9 'successful' case studies with projects receiving APC funding and not previously engaged; and
- 7 'unsuccessful' case studies with projects who were not successful in the application to receive APC funding.

It was noted during the delivery of the case studies that two unsuccessful projects were modified and then resubmitted to later APC competition rounds, becoming successful applications for funding. For example, SOHmatiX was unsuccessful in APC3 but the project was modified and successfully received funding in APC4 under the UK-ABSC project. As such, these two unsuccessful projects were excluded from the final QCA.

Step 3: Identify conditions for analysis

QCA is an iterative, theory-driven approach, so conditions being examined should reflect a prior theory about what matters. A condition may reflect any aspect of the theory of change i.e. a factor that is expected to cause an outcome. A condition could also reflect one or more project characteristics, a wider contextual factor that may have influenced outcomes in some way or the production of specific research outputs. Conditions should also be independent of one another.

With significant variation among the APC projects selected as case studies, there were many potential conditions that could be explored through QCA. However, the optimal number of conditions for QCA is typically six or seven. It was expected that the (non)existence of conditions would vary across case studies, meaning case studies could have the same or different configurations of conditions.

The conditions included in the QCA, detailed in Table E.1 below, are categorised in three groups:

- APC funding – whether the project received APC funding, to determine whether this had a causal role in project success (technical or commercial).
- Project characteristics – when funding was received (reflecting the context in which the project was delivered), grant size, and length.
- Consortium characteristics – number of partners and lead organisation type

Table F.1: Conditions for QCA

Analysis level	Category	Condition	0=	1=
Funding	Funding	1) APC funding	Case studies without APC funding	Case studies in receipt of APC funding
Project characteristics	Timing	2) Funded 2016 onwards	FY 2014/15 or 2015/16	FY 2016/17 or 2017/18
	Grant size	3) Large grant size	< £10k	> £10k
	Length	4) Longer duration	0-35 months	36+ months
Consortium characteristics	Collaboration size	5) Large consortia	0-5 partners	6+ partners
	Lead organisation	6) OEM/large lead company	SME	OEM/large company

Step 4: Develop and populate truth tables

Based on case study interviews and the documentation review, binary coding for each condition, and the outcomes (technical and commercial success) was completed for the 21 case studies included in the QCA. This coding was populated in Excel and using the QCA Add-in, a truth table was developed to explore all possible configurations for the number of conditions. For each configuration, the truth table was populated with the number of case studies where the outcome of interest was present or absent – with each case study only counted once. Table E.2 depicts an example truth table.

The analysis establishes whether the condition is necessary or sufficient for an outcome to have been achieved:

- Necessary: A condition is necessary if it is required for an outcome to be achieved but it cannot result in the outcome by itself.
- Sufficient: A condition is sufficient if the outcome will always occur if the condition is present.

This process was repeated for each outcome of interest, with a truth table for technical success and commercial success.

Table F.2: Example truth table

Configurations of conditions	Condition A: APC funding	Condition B: Large grant size	Condition C: OEM lead	Coverage	Number of cases with outcome	Number of cases without outcome	Consistency
I	1	1	1	9%	2	0	1
II	1	1	0	35%	6	2	0.75
III	1	0	1	0	0	0	NA
IV	1	0	0	9%	2	0	1
V	0	1	1	13%	1	2	0.33
VI	0	1	0	17%	4	0	1
VII	0	0	1	0	0	0	NA
VIII	0	0	0	17%	0	4	0
			Total cases:	23	15	8	

Step 5: Calculate the coverage and consistency of configurations (and improve consistency where possible)

The relative influence of different individual conditions and causal configurations can be evaluated in terms of coverage (the percentage of cases they explain) and consistency (the extent to which a configuration is always associated with a given outcome). In the example table above, the right-most column describes the consistency of each configuration: whether all cases with that configuration have one type of outcome (1=outcome present in all cases; 0=outcome absent in all cases), or a mixed outcome (i.e. some cases show the outcome while others do not).

Next, the consistency of configurations with mixed outcomes (i.e. anything other than 1 or 0) should be improved. This is done either by rejecting cases within an inconsistent configuration because they are outliers (with exceptional circumstances unlikely to be repeated elsewhere) or by introducing an additional condition (column) which distinguishes between those configurations which did lead to the outcome and those which did not.

