Physics and the Economy: Measuring the value of physics-based industries in the UK

A Cebr report for the Institute of Physics

November 2021

Authorship and acknowledgements

This report has been produced by Cebr, an independent economics and business research consultancy established in 1992. The views expressed herein are those of the authors only and are based upon independent research by them.

The report does not necessarily reflect the views of Institute of Physics.

London, November 2021

Contents

Headline findings

- This is a report by the Centre for Economics and Business Research (Cebr), on behalf of the Institute of Physics, detailing the **economic contribution of physics-based industries (PBIs) in the United Kingdom (UK), to the UK economy.**
- The report considers the **direct economic contributions** made by **PBIs**, as well as the wider economic footprint supported through **indirect** (supply-chain), **induced** (wider-spending) impact layers.
- In the graphic and headline findings below, we present the direct economic impact of the PBIs in the UK in 2019, although our analysis also covers trends over the nine preceding years.
- In 2019, it is estimated that in the UK, PBIs directly contributed to the UK economy:

Turnover
£634bn

Gross Value Added (GVA)
£229bn

Full-time equivalent (FTE) jobs
2.72m

Employee Compensation (COE)
£114bn

- Combining the indirect and induced impact layers, the aggregate economic contribution of PBIs increases significantly:

Turnover
£1,380bn

GVA
£563bn

Full-time equivalent (FTE) jobs
7.62m

COE
£269bn

- The economic footprint of PBIs was greatest in London (£40.73 billion in direct GVA), the South East (£35.80 billion) and Scotland (£28.38 billion).
- The PBIs accounted for 10.6% of all UK GVA value, with £229 billion in 2019.
- The biggest PBI sub-sector in terms of GVA was Physics Manufacturing, which contributed £71.93 billion, followed by Physics Science & Technology (£66.86 billion) and Telecommunications (£32.56 billion).

- There were 350,135 PBI enterprises operating in the UK. The regions with the most business entities were London (63,525), the South East (56,690) and the North West (37,065). Similarly, these regions employed the most people, with 334,050, 395,720 and 300,430 FTEs, respectively.
- In 2019 Physics Science & Technology was the PBI sub-sector with the greatest number of enterprises; 258,095 in the UK (73.5% of all PBI companies).
- Consistent with broader trends across the economy, 92% of PBI enterprises were considered micro companies. Of the remainder, 6.6% of enterprises were defined as small (10-49 employees), with the remaining 1.4% medium (50-249 employees) or large (250+).
- In 2019, 74,092 new PBI enterprises were created. This represented 21% of all PBI enterprises that year.
- Throughout the decade, in nominal terms, the turnover of PBIs grew by 24.1%, from £511 billion to £634 billion. The highest absolute growth was in the Physics Science & Technology sub-sector, which increased from £92 billion to £253 billion (65.9%), while the Space Transport & Air Transport Services sub-sector nearly doubled over the period (from £5.58 billion to £10.91 billion, 95.5%).
- Employment in the PBIs topped more than 2.72 million in 2019, and amounted to a 10.0% share of total UK employment. Employment growth averaged 1.3% annually.
- Of the PBI sub-sectors, Physics Science & Technology employed the largest number of people, equivalent to 40.5% of the total UK PBI employment. The Physics Manufacturing sub-sector had the second largest share with 37%. The Physics Manufacturing sub-sector was formerly the biggest employer, but the high growth rate of employment in the Physics Science & Technology sub-sector meant that by 2019, it had become the new biggest employer within the PBIs.
- PBIs experienced a steady growth of 3.1% on a yearly average employee compensation, from £87 billion to £114 billion over the period. This was a much higher growth rate compared to employment trends in the sector across the decade, meaning that average employee compensation increased throughout the period.
- Employee compensation per FTE worker increased overall across the PBIs to £42,000. The Physics Manufacturing sub-sector particularly had significant growth, by 31.8% over the period, to almost £44,000.
- Research and development (R&D) expenditure by PBIs in the UK was almost £15.8 billion in 2019, equivalent to approximately 60% of all R&D expenditure in the UK. This was dominated by the Physics Manufacturing and Physics Science & Technology sub-sectors, with these two accounting for over 92% of all PBI R&D expenditure.
- We also estimated the R&D contribution of a selection of industries with high ongoing levels of physics research: the physics-intensive industries. These conducted £8.9 billion of R&D in 2019, while this growth was strong (75.7% over the period). As of 2019, this represented 34.2% of all UK R&D expenditure.

- In order to meet UK R&D targets (2.4% of GDP), an £8.8 billion increase in PBI R&D would be required (assuming the share of UK R&D conducted by the PBIs remains the same). Per our modelling, PBI R&D has very strong returns: this would be associated with an increase in PBI GVA contribution of £34.3bn.
- While the scope of this analysis did not extend to cover the returns to R&D investment in the physics-intensive industries, in order for the UK to meet this R&D target, R&D investment in the physics-intensive industries would need to increase by £4.9 billion.
- Looking at revenue contribution, in 2019 the UK had the second largest physics-based sector in Europe, after Germany[1]. However, the UK's gross expenditure on R&D as a share of GDP is below the OECD average, lagging behind many of the major economies around the world, such as the United States, Germany, France and Japan.

1 https://cdn.ymaws.com/www.eps.org/resource/resmgr/policy/eps_pp_physics_ecov5_abs.pdf

1. Introduction

This report by the Centre for Economics and Business Research (Cebr) on behalf of the Institute of Physics (IOP), considers the contribution and importance of physics-based industries (PBIs) to the UK economy, an analysis that spans the period of 2010 to 2019. This report forms part of a series of six reports, which quantify the impact of the PBIs to the UK and Irish economies.

1.1 Background and general purpose of the study

According to the IOP's definition, PBIs are those where either:

- Ongoing research and development (R&D) in the industry consistently makes use of physics knowledge (and the R&D activity can be expected to significantly affect the fortunes of businesses within the industry)

Or

- The underlying technology supporting the industry requires significant physics knowledge for continued operation

In other words, PBIs can be thought of as those industries in which the industrial and technical activities associated with the industry require physics knowledge.

A different but overlapping list of *high physics-intensity industries* is made up of industries where:

- Ongoing R&D in the industry consistently makes use of physics knowledge, but the industry itself doesn't necessarily rely on physics for the bulk of its activities.

The majority of this analysis within this report focuses on the PBIs rather than the physics-intensive industries, however in Section 6.1 we do also consider the R&D conducted by firms within this physics-intensive segment.

This research provides up-to-date insights on the size and performance of the UK and Irish physics sectors, presenting a range of analyses which demonstrate different aspects of the economic value brought by the PBIs. The intention of this is to empower the IOP with a thorough and comprehensive knowledge and evidence base, such that they can support and advocate for the sector across the UK and Ireland.

An important task has been to develop an in-depth understanding of PBIs. To produce a robust study, it is necessary to analyse the available data to ensure that it captures the full range of activities that should be included in establishing the total economic 'footprint' of the industry. Following the collation of the necessary data capturing these activities, the values of key economic indicators were established to demonstrate the impact of the sector. The key macroeconomic indicators include:

- GVA[2] contributions to the UK and constituent regional GDP generated by the PBIs

2 GVA, or gross value added, is a measure of the value of production in the national accounts. Conceptually it can be considered the value of what is produced, less the value of intermediate goods and services used to produce it. GVA is distributed in three directions – to employees, to shareholders and to government. It is often used as the proxy for the contribution of a sector or industry to GDP: strictly this relationship is GVA + Taxes on products - Subsidies on products = GDP.

- Full-time equivalent (FTE) jobs supported by the sector[3]
- The value of the turnover of the PBIs
- The value of employee compensation[4] generated by PBIs, representing the total remuneration of employees operating in the sector
- The productivity of the PBIs (value added per worker)
- The number of PBI enterprises operating in the UK

In addition to the core modelling and analysis, we also undertake a range of comparisons to contextualise the findings, including:

- How the economic indicators vary over the period 2010-2019
- How the economic indicators vary across different categories or groupings of the PBIs
- How the economic indicators for the PBIs vary between the UK and other comparable nations
- How the indicators for the PBIs compare with other important sectors of the UK economy

Mapping UK PBIs

Here we set out how PBIs have been defined for the purposes of the study. The PBIs consist of over 120 four and five-digit SIC codes, in which ongoing R&D in the industry consistently makes use of physics knowledge, or the underlying technology supporting the industry requires significant physics knowledge for continued operation. The full list of SIC codes used within this study can be found in Appendix I**: SIC-based definitions of PBIs and sectoral alignment**.

For the purpose of this report, these SIC codes are then aggregated into 11 sectors.[5] These are:

- Oil & Gas Extraction
- Physics Manufacturing
- Physics Machine Services
- Energy Production, Transmission & Distribution
- Physics Waste & Recovery

3 The calculation of full-time equivalent (FTE) is an employee's scheduled hours divided by the employer's hours for a full-time workweek. When an employer has a 40-hour workweek, employees who are scheduled to work 40 hours per week are 1.0 FTEs. Employees scheduled to work 20 hours per week are 0.5 FTEs. We considered all parti-time workers to work 20 hours per week. Lastly, we subtracted the number of employees from the number of employment in order to get the number of self-employed individuals.

4 Compensation of employees (COE) or employee compensation, is the total remuneration, in cash or in kind, payable by an employer to an employee in return for work done by the latter. This consists of wages paid to employees; employers' actual social contributions (excluding apprentices); employers' imputed social contributions (excluding apprentices); and employers' social contributions for apprentices.

5 In order to visualise the data better, and avoid some volatility, we aggregated several of these smaller sub-sectors into an 'Other' category. 'Other' consists of: Oil & Gas Extraction; Physics Machine Services; Physics Waste & Recovery; Physics Machine Sales; Medical Equipment Sales; Space Transport and Air Transport Services; and Defence

- Physics Machine Sales
- Medical Equipment Sales
- Space Transport & Air Transport Services
- Telecoms
- Physics Science & Technology
- Defence

1.2 Earlier research

The IOP previously commissioned Cebr in 2016 to produce studies focused on measuring the impact of the PBIs to the UK and to the Irish economies.

In this suite of six reports, we go beyond the 2016 project and present a range of new materials, including assessment of:

- How the full range of economic indicators for the PBIs vary across the UK nations and English regions, as well as the Republic of Ireland
- How the economic indicators for the PBIs vary between the UK and Ireland and other international comparable countries
- How the indicators for the PBIs compare with other important sectors in the UK and Ireland (such as Construction or Transportation & Storage), and how they are broken down by the UK's constituent nations and regions.

In addition, the definition of the PBIs has been updated since the 2016 research; therefore, figures between reports in the two series are not directly comparable.

This report focuses on the UK specifically.

2. Enterprises in the PBIs

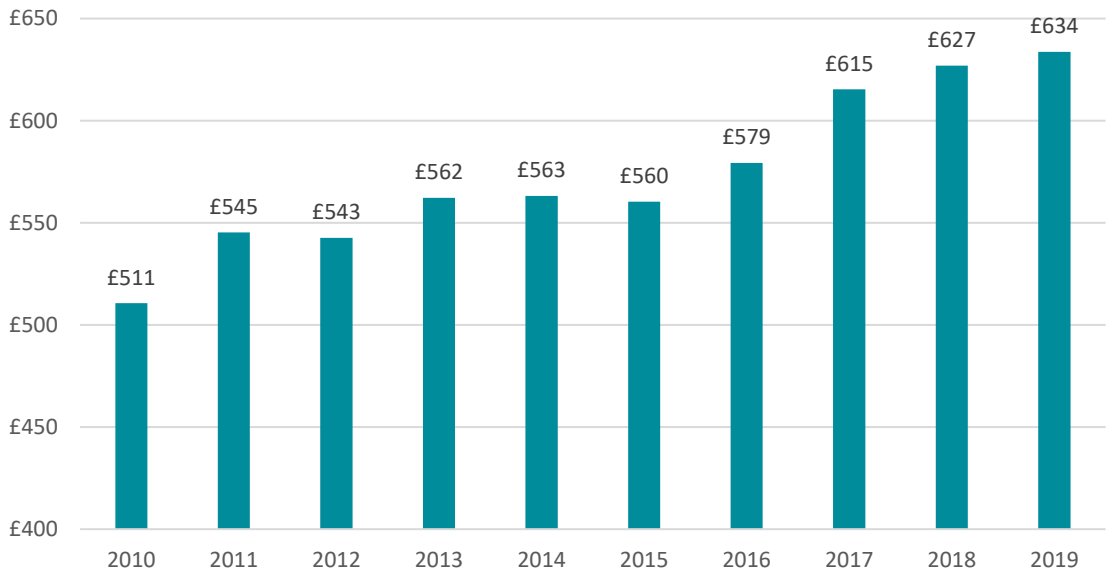
This section provides an assessment of the importance of PBIs to the UK, in terms of turnover and business demographics over the period 2010-2019.

2.1 Turnover

We firstly present the contribution of the PBIs to the UK economy, in terms of the turnover generated by those industries. In 2019, the PBIs generated £634 billion in turnover in the UK. Throughout the period, PBIs experienced an increase of £123 billion - a 24.1% rise over the period, and 2.4% annually.

The majority of the observed growth occurred over the 2016-2018 period, and the largest single increase was in 2017, when the turnover jumped £36 billion (6.2%). This is largely attributable to the Physics Science & Technology sub-sector, which increased by almost £15 billion in 2017 (11.6%).

Figure 1: Turnover in PBIs, £ billions, 2010-2019



Source: ABS, Cebr analysis

Figure 2: Turnover in the different categories of UK PBIs, presents a comparison of the different sub-sectors comprising the PBIs.[6] Their composition has remained reasonably constant throughout the 2010-2019 period, except for the Physics Science & Technology sub-sector, which contributed 6 percentage points more to the overall value in 2019 than it did in 2010 (24.1% compared to 18.0%). Overall, 49.6% of the total turnover growth in the PBIs over the period can be attributed to growth in the Physics Science & Technology sub-sector. Strong growth in this sub-sector was caused by a number of factors, including strong growth in enterprise numbers (Section 2.2) and the high level of UK government net expenditure on

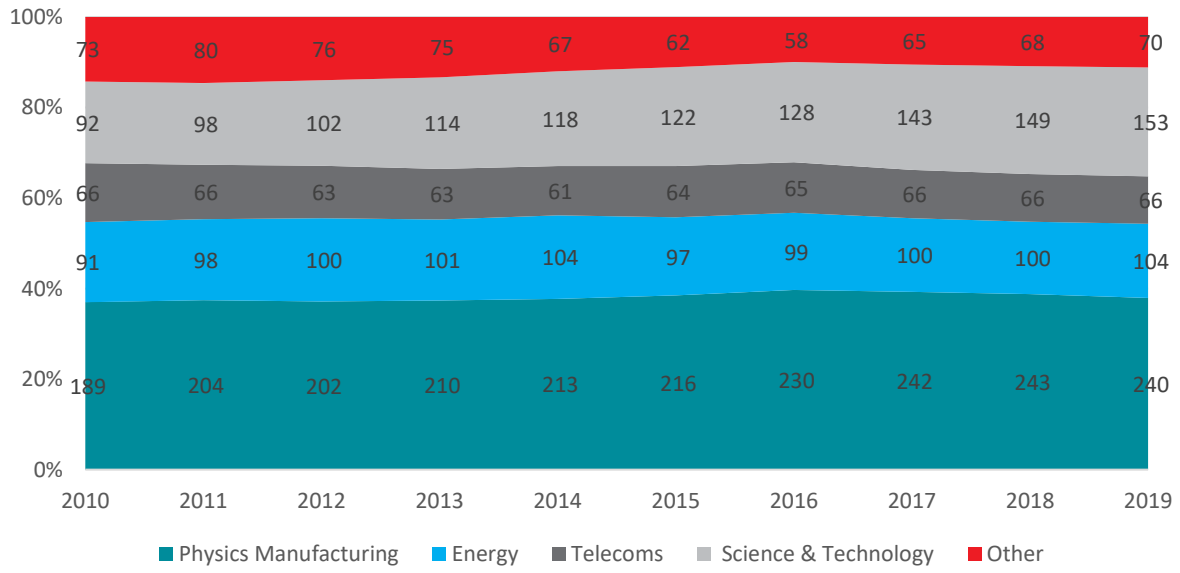
6 See Table 9 in Appendix III**: Supplementary figures and tables** for a full breakdown of the contribution to total turnover by UK PBIs, disaggregated by all industries.

Science, Engineering and Technology. This totalled over £10 billion annually in every year over the period, and also includes strong growth in Innovate UK grant numbers (Section 8).

PBIs in the Physics Manufacturing sub-sector occupied the largest share, around 38%, followed by those engaged in science and technology activities, approximately 21%. In the 'Other' sub-sectors, the turnover fluctuated because three sub-sectors saw their turnover shrink significantly over the period: Physics Machine Sales (from £3.25 billion to £2.53 billion, 19.1%); Defence (£5.95 billion to £4.42 billion, 25.7%); and Oil & Gas Extraction (£36.95 billion to £23.92 billion, 35.3%). The decline in the UK's Oil & Gas Extraction sub-sector was the most significant of these, which can be explained by a decline in annual UK crude oil production of nearly 14 million metric tonnes, or 21.4%, over the period.[7] While in 2010 these three sub-sectors represented slightly more than 9% of PBI-related activities, in 2019 they produced only 5% of the overall turnover.

The figures below present the turnover for selected categories of UK PBIs for both the entire period and solely for 2019, respectively; the full data, including the disaggregation of the 'Other' category, can be found in Appendix III**: Supplementary figures and tables**.

Figure 2: Turnover in the different categories of UK PBIs, % of PBI total (LHS axis) and monetary value (£bn, label), 2010-2019

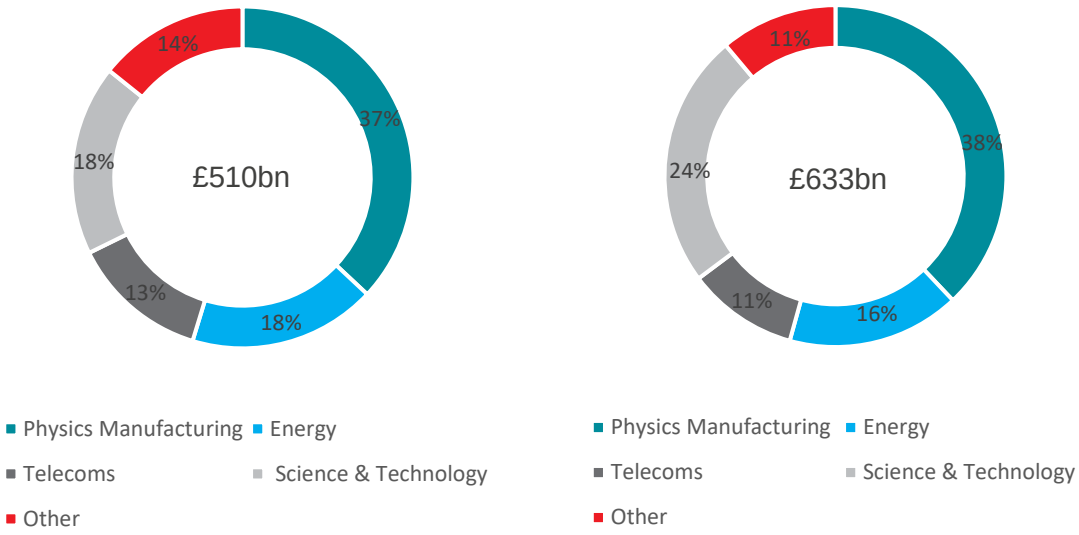


Source: ABS, Cebr analysis

Figure 3 below visualises the breakdown of turnover in 2010 and 2019.

7 https://www.statista.com/statistics/615905/crude-oil-production-trade-uk/

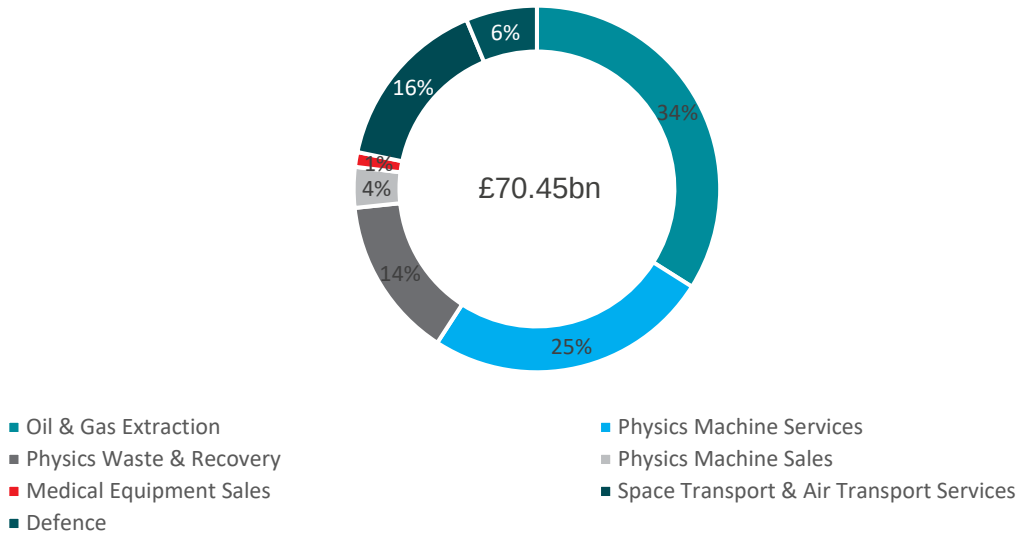
Figure 3: Turnover in the different categories of UK PBIs, £ billions, 2010 (LHS) and 2019 (RHS)



Source: ABS, Cebr analysis

Figure 4 below shows the full breakdown of the industries included within the 'Other' category, for 2019.

Figure 4: Breakdown by turnover of industries included within 'Other', £ billions and % of 'Other' total, 2019

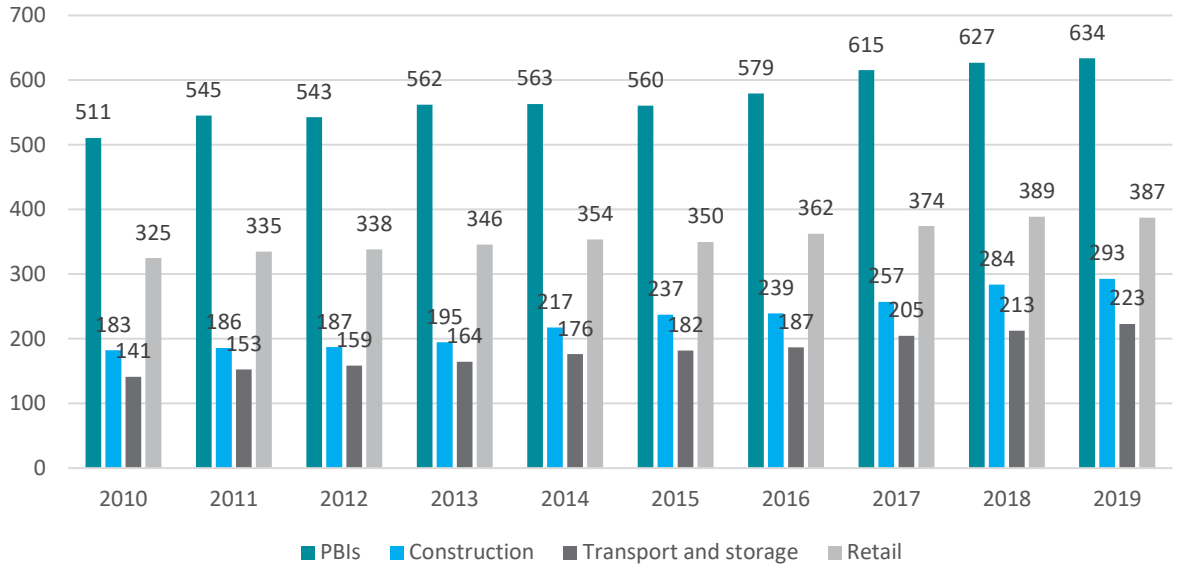


Source: ABS, Cebr analysis

Industry comparison

The turnover of the entire PBI sector is much larger than any of the other three sectors shown for comparison in Figure 5: Construction, Retail and Transport & Storage.[8] It is more than double Transport & Storage and Construction respectively in 2019, and almost £250 billion greater than Retail. However, both the Construction and the Transport sectors have a higher growth rate over the decade: 60.4% and 57.9%, respectively (relative to 24.1% for the PBIs).

Figure 5: Turnover in selected UK sectors, £ billions, 2010-19



Source: ABS, Cebr analysis

2.2 Business demography

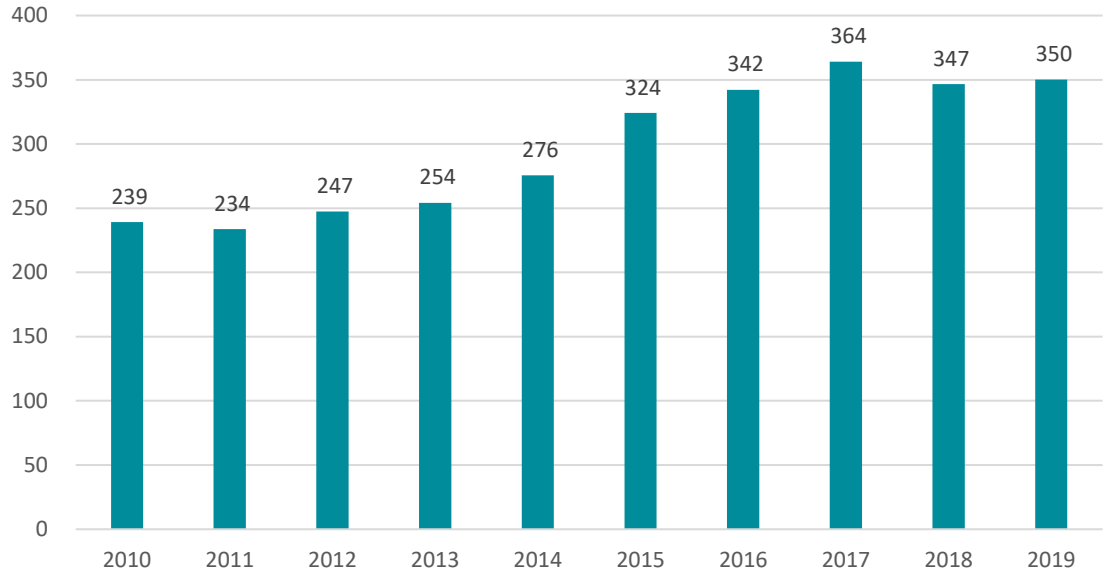
Business count[9]

In 2019, there were more than 350,000 PBI enterprises counted in the UK. The PBIs experienced a steady upward trend in terms of the number of enterprises between the period 2011-2017. In 2010, there had been close to 240,000 enterprises counted, which increased to more than 364,000 by 2017. The greatest change was seen in 2015, when the number jumped from 276,000 to 324,000 (17.6% increase). After this steady growth, however, the sum of enterprises dropped to 346,500 in 2018, and only increased marginally in 2019, as shown in Figure 6. Nonetheless, the overall result of the decade can still be considered as positive: the number of enterprises rose by 46.4% over the period.

8 These sectors are selected for comparison, as three of the larger SIC sections, which do not already have significant overlap with the PBIs.

9 Due to a lack of data, we didn't include the Defence sub-sector in the business demography analysis. SIC 84.22 Is dominated by a few very large companies, therefore omitting it doesn't alter the data on a significant level.

Figure 6: Number of physics-based enterprises in the UK, thousands, 2010-2019



Source: Nomis, Cebr analysis

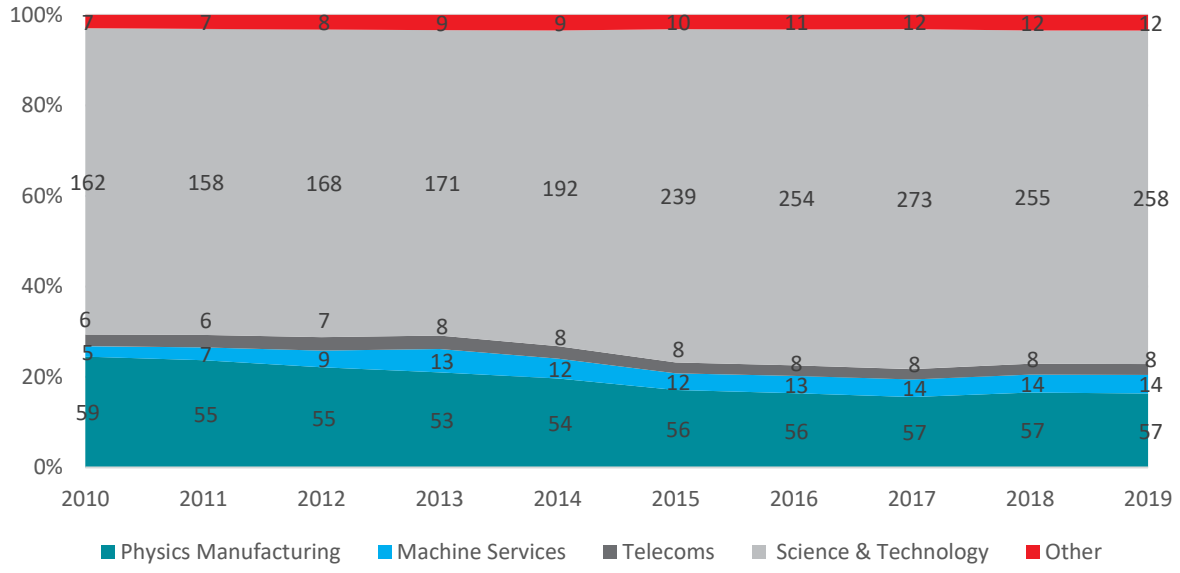
It is further notable that the trends for enterprise numbers in the physics sector broadly mirror those seen for turnover, with moderate growth in the first half of the decade but strong growth in the middle and later in the decade. However, while the number of PBI enterprises increased significantly in 2015 (a 17.6% single year increase), turnover actually declined slightly in the same year, before increasing significantly from 2015 through 2018. This lag between enterprise growth and turnover growth is intuitive, as it takes time for businesses to establish a significant footprint.

However, this may also be a potential cause for concern moving forwards; the decline in enterprise numbers from 2017 through 2019 began to be reflected by PBI turnover tapering off over the same period, but has not yet been reflected in declining economic performance to the same extent. Further identifying the potential continuation or otherwise of this trend is likely to be challenging, given the overwhelming impact of Covid-19, which would be expected to be observed in 2020 data onwards – still, it is worth being mindful of, as enterprise numbers might be useful indicator of the health and vitality of the sector post-Covid and a sign of the strength of the recovery. Significant declines in enterprise numbers over the Covid-19 period may signpost a slower post-Covid recovery.

Figure 7 shows the composition of the number of UK PBI enterprises. The Physics Science & Technology sub-sector has the significant majority of businesses, with this trend especially pronounced during the second half of the period. As will be seen, average business size in this sector is also lower than the PBI sector average. On average, this sub-sector contributed 71.6% of all physics-related enterprises, and this ratio peaked in 2017 with 75.1%. In addition, this sub-sector was the primary driver of total growth in enterprise numbers in the PBIs over the period.

The biggest sub-sector in terms of turnover and GVA contributions within the PBIs, Physics Manufacturing, has the second most enterprises with 18.8%. This can perhaps be explained by the strong economies of scale associated with manufacturing, where there are inherently competitive advantages associated with being a larger firm, with more scalable operations, relative to Physics Science & Technology enterprises.

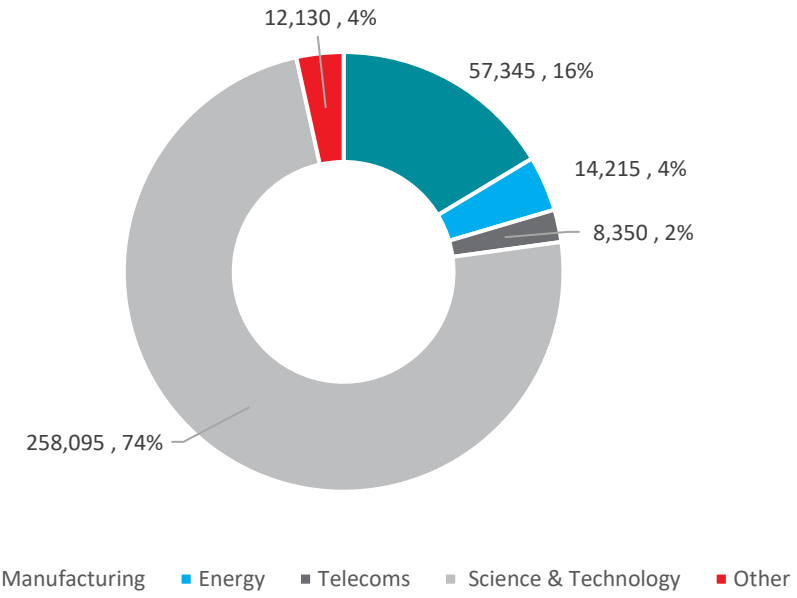
Figure 7: Number of enterprises in selected UK PBIs, % of PBI total (LHS axis) and value (thousands, label), 2010-2019



Source: Nomis, Cebr analysis

Figure 8 visualises the distribution of business within the PBI by sub-sectors for 2019.

Figure 8: Division of enterprises in UK physics-based industries, 2019



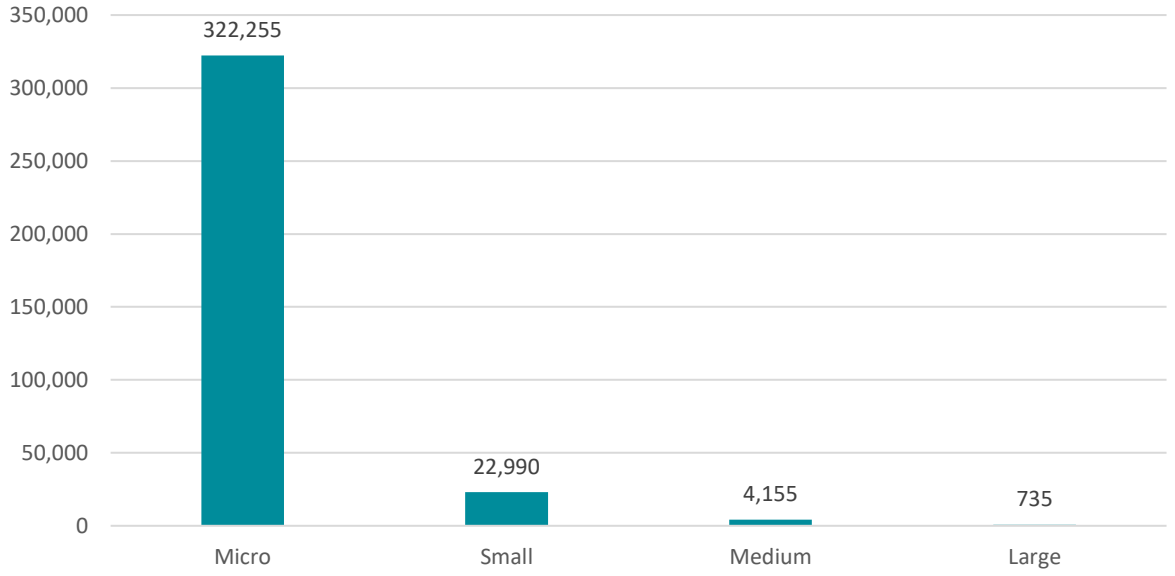
Source: Nomis, Cebr analysis

Size of enterprises

Consistent with wider trends in the economy, the PBIs are dominated by enterprises which employ a maximum of nine people; 92% (322,255) of enterprises are considered as micro companies. Of the remainder, 6.6% (22,990) of enterprises are defined as small (10-49 employees), with the remaining 1.4% (4,890) those which are medium (50-249 employees) or large (250+). By comparison, in the wider economy, 89.5% of firms are micro enterprises, 8.6% small and the remaining 2% medium or large. Physics-related enterprises on average

are therefore slightly smaller than those across the UK economy, although this trend does not significantly differ from the UK average.

Figure 9: Number of enterprises in UK PBIs distinguished between size, 2019



Source: Nomis, Cebr analysis

The Physics Science & Technology sub-sector has the most small and micro enterprises relatively, as 95% of all related enterprises are accounted as micro. As discussed, this relatively small average business size is a key driver for the share of total enterprises being higher than the wider economic contribution of this sub-sector. Supporting this, as will be seen below, Physics Science & Technology businesses are on average slightly younger across the PBIs; consistent with the trends of both smaller businesses on average, but also a growing sub-sector with new enterprises being registered.

The Physics Waste & Recovery sub-sector had the least micro firms proportionally (78%), while Oil & Gas Extraction had the highest number of large firms (4%). The full results by sub-sector can be seen in Appendix III**: Supplementary figures and tables**.

Table 1: Division of enterprises in UK physics-based industries, distinguished between size, 2019

Sub-sector	Micro	Small	Medium	Large
Physics Manufacturing	45,845	8,965	2,240	295
Physics Machine Services	12,940	1,070	165	40
Telecoms	7,460	690	155	45
Physics Science & Technology	245,375	10,985	1,435	300
Other	10,635	1,280	160	55
Total	**322,255**	**22,990**	**4,155**	**735**

Source: Nomis, Cebr analysis

Age of enterprises

In addition, we also analysed the age of enterprises in 2019. Due to data limitations, we could only distinguish the specific age of companies for those which are up to five years old; all firms either six years old or older are aggregated.

Table 2 shows the number of enterprises distinguished between age for the selected sub-sectors. It represents the conditions of 2019 – therefore 'New' means the company was founded in 2019, '1 year' means 2018, etc. '6+ years' means that the business was established in or before 2013. The Physics Manufacturing industry has the oldest companies by proportion: 59.7% of enterprises were six years or older. This is also consistent with trends of these enterprises on average being slightly larger and having a higher turnover. On the other end, the Physics Science & Technology sub-sector only had 13.8% of enterprises six years old or older. In fact, this sub-sector was the 'youngest': 24.6% of enterprises were founded in 2019, while for Physics Manufacturing, this value is only 9.1%.

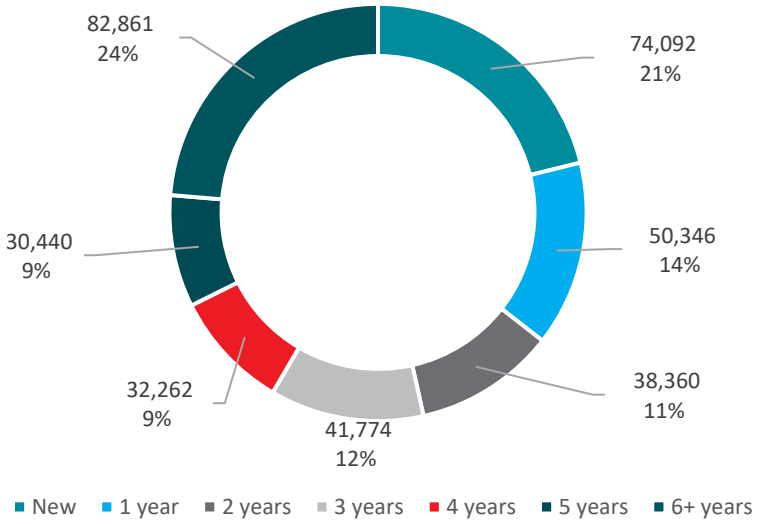
Table 2: Division of enterprises in UK PBIs, distinguished by age, 2019

Sub-sector	New	1 year	2 years	3 years	4 years	5 years	6+ years
Physics Manufacturing	5,214	5,555	4,143	3,274	2,623	2,326	34,211
Physics Machine Services	2,415	1,905	1,565	1,445	1,275	1,075	4,535
Telecoms	1,215	1,035	800	650	510	435	3,705
Physics Science & Technology	63,381	40,538	30,663	35,335	26,869	25,763	35,546
Other	1,867	1,313	1,188	1,071	985	841	4,864
Total	**74,092**	**50,346**	**38,360**	**41,774**	**32,262**	**30,440**	**82,861**

Source: Nomis, Cebr analysis

Figure 10 demonstrates this composition visually. 76% of all enterprises were founded in the past five years, and more than one in five was newly created in 2019. As of 2019, the (historic) five-year survivability rate stood at around 41.1% - this is the likelihood that a newly created firm will still exist five years later. It will be interesting to see how this develops over the next few years as further data is released, given the business stresses caused by the Covid-19 pandemic.

Figure 10: Division of enterprises in UK PBIs, distinguished between age, 2019

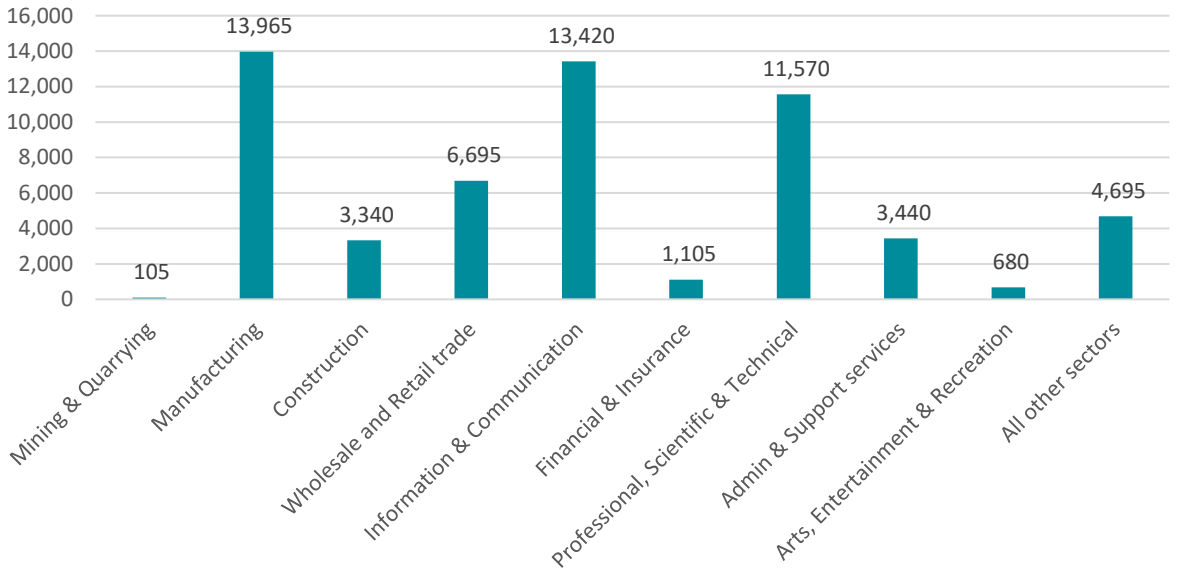


Source: Nomis, Cebr analysis

PBI enterprises conducting R&D

Finally, we also consider the number of enterprises in the PBIs conducting R&D. Firms can make R&D claims through two schemes: SME R&D tax relief (only available to SMEs) and R&D expenditure credit (RDEC, available to all firms, but less generous). Both schemes entail claiming back R&D costs from a previous accounting period; we have summed the number of claims made through both schemes, broken down by industry, to estimate the number of firms conducting R&D.[10] The results of this analysis, for all firms across the economy, can be seen in Figure 11.