Step 6: Minimisation of configurations

The final step involves reducing the number of configurations needed to explain all the outcomes, known as minimisation. An automated algorithm in the QCA Add-in examined the configurations, collapsing them until no further reductions are possible. This process provided the solutions reports in section 1.3 below.

Levels of analysis

The analysis was completed on two levels:

- APC as a condition of success: A key condition to test was the extent to which the presence of APC funding was associated positively with technical and/or commercial success. This analysis specifically compared case studies who received APC funding with those who did not receive APC funding.

- Additional characteristics as conditions of success: The next level of analysis only looked at case studies who received APC funding to examine how project (i.e. grant size, length, timing) and consortium (i.e. size, lead organisation type) characteristics affected project success.

Results

The tables below provide the results of the QCA analysis for both outcomes: technical success and commercial success. In each table, results from the first level of analysis are presented first to test APC as a condition of success. This is followed by the analysis of other characteristics and their effects on the outcomes.

Technical success

Evidence from case studies demonstrated that most successful projects appeared to have met or were on track to meet technical objectives, and the QCA provided evidence that APC funding on its own was a condition for technical success. In all solutions (see Table E.3 below), APC funding was found to be an important condition associated with the achievement of technical success. Follow-up analyses were conducted looking only at projects that received APC funding (successful projects) to explore these characteristics further. The results suggest that key success factors associated with technical success are projects awarded in later competition rounds, potentially suggesting that the timing of projects is significant, those with longer delivery periods (36+ months) and larger consortia (6+ partners).

Table E.3: Technical success – Overview of solutions by QCA model

Outcome	QCA solutions derived
APC as a condition of technical success (both successful and unsuccessful cases)	
Outcome: Technical success not achieved (0)	apcfunding
Outcome: Technical success achieved (1)	APCFUNDING*LATERROUND + APCFUNDING*LONGERDELIVERY + APCFUNDING*LARGECONSORTIA APCFUNDING*LATERROUND + APCFUNDING*LONGERDELIVERY + laterround*LARGECONSORTIA

Outcome	QCA solutions derived
	APCFUNDING*LATERROUND + APCFUNDING*LONGERDELIVERY + longerdelivery*LARGECONSORTIA APCFUNDING*LATERROUND + APCFUNDING*LONGERDELIVERY + LARGECONSORTIA*OEM/LARGE
Additional characteristics as conditions of technical success (successful cases only)	
Outcome: Technical success achieved (1)	LATERROUND + LONGERDELIVERY + LARGECONSORTIA

Source: Ipsos MORI (2019). N.B. Capitalisation represents condition presence (1) and lowercase, a condition's absence; * refers to the 'and' Boolean operator and + refers to the OR Boolean operator.

Commercial success

None of the case studies of projects that were declined funding were on course to meet their commercial objectives because only one of the cases was taken forward in a meaningful way (and at a reduced scope). Inevitably, the QCA pointed to a causal association between receiving APC funding and the realisation of commercial objectives – i.e. that applicants would not have achieved, or remained on track to achieve, their commercial objectives without receiving funding through the programme.

Among projects who received APC funding, results from the QCA indicated that receiving a comparatively large grant (greater than £10m) was associated with meeting or being on track to meet commercial objectives. Also, being in a consortium led by an OEM or large company (combined with being in a later competition round) showed some limited associations with improved likelihood of achieving commercial success. This may reflect that a subset of projects funded in earlier rounds were responding to market needs that have since become less relevant since the advent of electrification agenda.

Table E.4: Commercial success – Overview of solutions by QCA model

Outcome	QCA solutions derived
Examination of APC as a condition of commercial success (successful and unsuccessful project case studies)	
Outcome: Commercial success not achieved (0)	apcfunding + laterround*largegrant*longerdelivery + laterround*largegrant*LARGECONSORTIA apcfunding + laterround*largegrant*longerdelivery + laterround*LONGERDELIVERY*LARGECONSORTIA apcfunding + laterround*largegrant*longerdelivery + largegrant*LONGERDELIVERY*LARGECONSORTIA apcfunding + laterround*largegrant*LARGECONSORTIA + laterround*longerdelivery*largeconsortia
Outcome: Commercial success achieved (1)	APCFUNDING*laterround*oem/large + APCFUNDING*LATERROUND*OEM/LARGE + LARGEGRANT APCFUNDING*LATERROUND*OEM/LARGE + APCFUNDING*LONGERDELIVERY*oem/large + LARGEGRANT APCFUNDING*LATERROUND*OEM/LARGE + APCFUNDING*largeconsortia*oem/large + LARGEGRANT
Additional characteristics as conditions of technical success (successful cases only)	
Outcome: Commercial success achieved (1)	laterround*oem/large + LATERROUND*OEM/LARGE + LARGEGRANT LATERROUND*OEM/LARGE + LARGEGRANT + LONGERDELIVERY*oem/large LATERROUND*OEM/LARGE + LARGEGRANT + largeconsortia*oem/large