Figure 11: Number of firms across the economy conducting R&D by industry group, financial year 2018-19



Source: HMRC, Nomis, Cebr analysis

Provisional data for financial year 2018-19 suggests that just over 59,000 UK enterprises claimed for R&D relief. Of these, three sectors make the most claims: Manufacturing (13,965, or 23.7% of the total); Information and Communication (13,420, or 22.7% of the total); and Professional, Scientific and Technical services (11,570, or 19.6% of the total).[11]

Specific data on business R&D claims is available only at a two-digit SIC level. We have therefore estimated within each of these SICs, the share of R&D conducted by enterprises in

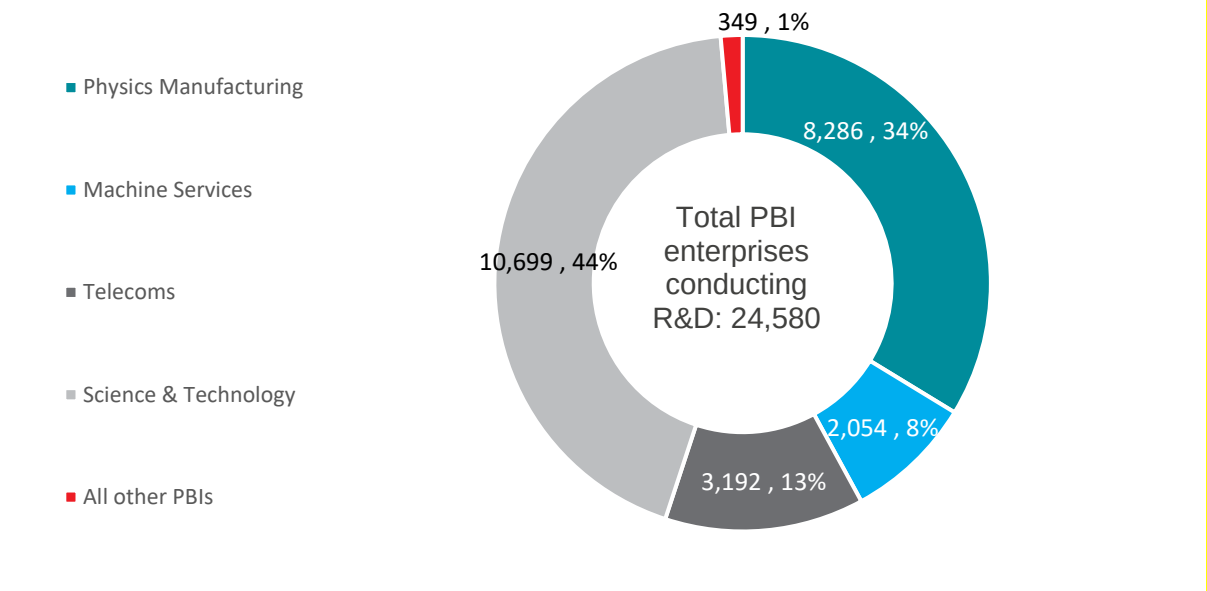
10 Note that this means if a firm is conducting R&D but does not claim tax relief through either scheme, they would not be included within the analysis.

11 Note that the data presented here (in Figure 11) considers the broader sectors of the economy, and not the PBI-specific sub-sectors. Data is referred to as provisional, as the HMRC tax credit data we used for the modelling lists financial year 18-19 data as provisional, with data from other years revised upon release of the next year's data.

the PBIs (further detail in Section 6) and assumed that the share of enterprises conducting R&D within these SICs is proportionate.[12]

Per this methodology, we estimate that 24,580 enterprises in the PBIs were conducting R&D in the financial year 2018-19. This is 41.7% of all enterprises conducting R&D. Across the UK, 2.2% of all enterprises claim for R&D expenditure, however in the PBIs this share rises to 7.0%. The distribution of these claims by the PBI sector can be seen below.

Figure 12: Number of PBI enterprises conducting R&D by sector and share of PBI total R&D enterprises conducting R&D, financial year 2018-19



Source: HMRC, Nomis, Cebr analysis

Of these claims in the PBIs, 44% (10,699) are from firms in the Physics Science & Technology sub-sector and 34% (8,286) are in Physics Manufacturing. The four main PBI sub-sectors seen above make up 98.6% of all business R&D claims, with the remaining sub-sectors responsible for just 1.4%. It is not surprising that the two largest PBI sub-sectors – Physics Manufacturing and Physics Science & Technology – conduct the most R&D.

These are the two largest PBI sub-sectors, although both conduct slightly more R&D than may be 'expected' based upon their GVA shares (both make up just under a third of total PBI GVA, as will be seen in the next section). However, this trend is to be expected given the nature of both sub-sectors: both sit in sectors within the wider economy (Manufacturing and Professional, Scientific & Technical services respectively) that generally conduct high levels of R&D (see Figure 11 above).

12 The underpinning assumption is that within a two-digit SIC, for firms conducting R&D in the PBIs, the average value of R&D expenditure, is equal to the average value of R&D expenditure conducted by firms within the wider SIC. In other words, if 50% of R&D within a SIC is conducted by firms in the PBIs, we have assumed that 50% of the enterprises conducting R&D are also in the PBIs.

3. Direct economic contribution of the PBIs to the UK economy

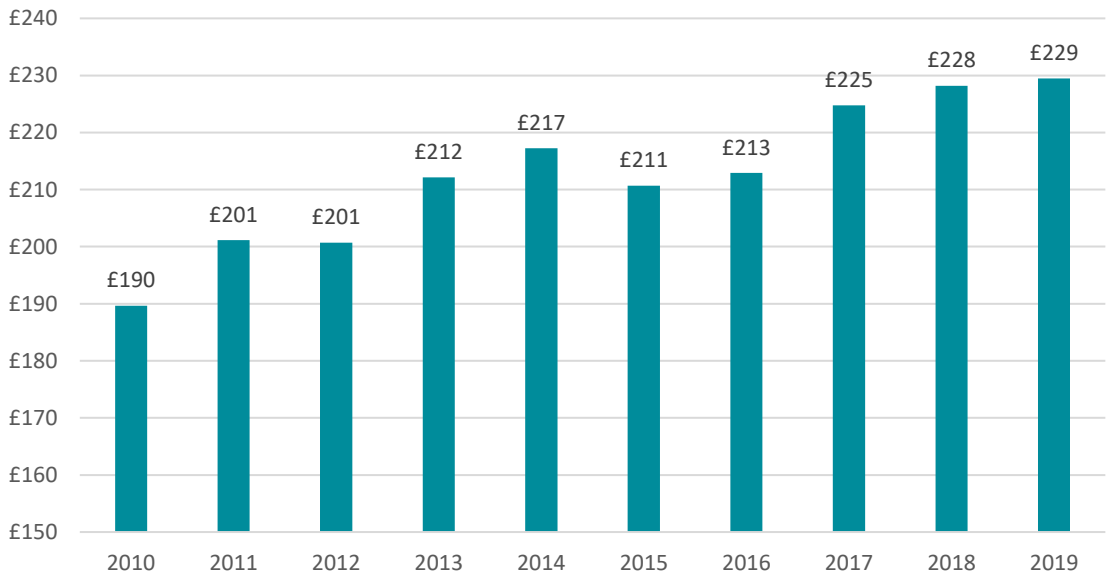
This section provides an assessment of the importance of PBIs to the UK in terms of GVA, employment and COE over the period 2010-2019.

3.1 GVA

We now focus on the economic contribution of the PBIs to the UK economy, in terms of their GVA contributions to GDP. GVA is a measure of the economic output of a sector, industry or economy; that is, the value of what they produce or provide after subtracting the inputs of goods and services required to do so.

We present our estimates of the UK PBIs' GVA contributions to GDP in Figure 13. The latest data suggests a £229 billion GVA contribution in 2019, which contributed 10.6% of the total UK value. Annual nominal growth averaged 2.1% between 2010 and 2019, but was strongest in 2011 at 5.9%.

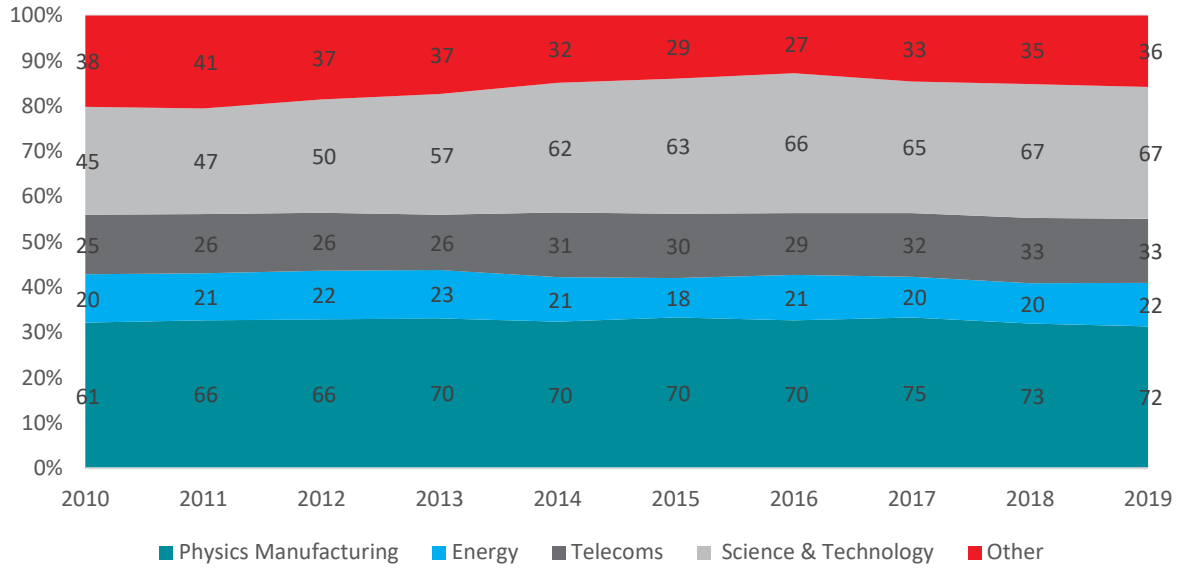
Figure 13: GVA in PBIs, £ billions, 2010-2019



Source: ABS, Cebr analysis

Consistent with turnover trends, the highest share of the PBIs' GVA contribution is again accounted for by Physics Manufacturing, as illustrated in Figure 14, contributing on average 32.6% over the period 2010-2019. The next largest contributor was the Physics Science & Technology sub-sector, which accounted for around 27.7%. However, the difference between the two largest sub-sectors has been narrowing: while Physics Manufacturing increased by 18% from £61 billion to £72 billion, the Science & Technology sub-sector rose by 48%, from £45 billion to £67 billion. The sub-sectors which experienced a decline in turnover over the period also experienced decline in GVA: Defence (22.1%), Oil & Gas Extraction (31.1%) and Physics Machine Sales (42.7%).

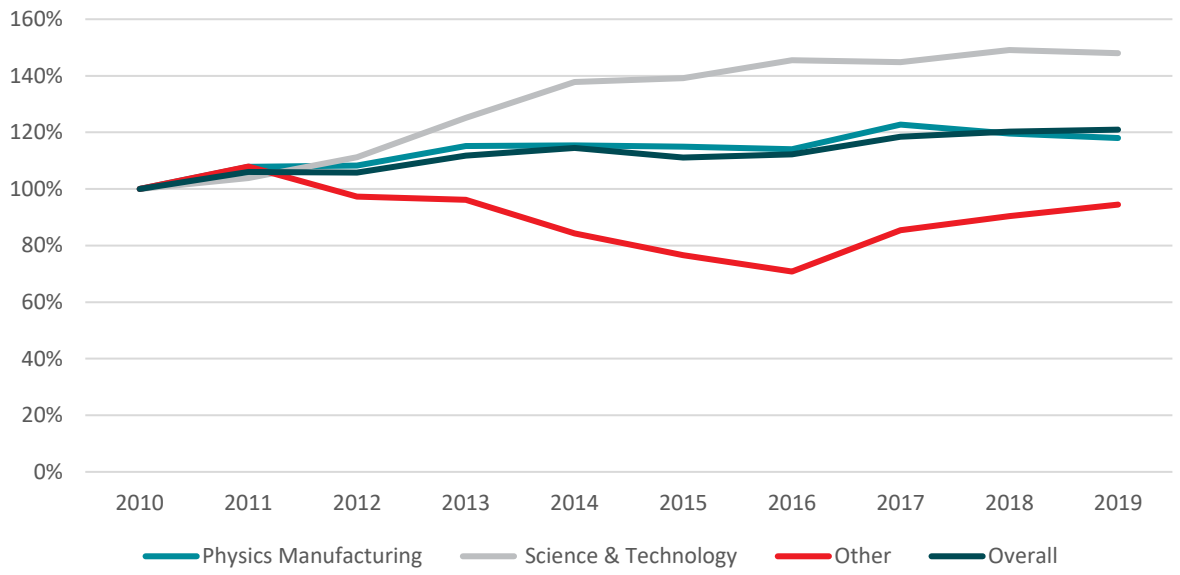
Figure 14: GVA in selected UK PBIs, % of PBI total (LHS axis) and £ billions, 2010-2019



Source: ABS, Cebr analysis

Figure 15 further demonstrates the trend observed above; the growth rate in the Physics Science & Technology sub-sector significantly exceeds that of the overall PBI average, and has been a key driver in PBIs' GVA growth over the last decade in the UK. The causes for this, including increased government support and increasing enterprise numbers, are likely consistent with those for increasing turnover of the sub-sector.

Figure 15: GVA in selected PBIs in the UK, % of 2010 value, 2010-2019



Source: ABS, Cebr analysis

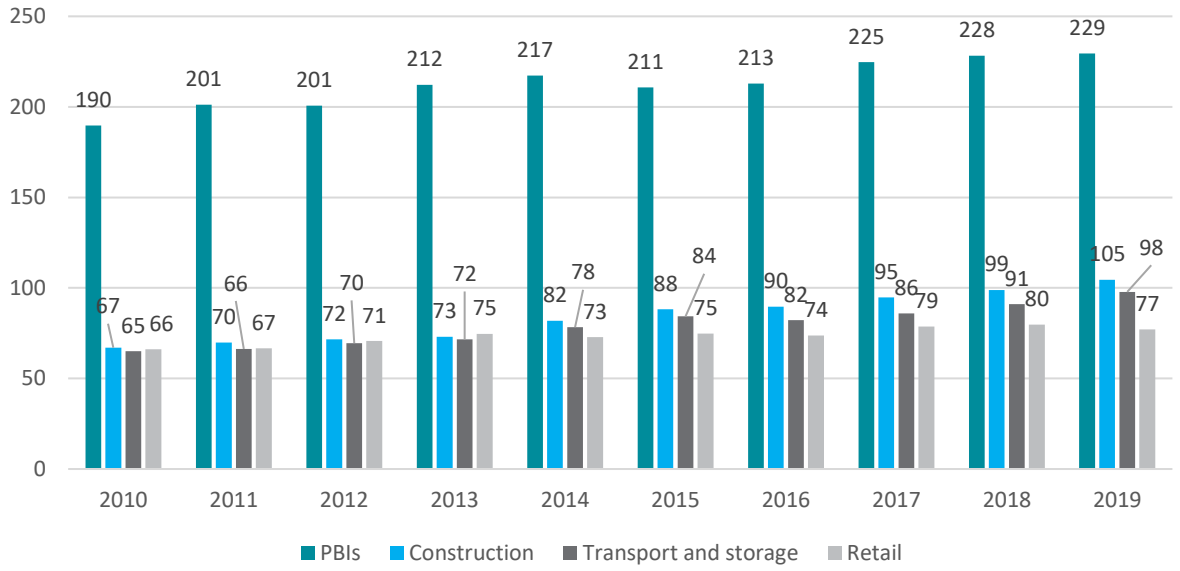
We note the significantly smaller range in the GVA contributions of these categories of PBIs than was observed for turnover. Using figures taken for 2019, this is driven by a relatively low rate of GVA generated per pound of turnover in the large Physics Manufacturing sub-sector (£0.32), compared to the overall average of £0.37 of GVA generated per pound of turnover. The sub-sector with the highest GVA contribution per pound of turnover is Physics Science &

Technology at £0.48, suggesting that a larger share of activity occurs 'in-house', with lower levels of externally-sourced goods and services.

Industry comparison

The GVA contributions of the PBIs is compared with the same selection of other sectors in Figure 16 below. On this measure, the gap is even wider between PBIs and the other sectors: the PBIs directly generate more than twice the GVA of all three sectors across the entire period.

Figure 16: GVA in selected UK sectors, £ billions, 2010-19

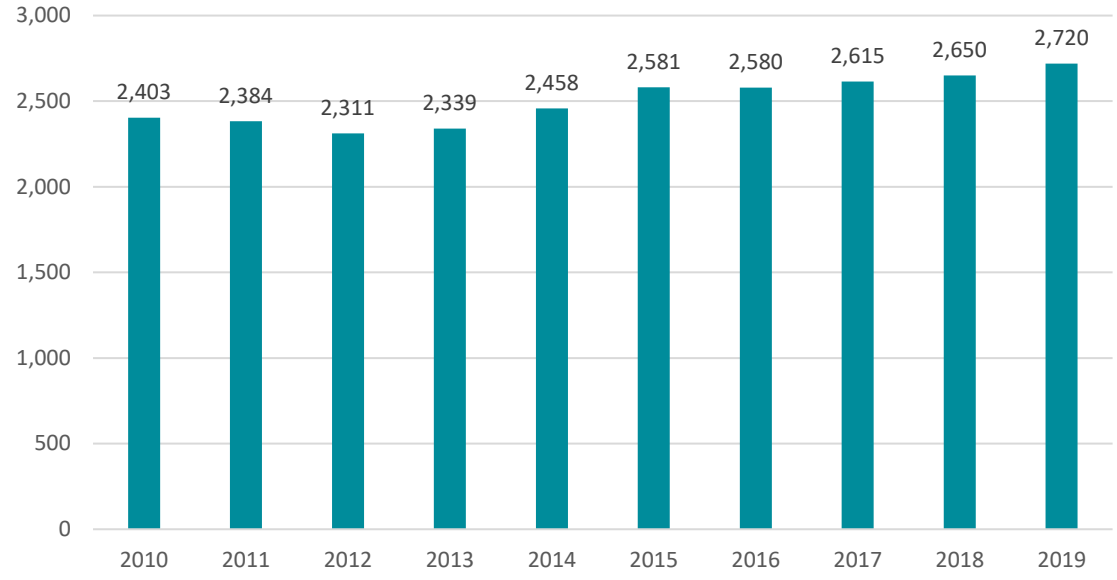


Source: ABS, Cebr analysis

3.2 Employment

Cebr's estimates suggest that employment in the PBIs topped more than 2.72 million in 2019 and amounted to a 10.0% share of total UK employment. Employment growth averaged 1.3% annually between 2010 and 2019 but was strongest in 2014, at 5.1%.

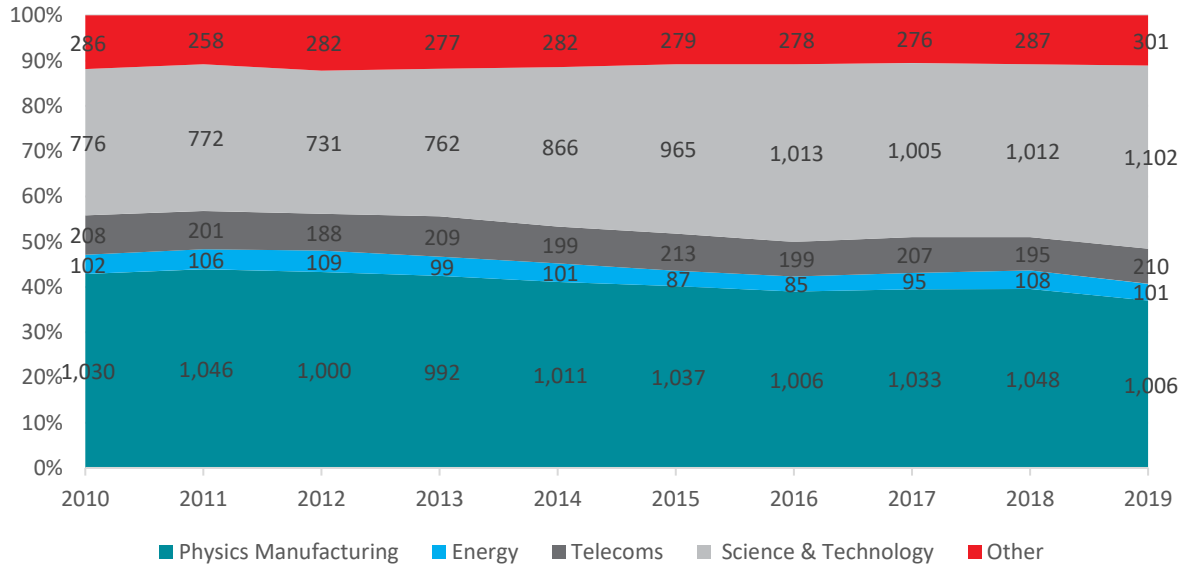
Figure 17: Physics-based employment in the UK, FTEs, thousands, 2010-19



Source: BRES, Cebr analysis

Large shares of employment in the PBIs are again accounted for by Manufacturing and Physics Science & Technology (37% and 40.5% recorded in 2019, respectively). However, while employment in the Physics Manufacturing sub-sector was relatively steady (just over 1 million FTEs over the whole period), the Physics Science & Technology sub-sector rose significantly, from 776,000 to 1.1 million (41.9%). In fact, this sub-sector grew more than the aggregated PBIs overall (325,000 compared to 318,000). Over the decade, PBI employment growth was heavily dependent on this industry.

Figure 18: Employment in selected UK PBIs, % of PBI total (LHS axis), thousands, 2010-2019



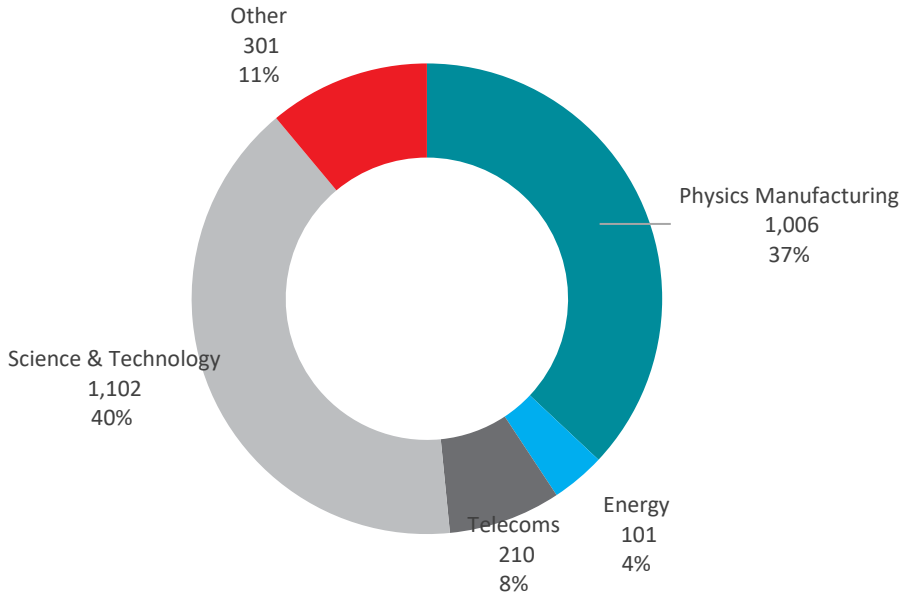
Source: BRES, Cebr analysis

Energy Production, Transmission & Distribution production (at 4%) and Telecommunication activities (at 8.1%) are the other sub-sectors of note contributing significant shares of employment within the PBIs. But, as Figure 18 above demonstrates, despite low shares of employment, these sub-sectors contribute much more significant shares of the PBIs' GVA,

with Energy Production, Transmission & Distribution accounting for 9.6% in 2019 (but higher shares of 10-11% in previous years) and Telecoms accounting for 14.2%.

Figure 19 shows the number and share of FTE employment across the most prominent sub-sectors for UK PBIs in 2019. See Table 17 in Appendix III**: Supplementary figures and tables** for a full breakdown of FTE employment estimates for all industries.

Figure 19: FTE employment across UK PBIs, FTE jobs and %, 2019



Source: BRES, Cebr analysis

Labour productivity

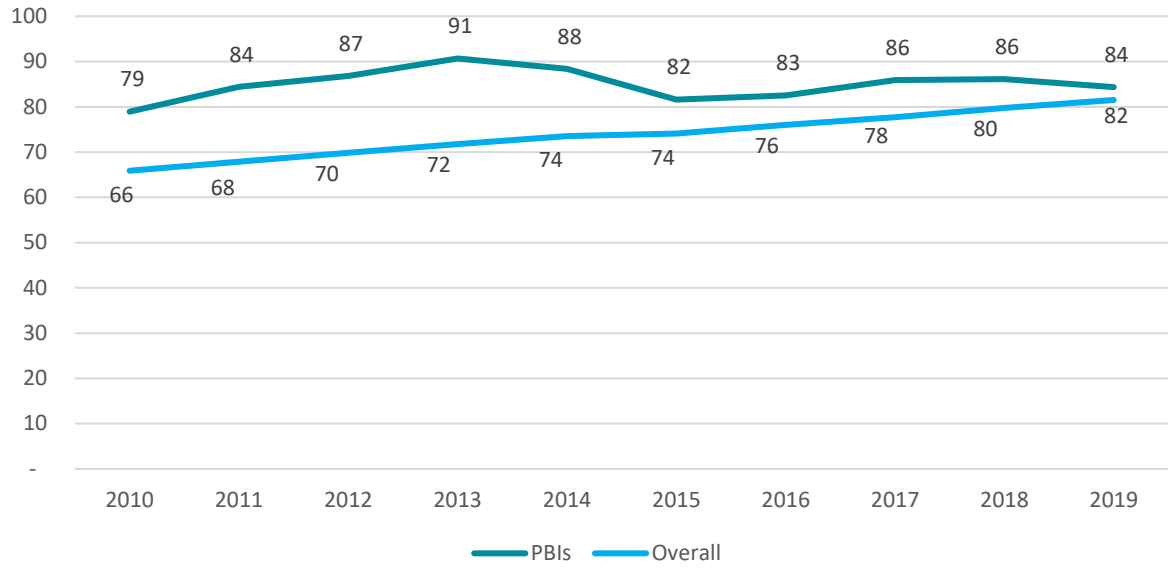
Labour productivity is defined as annual GVA over the number of FTE workers in the same year, or output per worker per year. For UK PBIs,

The Physics Science & Technology sub-sector had a vast rise in employment in the 2013-2016 period, while its GVA in the same years increased more slowly, which brought down its labour productivity. The Oil & Gas Extraction sub-sector is also responsible for the decreasing productivity: while GVA started to decrease in 2012, its FTE value stagnated, and since this is generally the sub-sector with the highest labour productivity, the decrease in share of PBI employment attributable to Oil and Gas Extraction contributed to a decline in aggregated PBI productivity.

Figure 20 shows the evolution of this metric over the period, compared to the same trend for the UK overall. For PBIs it is a fluctuating trend, but over the whole 2010 to 2019 period, labour productivity increased by 6.9% from £79,000 to £84,300. There was a local peak in 2013 at £90,700 of output per worker.

The Physics Science & Technology sub-sector had a vast rise in employment in the 2013-2016 period, while its GVA in the same years increased more slowly, which brought down its labour productivity. The Oil & Gas Extraction sub-sector is also responsible for the decreasing productivity: while GVA started to decrease in 2012, its FTE value stagnated, and since this is generally the sub-sector with the highest labour productivity, the decrease in share of PBI employment attributable to Oil and Gas Extraction contributed to a decline in aggregated PBI productivity.

Figure 20: Labour productivity for PBIs in the UK and for the UK overall, £ thousands, 2010-2019



Source: ABS, BRES, Cebr analysis

Table 3 presents a comparison between the share of total FTE employment in the UK PBI sector for each PBI and the share of the total GVA that is contributed by each respective sub-sector. In 2019, we find that these shares were broadly proportional, with the exception of four industries: Oil & Gas Extraction, Energy Production, Transmission & Distribution, Telecoms, and Physics Science & Technology. The Physics Science & Technology sub-sector's employment share was more pronounced than its GVA contribution, while in the Oil & Gas Extraction, Energy Production, Transmission, & Distribution and Telecoms sub-sectors, their contributions to the total GVA generated by the UK PBIs was greater than their respective shares of FTE employment. This suggests that labour productivity – defined as GVA per FTE employee – is higher in these three sub-sectors than the PBI average, while the reverse is true in the Physics Science & Technology sub-sector.

Table 3: Comparison between the shares of GVA and FTE employment by UK PBIs, 2019

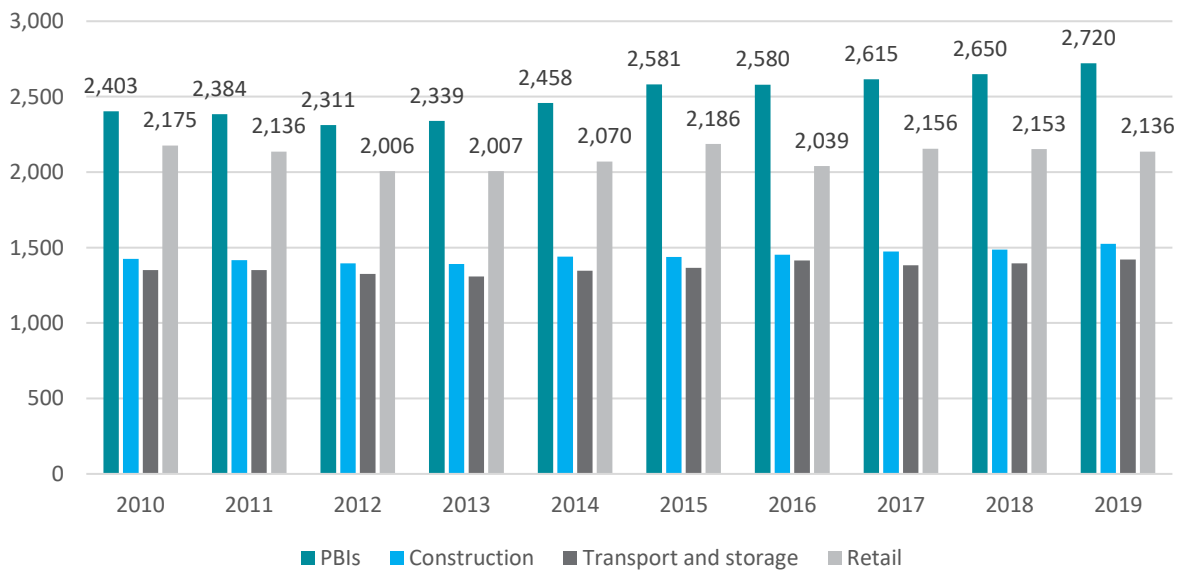
Sub-sector	Share of 2019 GVA	Share of 2019 employment
Oil & Gas Extraction	6.8%	0.5%
Physics Manufacturing	31.4%	37.0%
Physics Machine Services	3.2%	4.7%
Energy Production, Transmission & Distribution	9.6%	3.7%
Physics Waste & Recovery	1.1%	1.4%
Physics Machine Sales	0.3%	0.3%
Medical Equipment Sales	0.2%	0.3%
Space Transport & Air Transport Services	3.0%	2.0%
Telecoms	14.2%	7.7%
Physics Science & Technology	29.1%	40.5%
Defence	1.1%	1.9%

Source: ABS, BRES, Cebr analysis

Industry comparison

Compared to the same three external sectors, the PBIs contribute the greatest share of employment, as seen in Figure 21. However, this trend is not as pronounced as when considering turnover and GVA - suggesting a labour productivity advantage of the PBIs over the retail sector. For a similar share of UK employment, the PBIs generate a greater GVA contribution to GDP than the retail sector. Similar conclusions can be drawn about the PBIs relative to the Construction and Transport sectors.

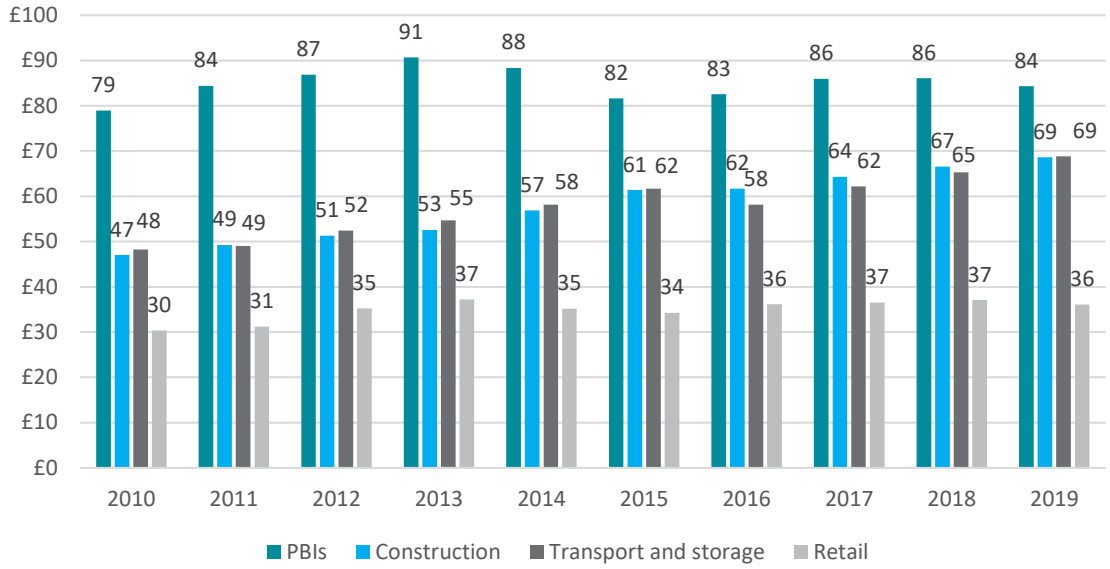
Figure 21: Employment in selected UK sectors, thousands, 2010-2019



Source: BRES, Cebr analysis

Figure 22 considers the labour productivity in the PBI sector and other selected UK sectors. Labour productivity is highest in the PBIs compared to the other comparator sectors, however productivity growth has been stronger in the Construction and Transportation & Storage sectors.

Figure 22: Labour productivity in the PBIs and selected comparator sectors, thousands, 2010-2019

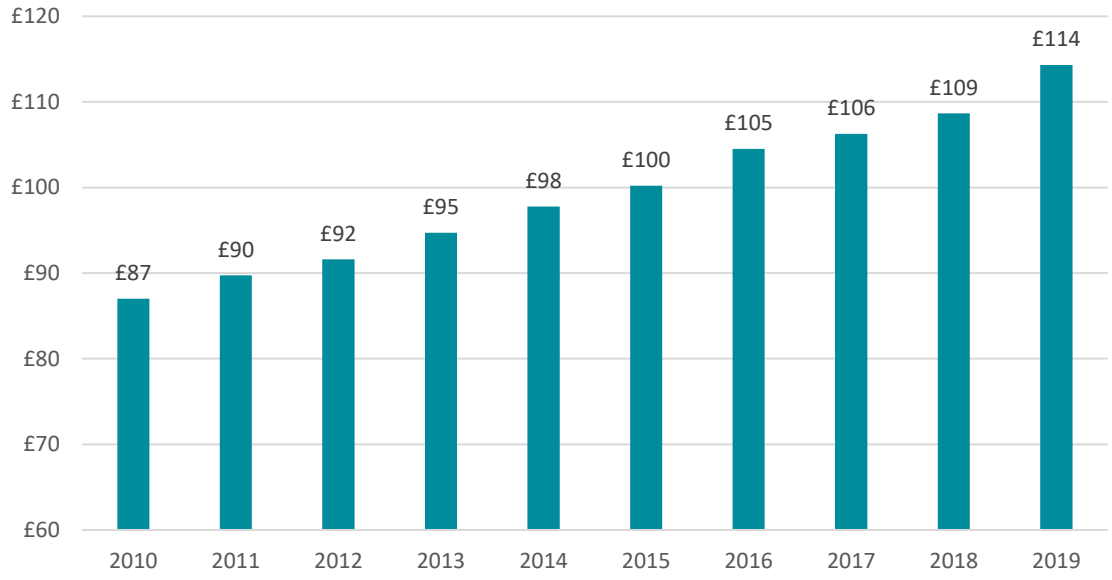


Source: ABS, BRES, Cebr analysis

3.3 COE

When it comes to compensation of employees (COE), PBIs experienced a steady growth of 31.3% from 2010-2019, or 3.1% on a yearly average, from £87 billion to £114 billion. This was a much higher growth rate compared to employment, meaning that average employee compensation increased throughout the period. Specifically, average compensation per employee (FTE) increased from £36,200 to £42,000 (16.1%) in the PBIs.

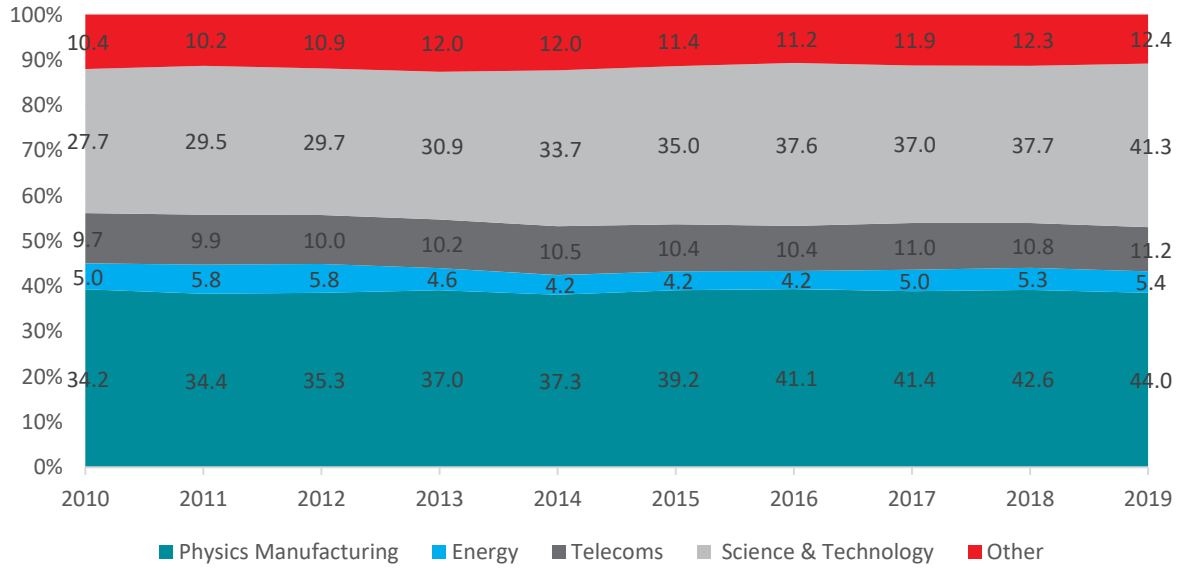
Figure 23: Physics-based COE in the UK, £ billions, 2010-19



Source: ABS, Cebr analysis

As before, the Physics Manufacturing sub-sector was the largest contributor, with 38.8% of all PBI employee compensation. The Physics Science & Technology sub-sector was a close second with 34.2%. The third largest was Telecoms, with a 10.5% share of the total employment costs. Unsurprisingly, these largely mirror the distribution of employment (see below in Table 4).

Figure 24: COE in selected UK PBIs, % of PBI total (LHS axis), £ billions, 2010-19



Source: ABS, Cebr analysis

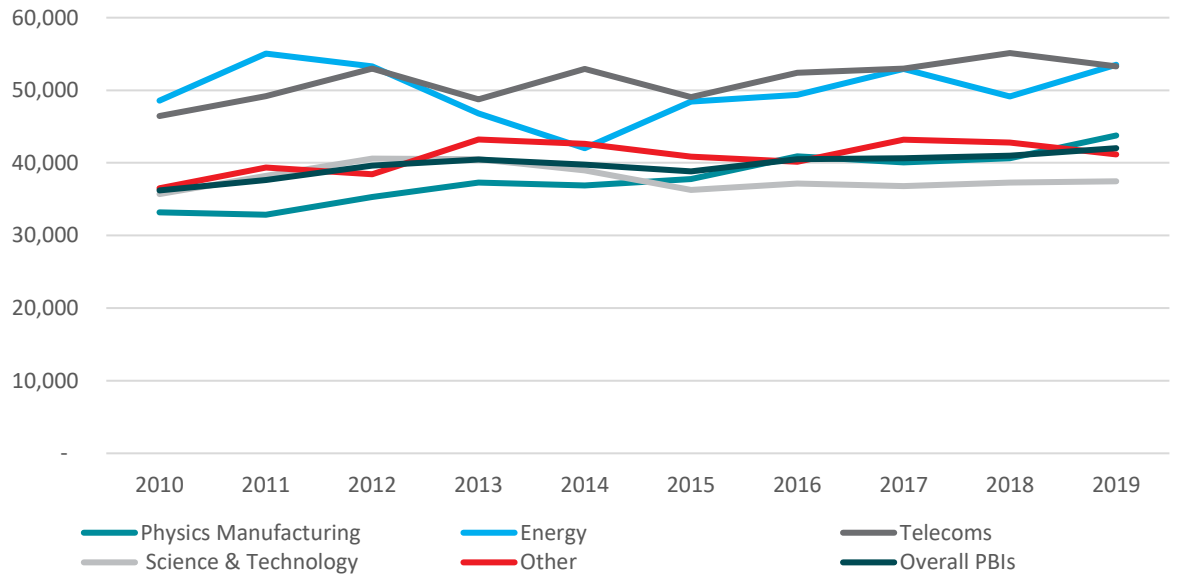
Table 4: Comparison between the shares of COE and FTE employment by PBIs in the UK, 2019

Sub-sector	Share of 2019 COE	Share of 2019 employment
Oil & Gas Extraction	1.7%	0.1%
Physics Manufacturing	38.5%	36.7%
Physics Machine Services	3.4%	4.8%
Energy Production, Transmission, & Distribution	4.7%	3.3%
Physics Waste & Recovery	1.4%	1.2%
Physics Machine Sales	0.3%	0.3%
Medical Equipment Sales	0.2%	0.3%
Space Transport & Air Transport Services	2.4%	2.0%
Telecoms	9.8%	7.7%
Physics Science & Technology	36.1%	41.7%
Defence	1.6%	1.9%

Source: ABS, BRES, Cebr analysis

The average compensation per FTE worker increased overall across PBIs. The Physics Manufacturing sub-sector particularly saw significant growth, increasing by 31.8% over the period. Out of the highlighted sub-sectors, Energy Production, Transmission & Distribution and Telecoms had the largest average employment benefit: more than £53,000 in 2019 for both. Aggregated, the PBIs experienced 16.1% growth in employee compensation per FTE worker over the period. This is very similar to the 16.4% growth in mean wages for full-time workers across all industries in the UK, over the same period.