Source: Ipsos MORI (2019). N.B. Capitalisation represents condition presence (1) and lowercase, a condition's absence; * refers to the 'and' Boolean operator and + refers to the OR Boolean operator.

Appendix G: Future Economic Impact Evaluation

This Appendix gives some outline recommendations for issues that may need consideration the development of methods to be deployed in a final impact evaluation of the programme:

- **Econometric modelling:** The analysis set out in this report provides proof of concept that econometric modelling driven by administrative data can yield insight into the economic impacts and benefits of the APC. As a final evaluation is likely to take place an extensive period after grants were awarded through the programme, this is advantageous. Secondary datasets will permit outcomes to be tracked in the long-term without the need for 'innovation surveys' gathering information on outcomes from those involved in the delivery of projects (who may have moved on in the longer term). It is recommended that this forms a key component of any final evaluation of the programme, and the following enhancements could potentially be explored:

    - **Other public funding:** The final evaluation should seek to establish the comparability of applicants that were and not funded in terms of historic grants received from the public sector to pursue R&D to probe the robustness of findings. Additionally, there may be benefits in seeking to establish how far the APC influenced the ability of applicants to secure funding from other public sector programmes. This can be achieved by linking records firms receiving funding to records of Innovate UK awards published through Gateway to Research (or Innovate UK's transparency data).

    - **Outcomes:** There may be opportunities to explore a broader range of outcomes. For example, it is possible to link records of APC applicants to records on the training activity of applicants through the Individualised Learner Record. Given the objective of the programme to safeguard the competitiveness of the automotive industry in the UK, it will also be helpful to examine the effects of the programme in retaining activity in the UK, encouraging firms to open new production plants, and effects on trade (i.e. imports and exports). These types of effects can be examined through the detailed records of spatial structure provided by the Business Structure Database and data on import and export activity provided by the Annual Business Survey.

    - **Context:** A key challenge for econometric analysis will be handling two significant changes in context that will have an influence over the outcomes of interest – i.e. the COVID-19 pandemic and changes in trading relationships with the EU. These external shocks will not invalidate the general approach put forward as they will affect both the treatment and comparisons groups for the analysis. However, it is possible that individual firms will be more or less exposed to these contextual changes and it may be helpful to control for this exposure in the analysis. For example, including levels of imports and exports from and to the EU as a percentage of output (fixed in 2019) would potentially capture the exposure of an individual firm to disruptions to the prevailing trading regime. COVID-19 has resulted in a demand and a supply side shock to the automotive industry (and dummy variables capturing the on-going effects of this could be included).

- **Knowledge spill-overs:** As highlighted, it has been difficult to obtain records of the knowledge based outputs of APC projects (patents and publications) which has hindered attempts to explore knowledge spill-overs arising from the programme through bibliometric and patent analysis. It is recommended that BEIS address this gap in monitoring to enable a more detailed quantitative investigation to take place in later studies.

- **Case studies:** A focus on the methods outlined above would not provide comprehensive evidence on the outcomes of the programme or information on why the programme achieved its successes (or why not). An extensive programme of case studies (aiming to provide close to near complete coverage of the project portfolio) is suggested for the final evaluation to obtain evidence on the technical progression of individual technologies and their commercialisation. However, it is important to note that gathering data from applicants that were declined possible was highly challenging (as these teams were often disbanded following the rejection of the application) and this issue is likely to become more acute moving forwards. As such, it may be challenging to put together a high quality dataset capturing the experiences of unsuccessful applicants, which would limit the extent to which QCA would be a viable methodology for exploring the impact of the programme (though it could be used as a means of exploring why some types of project were successful and some were not).

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