Figure 25: Compensation per FTE in selected UK PBI sub-sectors, 2010-2019



Source: ABS, BRES, Cebr analysis

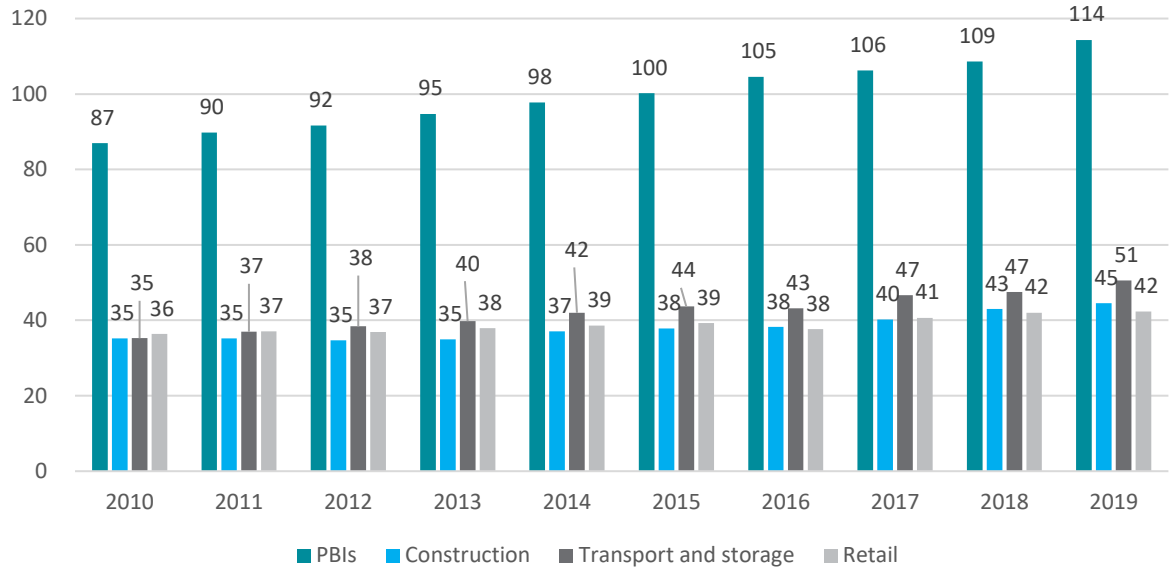
It is notable that while employment growth as a whole in the UK's physics sector over the period was predominantly driven by the Physics Science & Technology sub-sector (total employment growth over the period of 325,000 FTEs, compared to just 317,500 for the aggregated PBIs), this increased demand for employees in the sub-sector did not result in a significant increase in average COE. Average COE/FTE in the Physics Science and Technology sub-sector grew by just 4.9% (£1,755) over the period, well below the average COE/FTE growth in the wider PBIs of 16.1%.

Perhaps explaining this, labour productivity in the sub-sector only increased by 4.3% (£2,500) over the decade. This could be a function of the growth in the sub-sector in absolute terms being supported by an increased labour supply rather than an increase in capital investment (an expanded capital base per worker typically increases labour productivity), but further research would be required to identify this with confidence.

Industry comparison

Figure 26 shows the employee compensation of the PBIs and the comparator sectors. Unsurprisingly, the trend is very similar to that seen for GVA. While the number of employees was also greater within the PBI sector, the difference was not as drastic as when considering employee compensation here. This suggests that the average COE/employment ratio was much higher compared to the other three sectors. Furthermore, both Construction and Retail had lower yearly average COE growth than the PBIs: 2.7% and 1.7%, respectively. Only the Transport & Storage sector growth exceeded the PBIs, with 4.1% average growth.

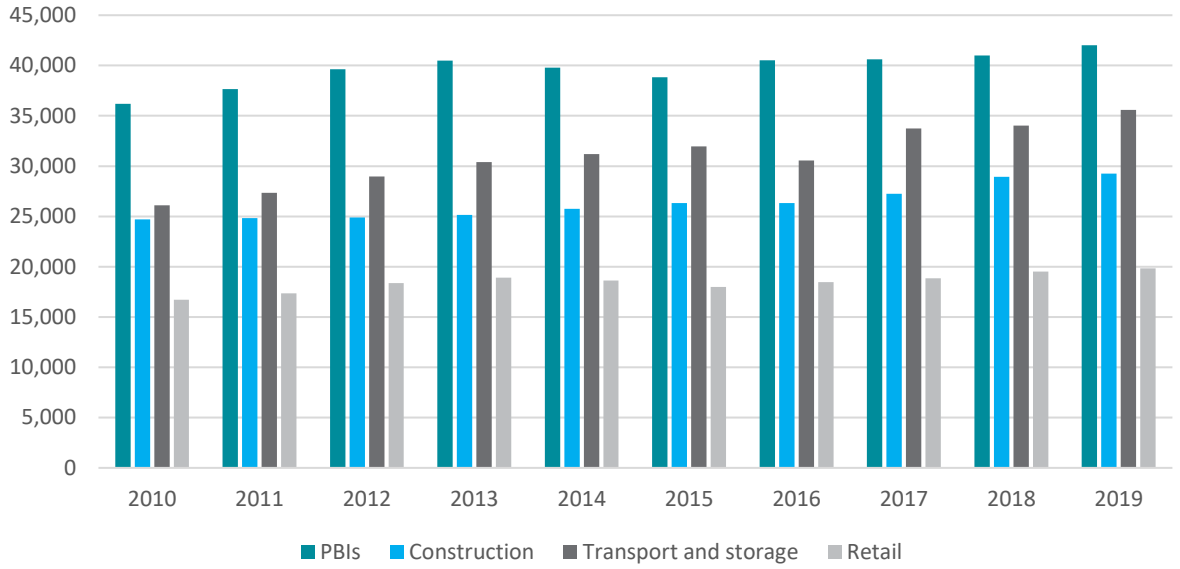
Figure 26: COE in selected UK sectors, £ billions, 2010-19



Source: ABS, Cebr analysis

Average employee compensation per FTE employee was also highest in the PBIs, compared to the comparator sectors, with slightly more than £42,000 in 2019.

Figure 27: Average compensation per FTE employee in selected UK sectors, £, 2010-2019



Source: ABS, BRES, Cebr analysis

4. Aggregate economic contribution of the PBIs to the UK economy

4.1 Modelling overview and PBI supply chain

The wider economic footprint of the PBIs goes beyond the direct impacts discussed in the prior section. This section identifies the aggregate footprint supported by considering two further impact layers:

- **Indirect impacts** – Businesses in the PBIs place demands on their upstream supply chains, purchasing goods and services they need for operations. This supports significant further demand along supply-chains, and output and jobs amongst their suppliers. In turn, these suppliers place demands on their suppliers which support further output and jobs. The indirect impact captures the revenue, GVA, employment and COE supported along the supply-chains as a result of these operations.
- **Induced impacts** – The workers who receive income and employment benefits through the direct (PBI employees) and indirect (suppliers to the sector and in turn their suppliers) channels spend their increased earnings on goods and services in the wider economy. This helps to further stimulate demand, supporting additional revenue, GVA, employment and COE. The induced impact captures these wider-spending effects.
- Summing these direct, indirect, and induced impact layers allows us to estimate the **aggregate footprint** supported by the PBIs.

To compute these impacts, Cebr uses input-output (IO) modelling. This allows us to identify the key sectors of the economy from which firms in the PBIs purchase their inputs.

Table 5 illustrates the composition of the PBI supply-chain, based on aggregated data detailed in the ONS' UK National Accounts.[13] As can be seen, there is a high-degree of interconnectivity within the PBIs, with just under half of supply-chain inputs demanded from other firms also within the PBIs.[14]

13 https://www.ons.gov.uk/economy/nationalaccounts

14 Note that the sectors seen in Table 5 are broader sectors of the economy; many of their respective sub-sectors have an overlap with the PBIs, but for the purposes of this analysis that interlinkage has been stripped out. For example, the 6.6% of Manufacturing inputs, is the non-Physics Manufacturing component of the wider manufacturing sector.

Table 5: Disaggregation of composite supply chain associated with PBIs, 2017[15]

Sector	% of inputs
Other PBIs	45.5%
Wholesale and retail trade, repair of motor vehicles	12.1%
Manufacturing	6.6%
Professional, scientific and technical activities	6.4%
Financial and insurance activities	5.1%
Electricity, gas, steam and air-conditioning supply	4.5%
Transportation and storage	3.9%
Administrative and support service activities	3.9%
Information and communication	3.6%
Construction	2.2%
Real estate activities	1.4%
Public administration and defence; compulsory social security	1.3%
Mining and quarrying	1.0%
Water supply; sewerage, waste management	1.0%
Accommodation and food service activities	0.6%
Education	0.4%
Agriculture, forestry and fishing	0.2%
Other service activities	0.1%
Human health and social work activities	0.1%
Arts, entertainment and recreation	0.0%
Activities of households	0.0%

Source: ONS supply-use tables, Cebr analysis

The input-output model employed uses this supply-chain disaggregation to calculate the economic contributions supported along the supply chains of PBIs. We then use typical employee-spending patterns, per the UK National Accounts to estimate the induced impact layer.[16]

15 Supply-chain decomposition based on the most contemporaneous granular supply-use data, which was released earlier in 2021, for the structure of the economy in 2017.

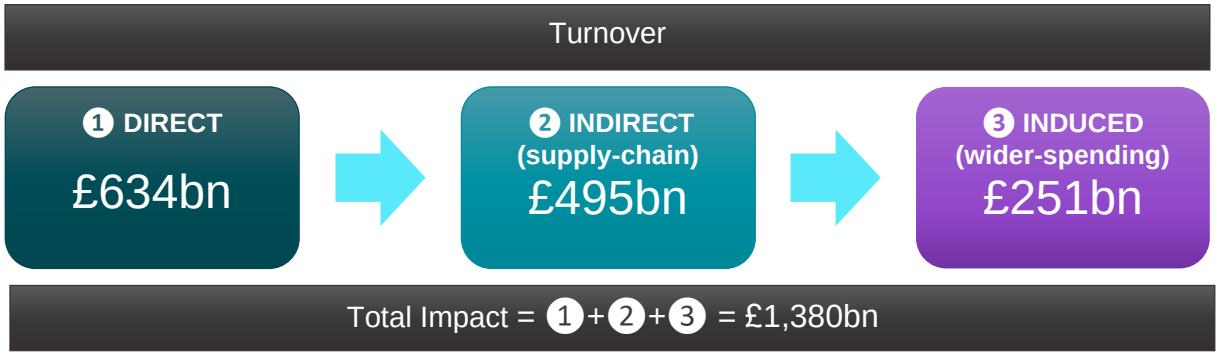
16 A way to conceptualise this is to think of the compensation of employees (and thus employee compensation) as an intermediate consumption purchase. We are not interested in the amount spent on compensation on a first order basis, but we are interested in where households go on to spend this money, i.e. the intermediate consumption of the "employee compensation industry".

4.2 Turnover

The PBIs directly generated an estimated £634 billion in turnover in 2019. Through our input-output modelling, we estimate that this direct turnover supports an additional £495 billion worth of turnover along the supply-chains (the indirect effect). Furthermore, it is estimated that the increase in wider-spending that occurs when PBI employees (and the employees supported along the supply-chains) spend their earnings in the wider economy supports £251 billion (the induced effect).

Combining these direct, indirect, and induced impacts, it is estimated that the PBIs support an aggregate footprint of £1,380 billion in turnover.

Figure 28: Turnover multiplier results, 2019[17]



Source: ONS supply-use tables, Cebr analysis

These figures should be interpreted as follows. For every £1 in turnover directly generated by the PBIs, a further £0.78 of turnover is supported in firms along their supply chains. Furthermore, £0.40 of turnover is supported in UK businesses when individuals associated with the direct and indirect impact layers spend their earnings in the wider economy. Summing the indirect and induced layers together, we can say that **for every £1 of turnover directly generated by the PBIs, a further £1.18 worth of turnover is supported in the wider economy**.

5.3 GVA

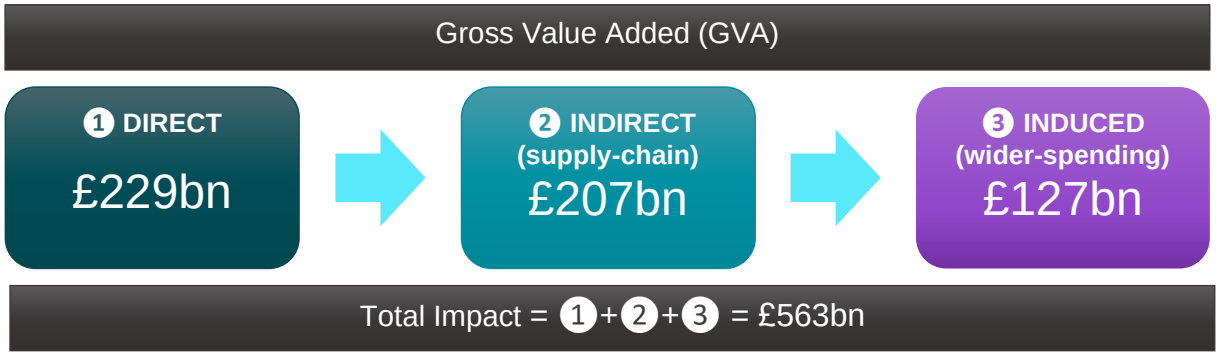
In 2019, the PBIs directly generated £229 billion in GVA contributions.

It is estimated that a further £207 billion worth of GVA contributions are supported along the supply-chains (the indirect effect) and £127 billion is supported when PBI employees (and employees along their supply chains) spend their earnings in the wider economy. Combining the direct, indirect and induced impact layers, it is estimated that the PBIs supported an aggregate economic footprint of £563 billion worth of GVA in 2019.

Figure 29 illustrates our calculated GVA multipliers for the PBIs.

17 Due to rounding, the total impact figure does not correspond precisely with the sum of the separate figures.

Figure 29: GVA multiplier results, 2019



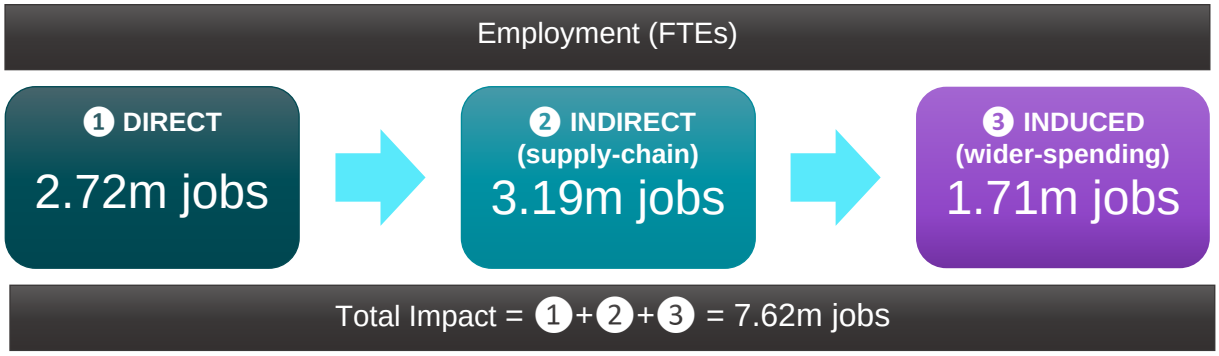
Source: ONS supply-use tables, Cebr analysis

Once again, it is possible to generalise this result by considering the ratios between the direct, indirect and induced impact layers. **For every £1 in GVA directly generated by the PBIs, a further £1.46 is supported through the indirect and induced impact channels.**

5.4 Employment

Figure 30 illustrates our calculated employment multipliers for the PBIs.

Figure 30: Employment multiplier results, 2019[18]



Source: ONS supply-use tables, Cebr analysis

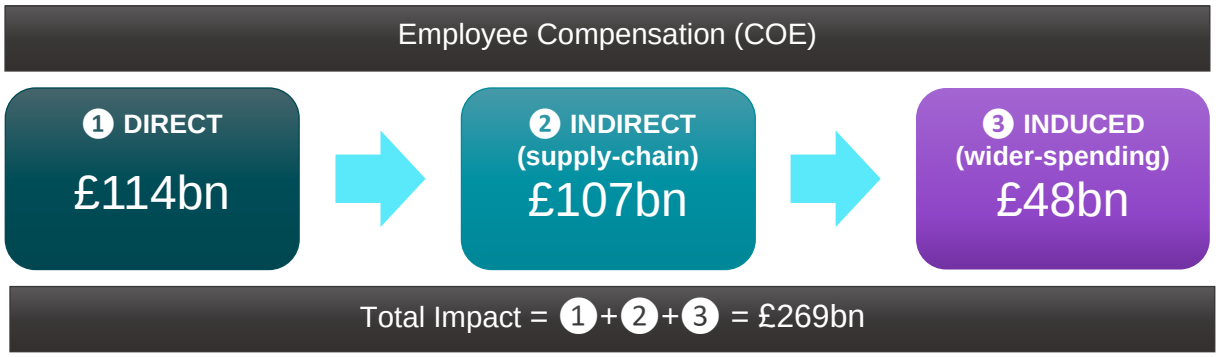
The modelling shows that for every ten jobs directly generated by the PBIs, a further 12 jobs are supported along their supply chains. Moreover, a further six are supported when employees associated with the direct and indirect impact layers spend their earnings in the wider economy. By combining the indirect and induced impact layers, our modelling shows that **for every ten jobs directly generated by the PBIs, a further 18 jobs are supported in the wider economy.** Overall, on an FTE basis, 7.6 million jobs are supported across the economy.

5.5 COE

Finally, we are interested in the aggregate compensation of employees supported by the PBIs. In 2019, COE was £114 billion. The effects of the additional indirect and induced impacts are set out below, in Figure 31.

18 Due to rounding, the total impact figure does not correspond precisely with the sum of the separate figures.

Figure 31: COE multiplier results, 2019



Source: ONS supply-use tables, Cebr analysis

In addition to the direct impact, we estimate that the indirect and induced economic activity supported by the PBIs supports an additional £155 billion of employee compensation. **For every £1 in employee compensation directly generated by the PBIs, a further £1.36 of compensation is supported through the indirect and induced impact channels.**

5. Contribution to the national and regional economies

This section provides an assessment of the importance of PBIs to the UK nations and regions in terms of employment, turnover, GVA and business demographics over the period 2010-2019. Further detailed comparisons between the respective nations are available in the respective nation reports.

5.1 Turnover

Table 6 provides a detailed breakdown of the PBIs' turnover on a yearly basis, between the constituent UK nations and English regions. Across the decade, more than 80% of all PBI turnover was generated in England (83% on average over the period), and this proportion grew: in 2010 England contributed slightly less than 82% of total PBI turnover in the UK, by 2019 this reached 84.1%. Welsh-based PBIs also increased their contribution to turnover across the period (from 3.8% to 4.2%), while PBIs in Northern Ireland consistently contributed approximately 1.6% to the total UK turnover. Scotland, whose economy is heavily dependent on the Oil & Gas Extraction sector, saw a reduction in its share of UK-wide PBI turnover during the period.

Table 6: Turnover in UK PBIs, distinguished between nations and English regions, £ billions, 2010-2019

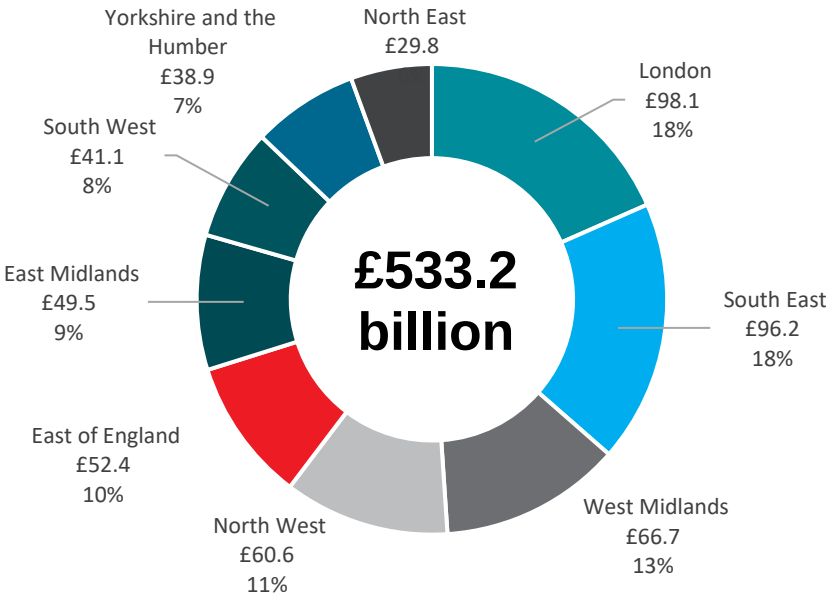
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
England	417.1	442.1	452.3	462.9	463.2	459.3	482.9	517.1	530.2	533.2
Scotland	65.9	70.8	58.1	64.0	62.8	59.5	60.8	58.4	60.4	63.8
Wales	19.6	23.5	23.2	25.9	25.6	30.4	26.1	30.2	26.7	26.7
Northern Ireland	8.0	8.9	9.1	9.4	11.5	11.1	9.6	9.7	9.6	10.1
East of England	39.7	42.6	40.7	42.4	40.9	44.4	50.9	48.8	53.5	52.4
East Midlands	30.9	33.3	36.2	36.2	38.2	40.4	37.4	46.2	46.4	49.5
London	73.8	78.3	85.5	85.8	89.4	80.5	82.9	90.9	97.6	98.1
North East	23.3	33.9	30.3	34.3	34.3	31.2	32.2	32.6	31.5	29.8
North West	47.0	52.9	49.9	52.5	52.2	53.6	57.7	65.0	65.0	60.6
South East	97.3	92.0	90.0	92.4	86.9	81.8	96.4	95.4	95.2	96.2
South West	35.2	38.6	35.9	39.0	39.0	44.4	41.1	46.3	38.9	41.1
West Midlands	39.0	40.3	47.2	47.1	46.0	48.8	52.2	57.6	63.3	66.7
Yorkshire and the Humber	30.9	30.1	35.7	33.0	35.9	34.2	32.1	34.3	38.8	38.9

Source: ABS, BRES, Cebr analysis

When it comes to the English regions, the greatest contributor up until 2018 was the South East, which accounted for 16.1% of the total turnover on average, followed by London with around 15%. Since 2018, PBIs in London contributed slightly more turnover than those in the

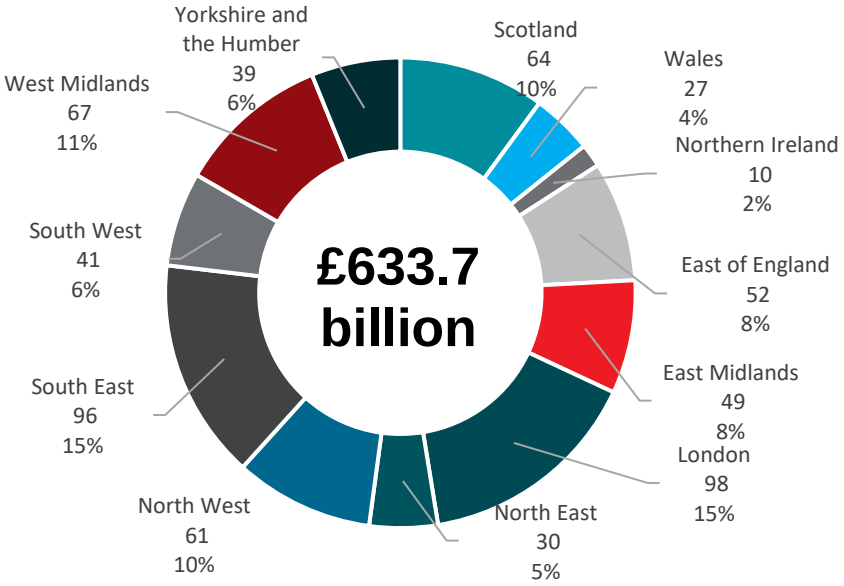
South East and is now considered the most significant region in terms of PBI turnover. The third most influential region was the North West, with a share of 9.7% of all UK PBI turnover on average. Figure 32 displays the proportion of PBI turnover generated in each English region visually for 2019, while Figure 33 shows the proportion of each UK nation for the same year.

Figure 32: Turnover in the different regions of English PBIs, £ billions, 2019



Source: ABS, BRES, Cebr analysis

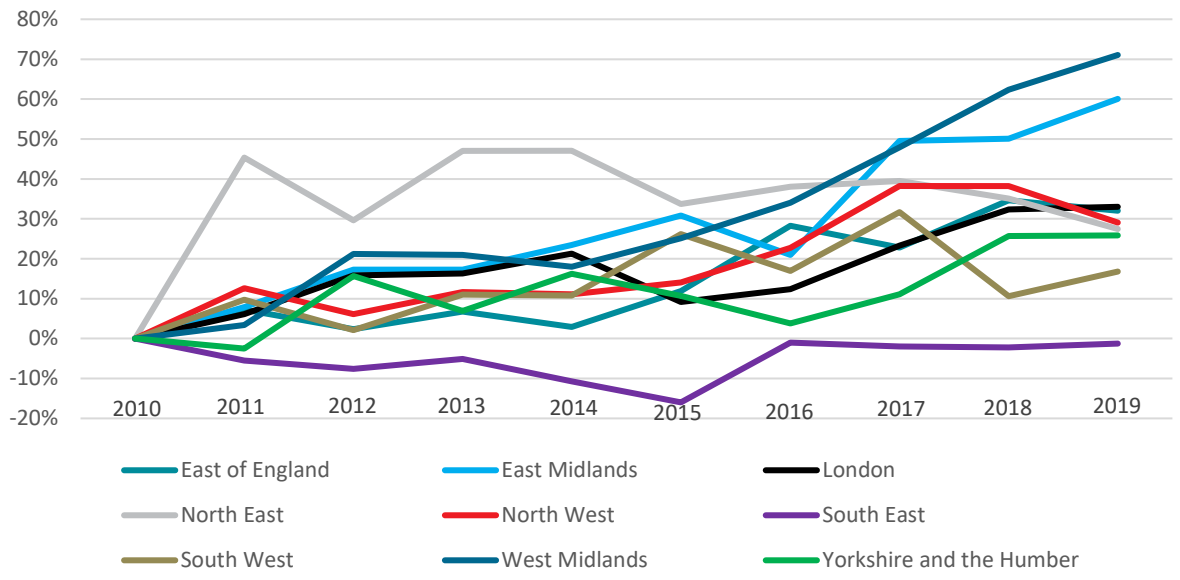
Figure 33: Turnover in PBIs across the different UK nations and regions, £ billions and %, 2019



Source: ABS, BRES, Cebr analysis

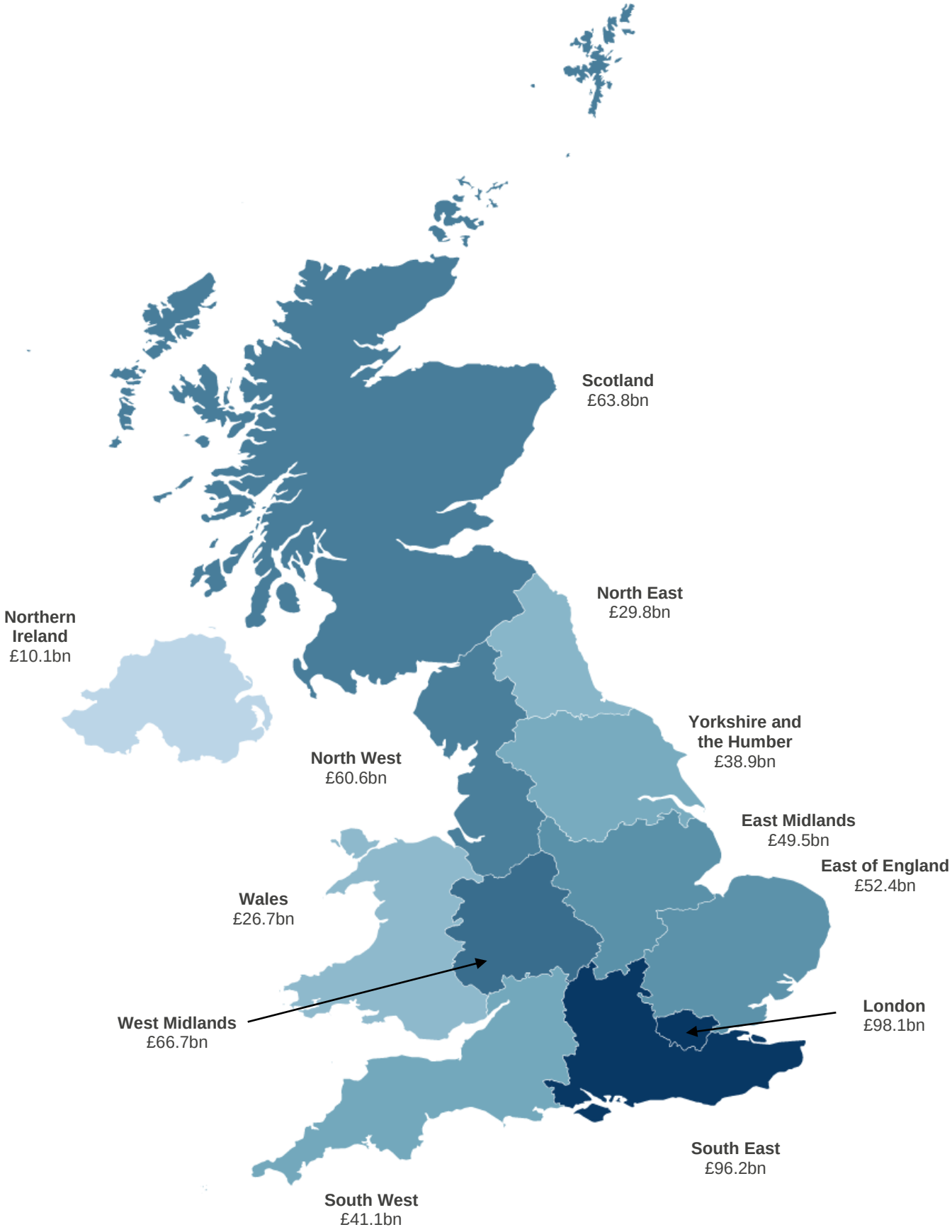
We also compare the turnover growth rates within each English region over the period, to understand the relative growth of the PBIs over the decade. In absolute terms, the relatively higher concentration of PBI activity in London and the South East is to be expected, given the respective broader economic contribution of these regions. However, in relative terms, the PBIs have enjoyed the strongest growth in the two Midlands regions; East Midlands and West Midlands. In both, nominal turnover growth in the PBIs grew by over 60% from 2010 to 2019. Full results can be seen below in Figure 34.

Figure 34: Cumulative turnover growth in the PBIs by English region benchmarked against 2010 regional turnover, 2010-2019



Source: ABS, BRES, Cebr analysis

Figure 35: Turnover breakdown by nation and region, 2019



Source: ABS, BRES, Cebr analysis

5.2 GVA

We now focus on the economic contribution of the PBIs to the UK national and regional economies in terms of their GVA contributions to GDP. Table 7 presents the nations' and regions' PBI GVA broken down by year. Comparing to the turnover, a similar pattern emerges: GVA generated by PBIs in England contributes more than 80% of UK PBI GVA every year, with an average of 83.2%. Importantly, this is slightly lower than the average value of England's GVA contribution to the total UK economy, which is 86.6%, showing the value created in PBIs across Wales, Scotland, and Northern Ireland to the UK economy.

The trend in Northern Ireland is more positive than for turnover; the total share of UK PBI GVA contributed by the PBIs in Northern Ireland increased over the period, from 1.2% to 1.5%. Scotland's share of the total GVA generated by UK PBIs decreased slightly over the period (from 14.3% to 12.4%), however this percentage contribution was higher than its turnover share, meaning that Scotland's GVA-turnover ratio is comparatively strong. Wales peaked in 2015 (3.9%), but then declined back to its 2010 proportion (3.2%) by 2019.

In absolute terms, the contribution of the PBIs in nominal terms to each UK nation increased over the period, demonstrating the consistent value of the physics sector.

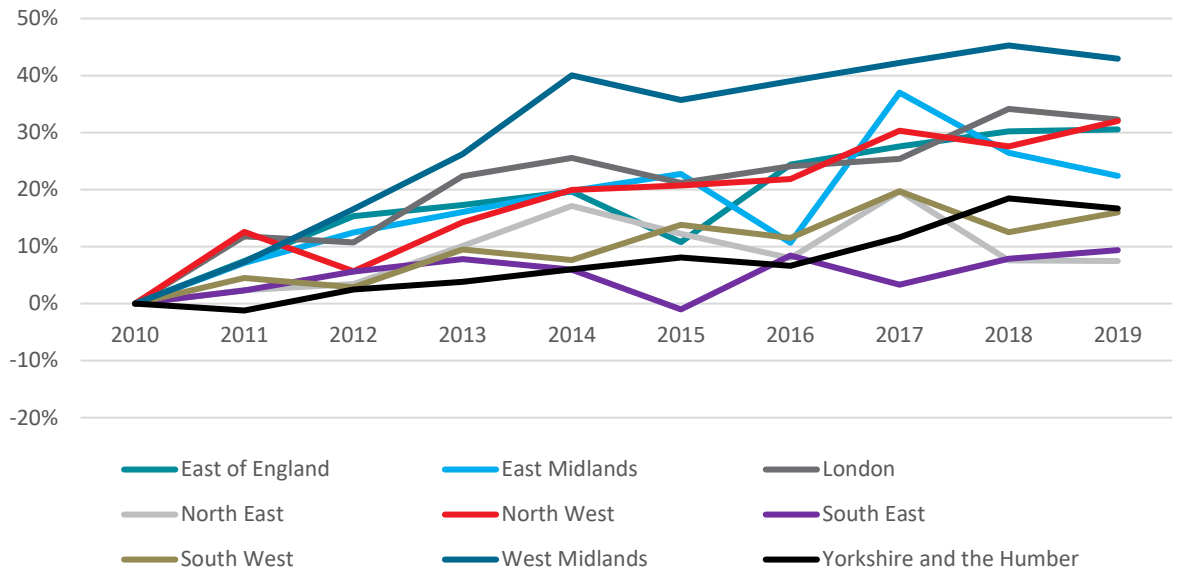
Table 7: GVA in UK PBIs, distinguished between nations and English regions, £ billions, 2010-2019

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
England	153.9	164.1	166.9	176.5	181.1	176.8	181.1	187.8	190.1	190.2
Scotland	27.2	27.7	24.1	24.9	25.0	22.2	21.4	25.9	26.6	28.4
Wales	6.1	6.6	6.9	7.6	8.2	8.2	7.3	8.1	8.2	7.3
Northern Ireland	2.4	2.7	2.7	3.2	3.0	3.4	3.1	2.9	3.3	3.5
East of England	14.6	15.7	16.8	17.1	17.4	16.1	18.1	18.6	19.0	19.0
East Midlands	10.8	11.6	12.1	12.5	12.9	13.2	11.9	14.8	13.6	13.2
London	30.8	34.4	34.1	37.7	38.7	37.3	38.2	38.6	41.3	40.7
North East	7.7	7.9	8.0	8.5	9.0	8.6	8.3	9.2	8.3	8.3
North West	17.9	20.2	18.9	20.5	21.5	21.6	21.8	23.3	22.9	23.7
South East	32.7	33.5	34.6	35.3	34.7	32.4	35.5	33.8	35.3	35.8
South West	14.5	15.1	14.9	15.9	15.6	16.5	16.2	17.4	16.3	16.8
West Midlands	13.9	14.9	16.2	17.6	19.5	18.9	19.4	19.8	20.2	19.9
Yorkshire and the Humber	11.1	11.0	11.4	11.5	11.8	12.0	11.8	12.4	13.2	13.0

Source: ABS, BRES, Cebr analysis

As for the English regions, the greatest contributor is London, with South East following, while in every region the GVA contributed by the PBIs increased over the decade. The PBIs in the West Midlands in particular enjoyed strong growth (42.9%), from £13.9 billion to almost £20 billion. The East of England, London, and the North West also increased by more than 30%. These full results can be seen below.

Figure 36: Cumulative GVA growth in the PBIs by English region benchmarked against 2010 regional GVA, 2010-2019

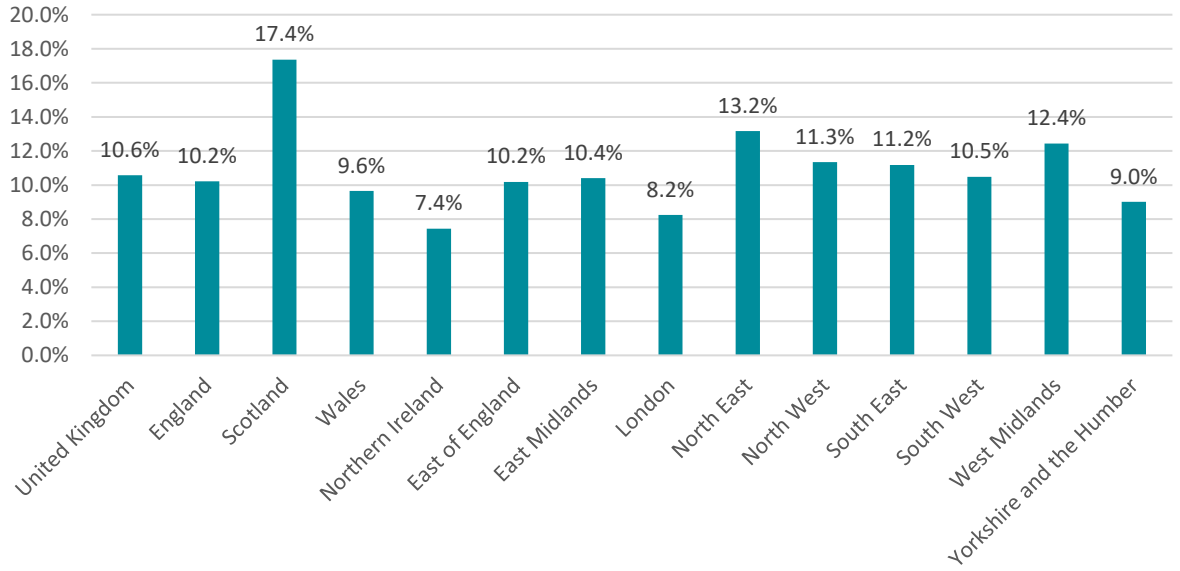


Source: ABS, BRES, Cebr analysis

As a further comparison, we consider the share of GVA in each nation and English region, attributable to the PBIs. By standardising for the wider level of economic activity within each nation or region, we can estimate the relative contribution of the PBIs to economic output within each area. The PBI sector is most influential in Scotland, where it contributes 17.4% of all GVA; this is driven by the high share of Oil & Gas Extraction activity in Scotland.

Despite the high GVA contribution in absolute terms, as a share of total regional GVA, London was also on the lower end with 8.2%. The rest of the nations and regions stood between 9-13%, although the contribution of the PBIs to the North East (13.2% of regional GVA) and the West Midlands (12.4%) is notable.

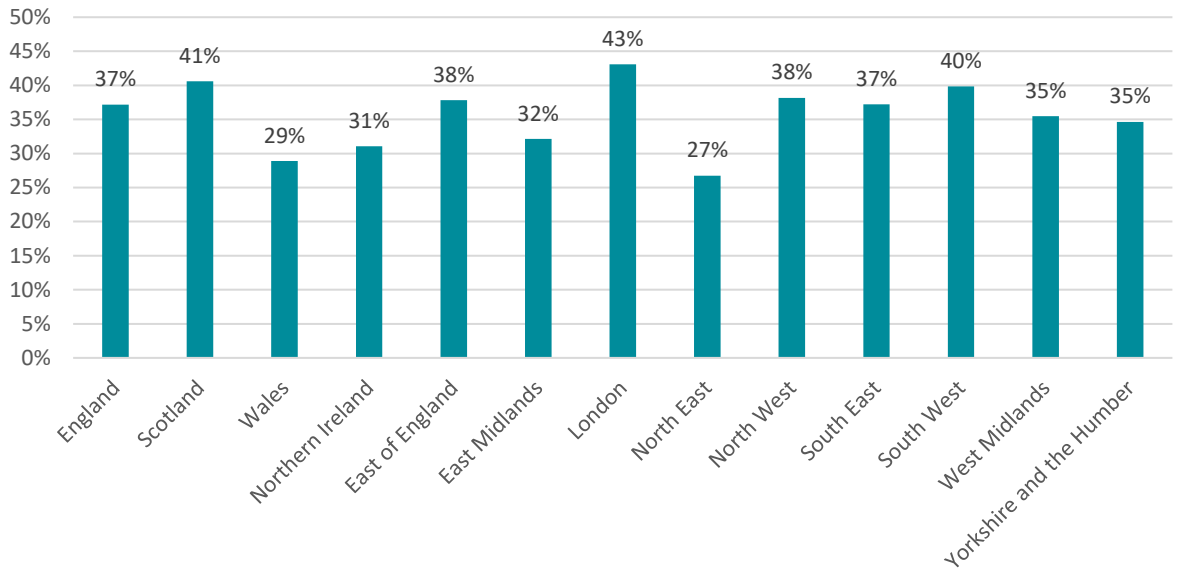
Figure 37: GVA share in UK PBIs, distinguished by nation and region, 2019



Source: ABS, Cebr analysis

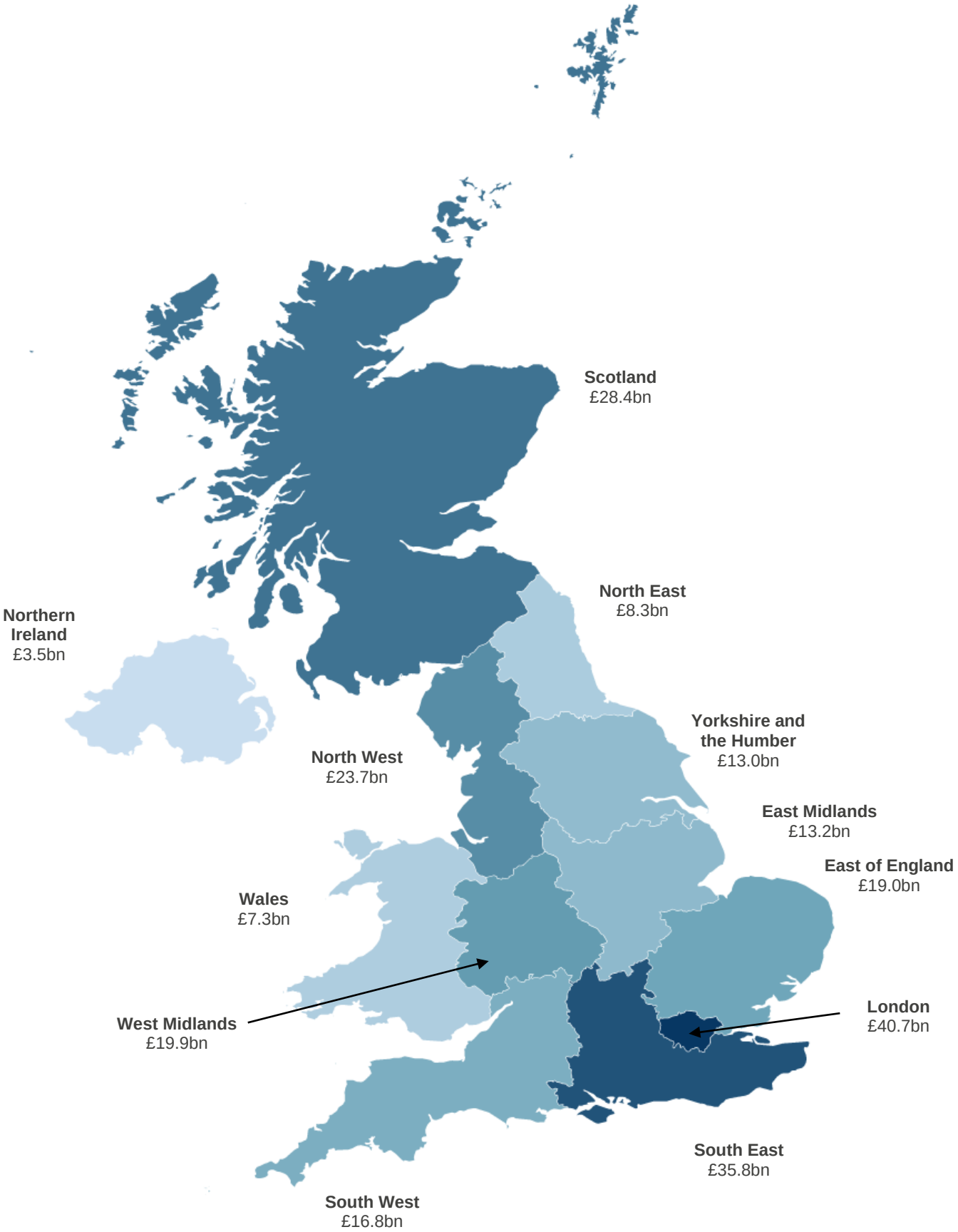
London and the South West are the English regions in which the PBIs have the highest GVA-turnover ratio, whilst Scotland is the only nation for which this holds true. This means that in these geographies, turnover most efficiently translates to direct GVA. Figure 38 shows this ratio in all UK nations and regions.

Figure 38: GVA-Turnover ratio in UK PBIs, distinguished by nation and region, average of 2010-2019



Source: ABS, Cebr analysis

Figure 39: GVA breakdown by nation and region, 2019



Source: ABS, BRES, Cebr analysis

5.3 Employment

As before, England provides the majority of the workers in PBI industries, with 85.3% (over 2 million FTE workers) of the total employment on average. This is broadly to be expected; this share is very similar to the share of FTE employment across the UK economy in all sectors, attributable to England (84.9%). The share of English PBI employment is slightly higher than for turnover and GVA, and the same pattern is seen in Wales (4.6%, over 100,000 FTE workers) and Northern Ireland (1.8%, nearly 50,000 FTE workers). Scotland on the other hand provides 8.3% of FTEs on average (just over 200,000 on average), which results in a much higher turnover/FTE and GVA/FTE ratio than in other countries. This is again due to the strong influence of the Oil & Gas Extraction sector in the nation, which has relatively high average wages and strong labour productivity.

Table 8: Employment in UK PBIs distinguished between nations and English regions, thousands, 2010-2019

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
England	2,055	2,037	1,971	1,991	2,075	2,187	2,211	2,237	2,257	2,338
Scotland	203	197	193	196	217	211	207	218	220	220
Wales	104	106	105	109	123	131	118	119	125	113
Northern Ireland	40	44	41	44	43	52	44	41	48	49
East of England	228	223	227	221	230	231	257	250	260	266
East Midlands	174	170	168	161	179	196	171	197	190	194
London	266	271	251	274	281	306	326	323	324	345
North East	102	107	95	95	107	123	112	124	105	108
North West	262	273	249	253	271	278	279	291	290	306
South East	378	362	357	362	370	370	398	374	396	403
South West	239	236	221	222	229	246	241	236	231	251
West Midlands	229	220	227	227	229	248	245	257	262	271
Yorkshire and the Humber	176	174	176	176	179	189	182	187	197	193

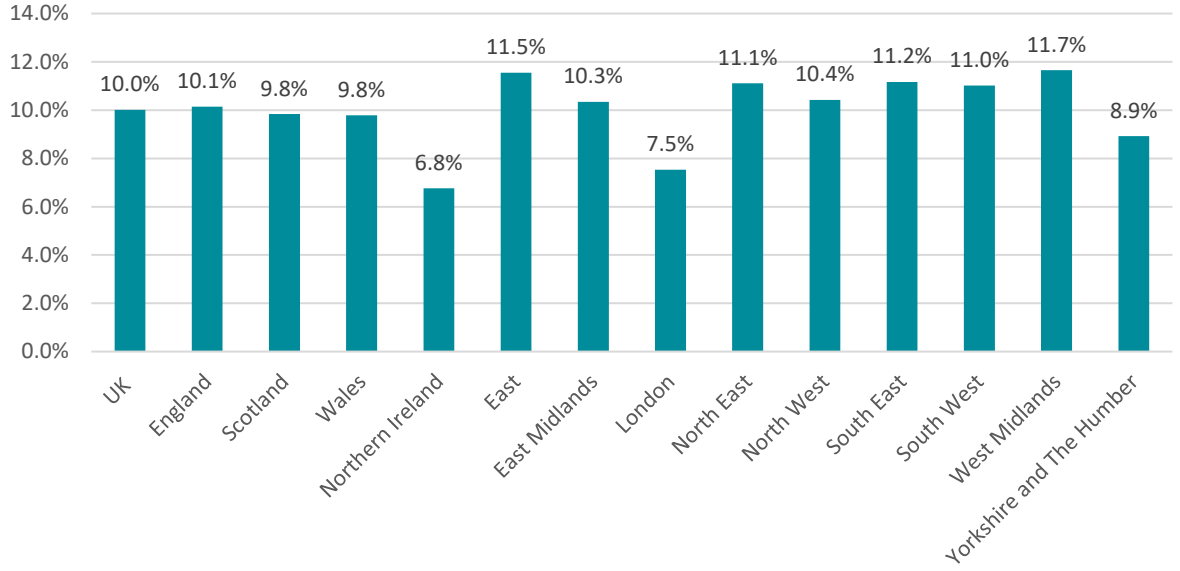
Source: ABS, BRES, Cebr analysis

When it comes to regions, the South East is the region with the largest proportion of PBI workers, 15.1% on average during the period. This is significantly higher than London, which had the second largest proportion (11.8%), although London did see a 29.4% increase in FTE employment over the period, supporting the strong growth trend observed for both GVA and turnover over the period. The West Midlands and the North West also grew by almost 20%, but the PBIs in all regions employed over 5% more people in 2019 than in 2010.

As with GVA, we consider the share of employment in each nation and region attributable to the PBIs. This distribution is relatively even, with around or just over one in every ten FTE employees in most geographies attributable to the PBIs. The exceptions here are Northern

Ireland, London and Yorkshire & the Humber, where while still providing significant levels of employment, the contribution of the PBIs is slightly lower.

Figure 40: FTE share in UK PBIs, distinguished by nation and region, 2019

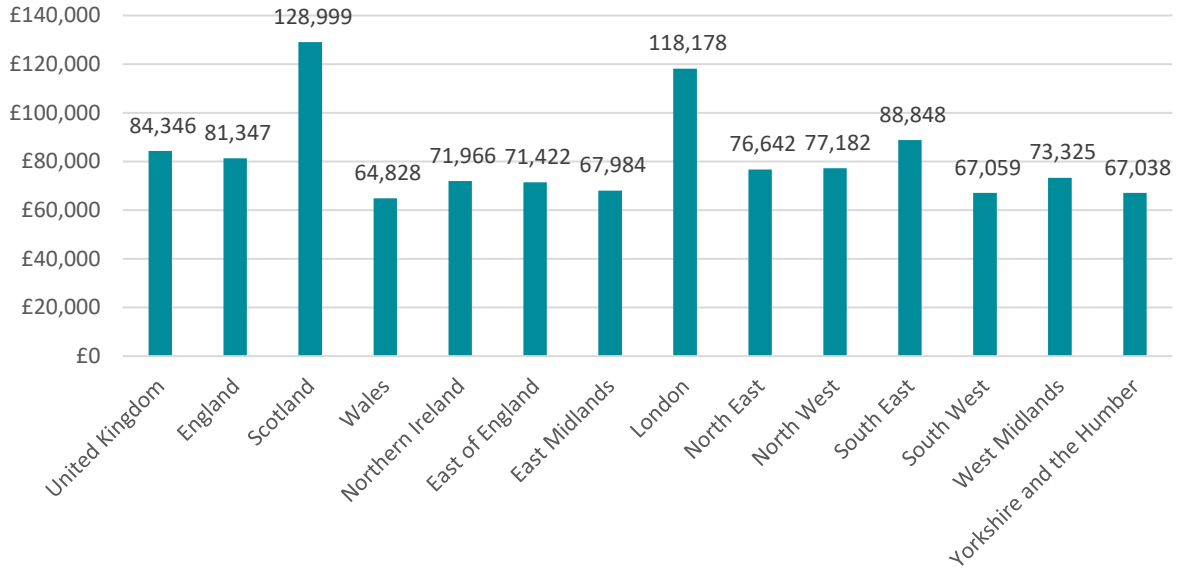


Source: APS, BRES, Cebr analysis

London's GVA per FTE worker is the highest in England, with an average of £118,000 GVA per worker, which is a significantly higher value than the second highest region, the South East's £89,000. Scotland's high productivity – driven by the concentration of high productivity Oil & Gas Extraction activity – is also notable. The rest of the geographies have productivity rates of £64,000-78,000.

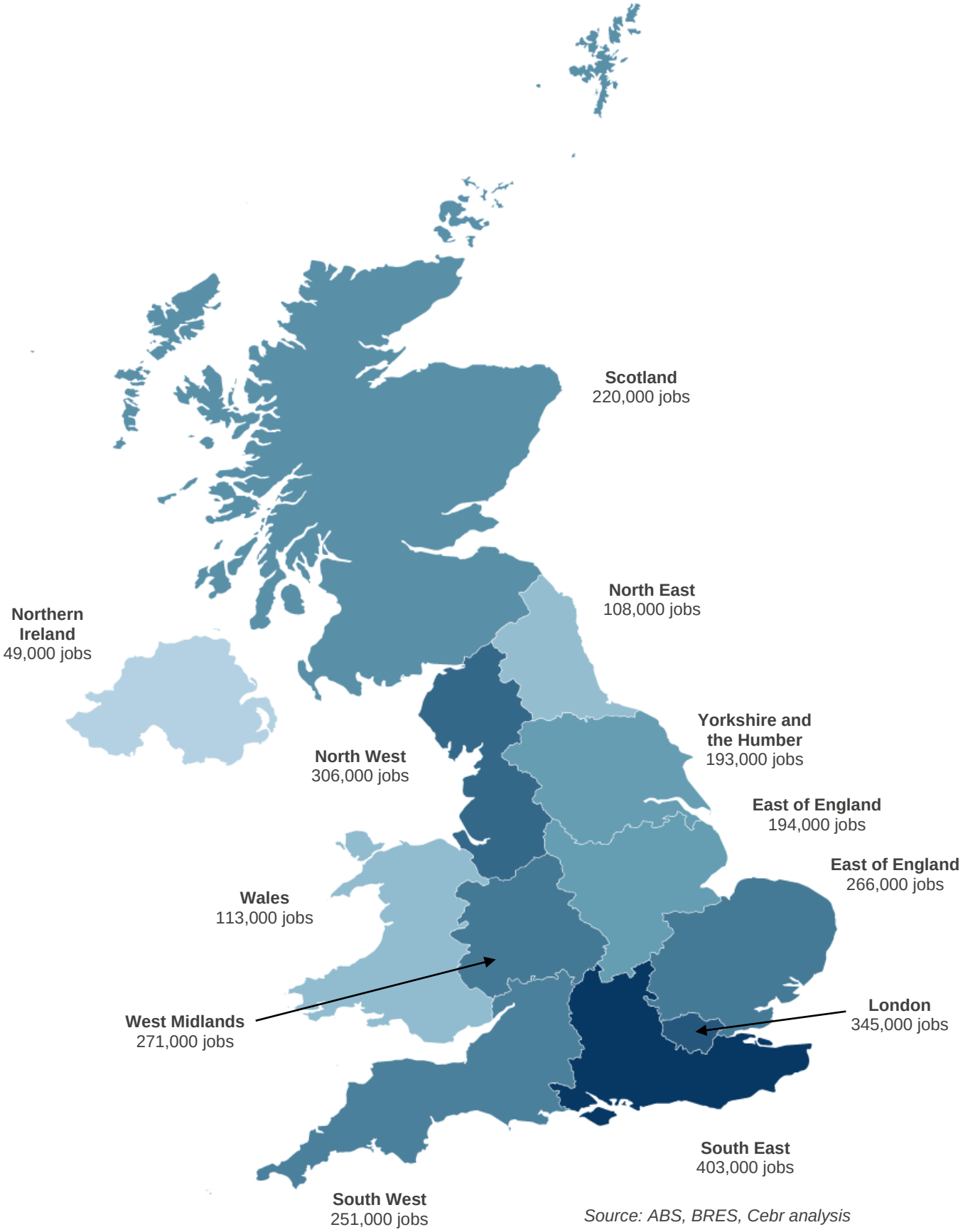
Figure 41 shows the average GVA per each FTE in each country and English region.

Figure 41: Labour productivity (GVA per FTE) in the PBIs in UK countries and regions, £, 2019



Source: ABS, BRES, Cebr analysis

Figure 42: Employment breakdown by nation and region, FTE jobs, 2019



Source: ABS, BRES, Cebr analysis

5.4 COE

On average, 85.1% (£98.2 billion) of employee compensation was contributed by England; Wales contributed close to 4% (ranging from £2.9 billion to £4.8 billion), while Northern Ireland provided 1.5% (around £1.5 billion on average). The COE/FTE ratio was highest in Scotland (£47,000), England was second (£42,000), and Wales and Northern Ireland were very similar (£36,000 and £35,000, respectively). Every other external sector discussed before (Construction, Transport & Storage, Retail) had significantly lower values in each nation, except for the Transport sector in Wales, which stood close to £36,000).

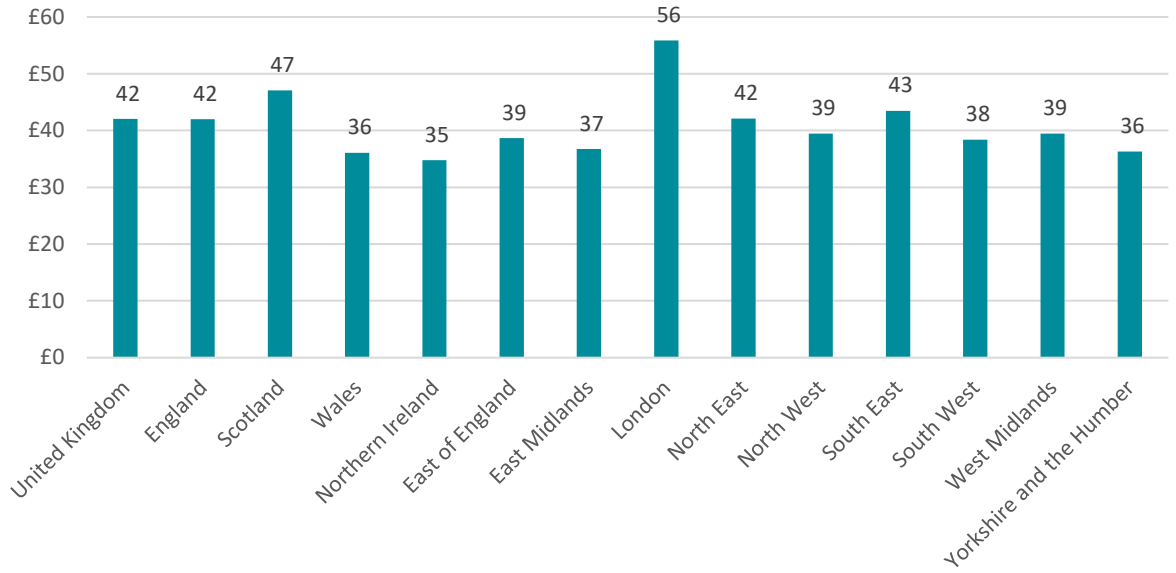
Table 9: COE in UK PBIs, distinguished between nations and English regions, £ billions, 2010-2019

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
England	74.2	76.5	78.5	80.6	82.5	84.5	88.8	89.9	92.5	98.2
Scotland	8.8	8.7	8.4	9.1	10.0	9.7	9.7	10.0	10.0	10.4
Wales	2.9	3.1	3.4	3.6	3.7	4.2	4.5	4.8	4.4	4.1
Northern Ireland	1.2	1.3	1.3	1.3	1.5	1.7	1.5	1.7	1.7	1.7
East of England	7.8	7.5	8.5	8.2	8.1	8.2	9.1	9.0	9.6	10.3
East Midlands	5.4	5.4	5.4	5.8	6.2	6.3	6.3	7.0	7.1	7.1
London	14.3	15.5	14.9	16.3	16.1	16.5	17.3	17.1	17.5	19.3
North East	3.4	4.1	3.7	3.9	4.3	4.7	4.4	5.0	4.0	4.5
North West	8.6	9.8	9.3	9.1	9.9	10.7	11.7	11.8	12.1	12.1
South East	14.8	14.6	14.9	15.5	15.8	15.4	17.0	16.5	17.2	17.5
South West	7.6	7.8	7.9	7.9	8.4	8.6	8.6	8.7	9.0	9.6
West Midlands	6.9	6.6	7.7	7.8	7.7	7.8	8.5	8.6	9.5	10.7
Yorkshire and the Humber	5.4	5.4	6.2	6.0	5.9	6.3	6.0	6.1	6.6	7.0

Source: ABS, BRES, Cebr analysis

When it comes to the English regions, COE is highest in London (£14.3 billion to £19.3 billion), with 16.6% of the total value on average, which results in the highest COE/FTE ratio (£56,000). The region with the second greatest share is again the South East, with 16% (£14.8 billion to 17.5 billion) and the second highest ratio (£43,000). All other regions had a value between £36,000 and £42,000. Figure 43 shows the average employee compensation per FTE worker in each UK nation and region.

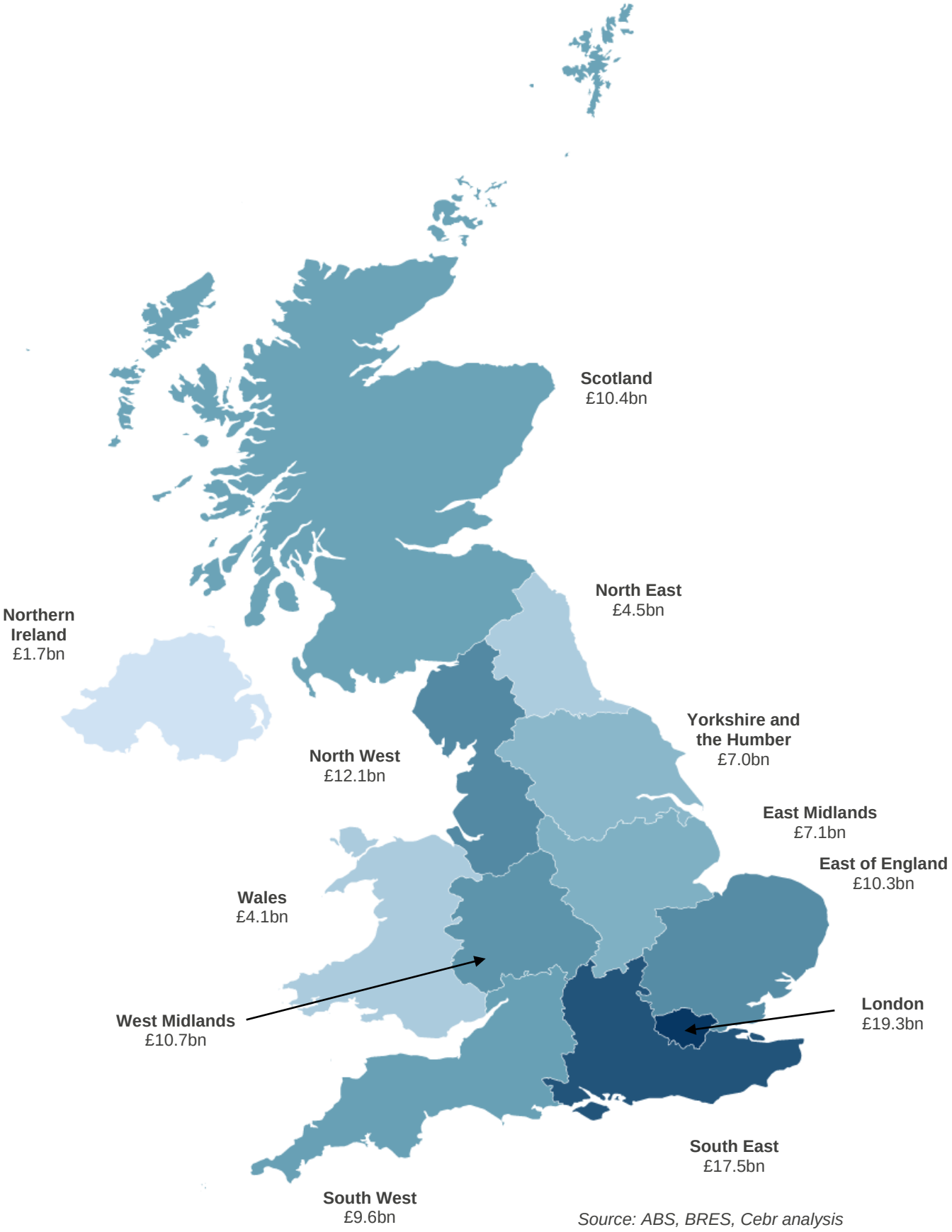
Figure 43: Compensation per FTE worker in UK nations and English regions, thousands, 2010-2019



Source: ABS, BRES, Cebr analysis

Interestingly, this is not the same as in the wider UK economy. While in 2019 annual gross pay for full-time workers across all sectors lagged slightly in Wales and Northern Ireland (£31,172 and £32,104 respectively), English workers in all sectors averaged higher annual gross pay (£38,270) than their Scottish counterparts (£34,936). This difference for the PBIs is driven by the respective composition of the English and Scottish physics sectors - in particular the concentration of the high-average-wage Oil & Gas Extraction sector in Scotland.

Figure 44: COE breakdown by region, 2019



Source: ABS, BRES, Cebr analysis

5.5 Business demography

When it comes to the number of businesses in UK PBIs, an average of 87.4% (205,000-320,000) can be found in England over the period. As expected, based on overall population and economy sizes, Scotland accounts for the next largest share at 7.8%, with the smaller UK nations of Wales (3.4%) and Northern Ireland (1.4%) following.

Table 10. Division of businesses in UK PBIs, distinguished between nations and English regions, thousands, 2010-2019

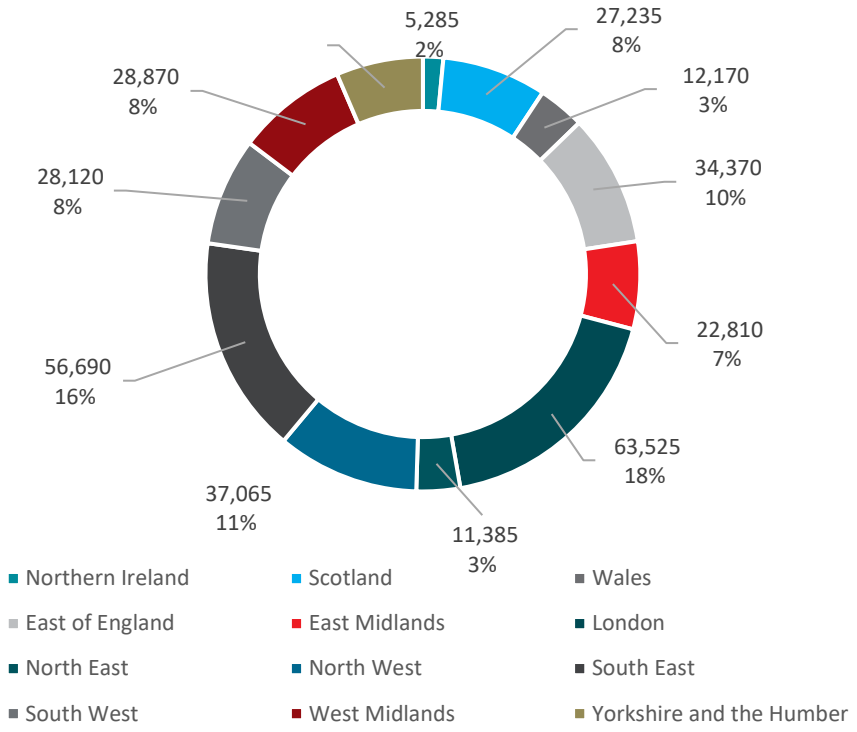
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
England	210.1	204.6	216.2	221.5	239.8	282.7	299.4	320.1	302.9	305.4
Scotland	16.9	17.5	19.4	20.6	22.8	26.1	26.8	27.1	26.8	27.2
Wales	8.3	8.0	8.2	8.3	9.2	11.3	11.7	12.1	11.8	12.2
Northern Ireland	3.8	3.7	3.7	3.8	3.9	4.1	4.4	4.8	5.1	5.3
East of England	26.0	25.0	26.1	26.4	28.2	31.8	34.0	41.2	33.7	34.4
East Midlands	16.6	16.1	16.8	17.1	18.4	21.7	24.3	23.7	23.3	22.8
London	34.8	34.2	37.8	40.9	46.3	57.4	62.1	67.1	62.4	63.5
North East	7.3	7.2	7.8	8.0	9.1	11.0	11.4	11.9	11.3	11.4
North West	25.5	24.6	25.5	26.0	28.3	33.5	35.0	37.0	37.5	37.1
South East	41.5	40.6	42.9	43.3	45.7	51.8	53.8	55.5	54.7	56.7
South West	21.0	20.6	21.6	21.8	23.3	26.7	27.6	29.7	27.9	28.1
West Midlands	21.5	20.7	21.3	21.5	22.8	26.3	28.2	30.1	29.8	28.9
Yorkshire and the Humber	15.9	15.6	16.3	16.5	17.7	22.5	23.0	23.9	22.4	22.6

Source: Nomis, Cebr analysis

In the first half of the decade, the South East of England was the region with the most enterprises, but by 2014 it was overtaken by London. Due to the similar turnover value and number of businesses, these two regions have a similar turnover/business value (£1.8 million per business in London, £1.9 million in the South East). Interestingly, the North East has the highest average turnover per business, with £3.3 million turnover. This is due to the much smaller number of businesses present in the region. Its turnover/enterprise ratio was especially high in the Energy Production, Transmission & Distribution and Physics Manufacturing sub-sectors. Furthermore, this region saw an increase in its number of enterprises by 55.6%, which is the second highest growth rate among the regions. The high level of enterprise growth in London (82.3% over the period) is principally due to a combination of strong enterprise growth in the Physics Science & Technology sub-sector in London (and indeed across the UK), and the relatively high concentration of the Physics Science & Technology sub-sector in London.

Figure 45 shows the composition of the number of businesses in 2019 visually.

Figure 45: Number of PBI businesses in the different nations and English regions of UK, 2019



Source: Nomis, Cebr analysis

6. The value of R&D investment in the PBIs

This section considers the R&D spending undertaken by businesses within the PBIs, alongside an additional collection of SIC codes, referred to as the physics-intensive industries.[19] These physics-intensive industries are industries where physics plays a major role in current business-led R&D efforts and they are additionally analysed specifically within this section.

This section provides estimates of the following:

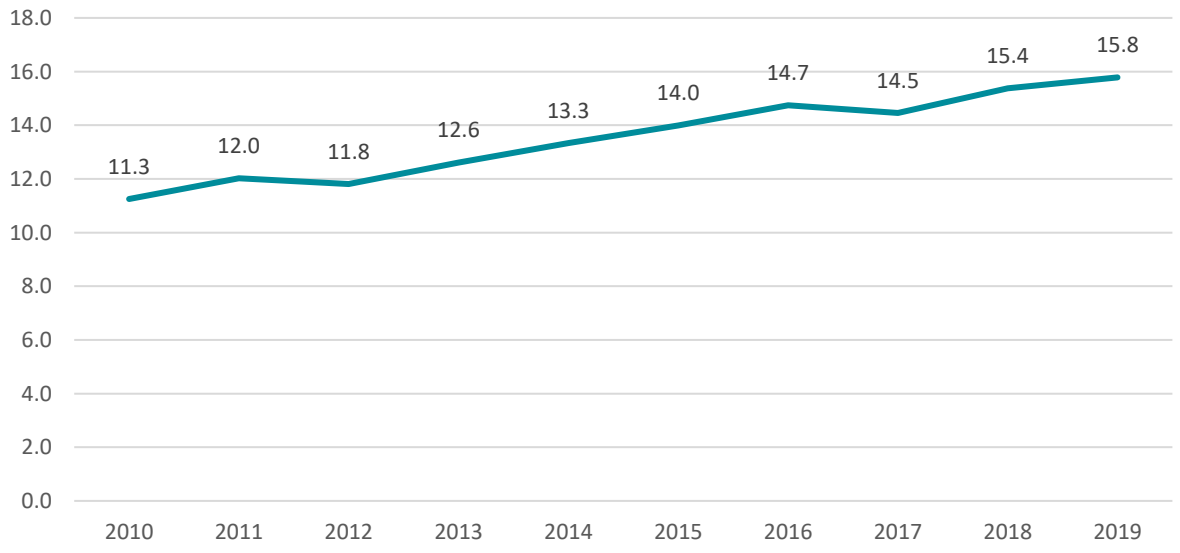
- The level of R&D spending in the PBIs in 2010-2019
- The level of R&D spending in the physics-intensive industries in 2010-2019
- The economic value of the PBI R&D investment in terms of contribution to PBIs' turnover, PBIs' GVA and national GDP by 2027

6.1 The level of R&D spending

We firstly present estimates of the level of R&D spending of the PBIs over the period 2010-2019. **In 2019, the total value of R&D spending in the PBIs was £15.8 billion.** This was a £4.5 billion increase overall on PBI R&D levels in 2010, equivalent to 40.3% growth as a whole over the decade, and 3.8% annually on average. As can be seen in Figure 46, this growth was relatively steady over the period.

Notably, despite only contributing just over 10% of UK GDP, PBI R&D comprises over 60% of total UK R&D over the entire period (60.8% in 2019, or £15.8bn out of a total of £25.9bn).

Figure 46: R&D expenditure in PBIs, £ billions, 2010-2019

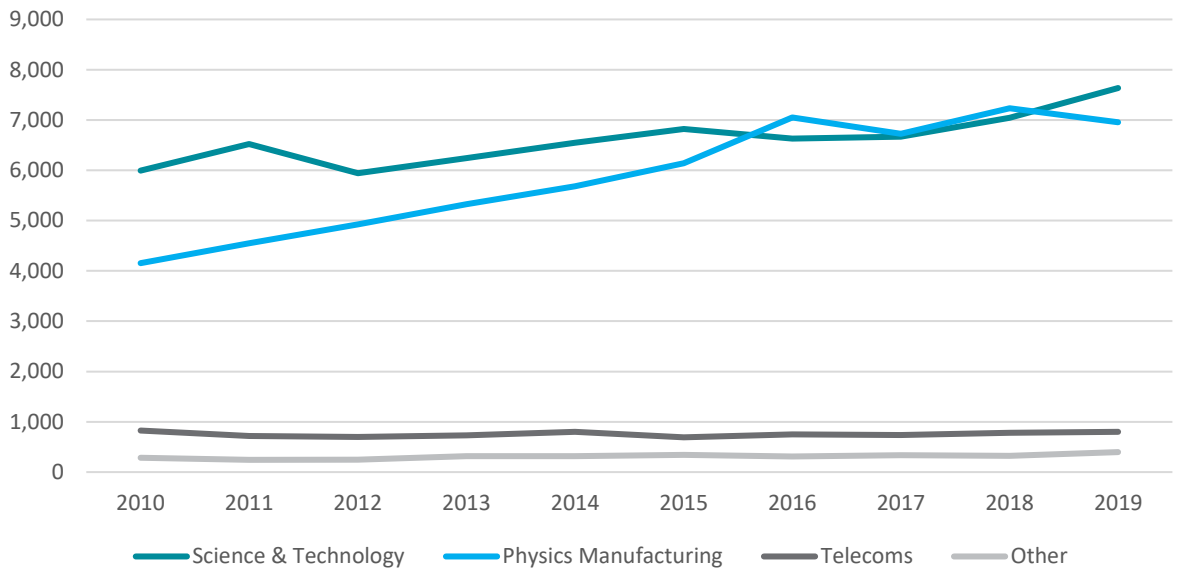


Source: ABS, ONS, Cebr analysis

19 See Appendix II for the full list of physics-intensive industries' SIC codes used within this section.

Within the PBIs, R&D is dominated by two sub-sectors: Physics Manufacturing and Physics Science & Technology. The former counts for 43.4% of all PBI R&D expenditure on average, and the latter contributes 48.8%. However, the Physics Manufacturing sub-sector had a much higher increase in its value over the decade: £2.8 billion (67.5% increase) compared to £1.6 billion for Physics Science and Technology (27.3%) (although the two have been increasing at approximately equal rates and levels since 2016). This trend is to be expected: alongside being the two largest PBI sub-sectors, as discussed more extensively in Section 2.2, both sit within wider sectors of the economy that conduct relatively high levels of R&D expenditure (specifically Manufacturing and Professional, Scientific & Technical Services, respectively), and they are both more research-heavy in nature, requiring higher-than-average levels of R&D spending in order to remain innovative and competitive.

Figure 47: R&D in the different categories of UK PBIs, £ millions, 2010-2019

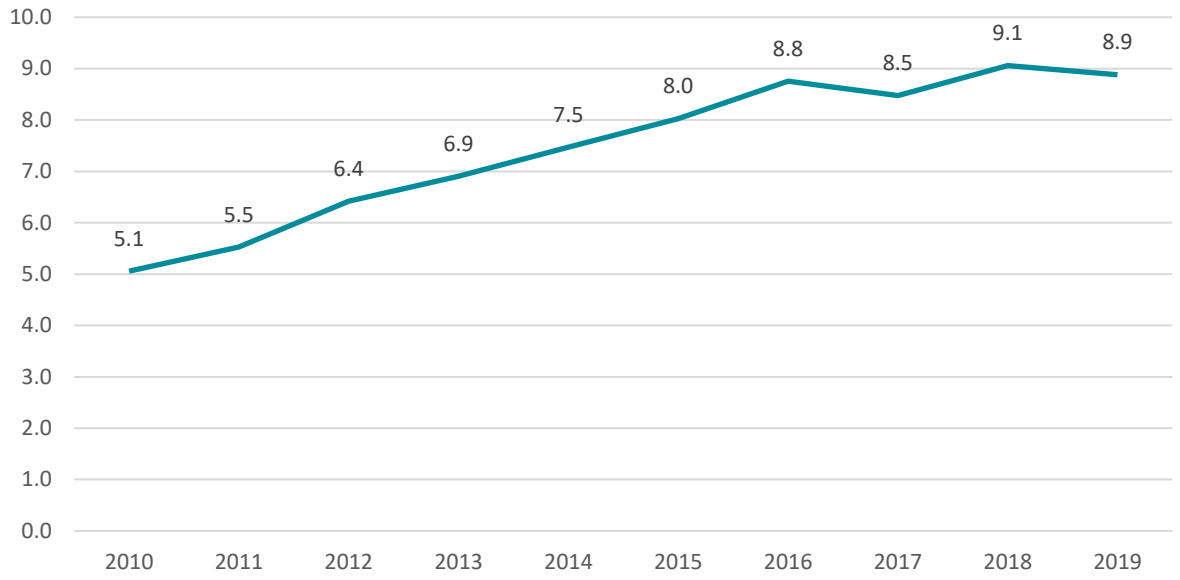


Source: ABS, ONS, Cebr analysis

In addition to R&D investment undertaken by the PBIs, we consider the level of R&D spending conducted by a collection of the physics-intensive industries[20] (see Figure 48 below). While the absolute level of R&D spending is lower (to be expected, given the smaller collection of industries comprising the physics-intensive industries), strong R&D growth (75.7% over the period) is observed over the period, reaching £8.9 billion in 2019.

20 As noted in the Introduction, physics-intensive industries are different but overlapping with the PBIs and are made up of industries where the ongoing R&D in the industry consistently makes use of physics knowledge, but the industry itself doesn't necessarily rely on physics for the bulk of its activities. These industries overlap with the PBIs, but as there are some PBI SIC codes not included within the physics-intensive definition; there are also some included within the physics-intensive industries, but not the PBIs.

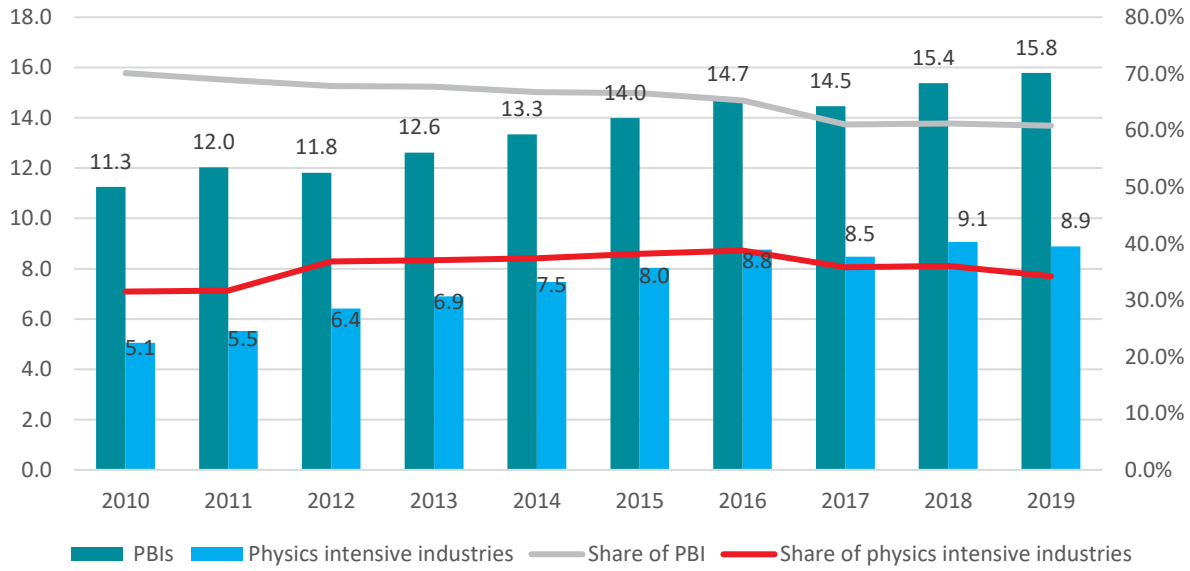
Figure 48: R&D expenditure in the physics-intensive industries, £ billions, 2010-2019



Source: ABS, ONS, Cebr analysis

Figure 49 provides the share of UK R&D expenditure conducted by the PBIs and physics-intensive industries, alongside the absolute level of R&D expenditure conducted by the PBIs and physics-intensive industries.

Figure 49: Level (bars, LHS) and share (line, RHS) of UK R&D expenditure conducted by the PBIs and physics-intensive industries, 2010-2019

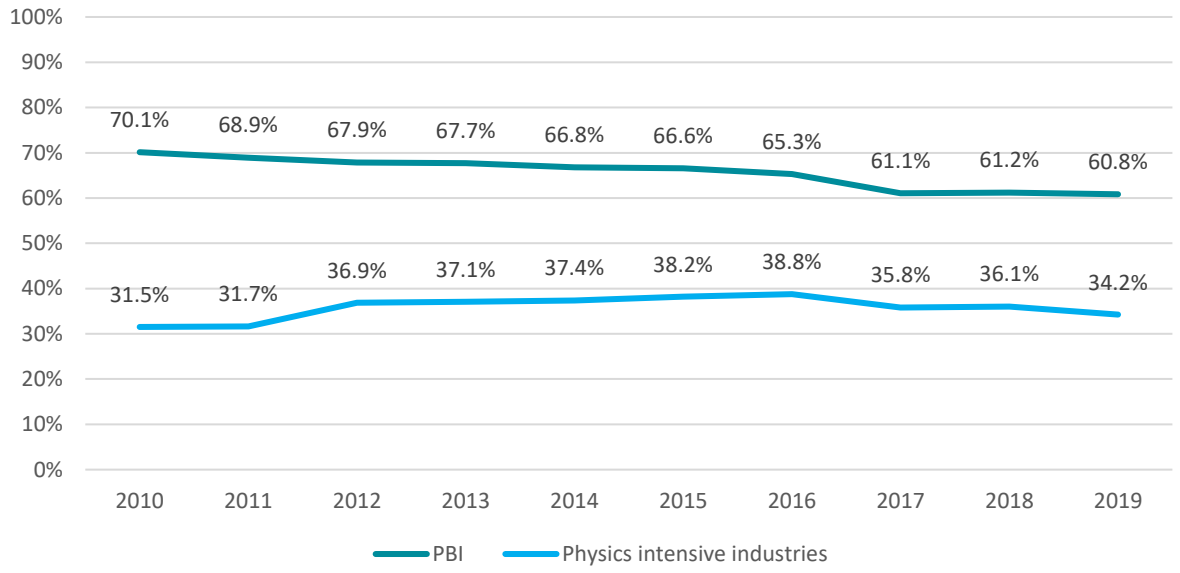


Source: ABS, ONS, Cebr analysis

While more than 60% of UK R&D expenditure was conducted by the PBIs in 2019, this share has been declining since 2010 (70.1%). However, as seen by the increasing absolute level of PBI R&D expenditure, the decline in the share of R&D expenditure is caused by increasing R&D expenditure in other sectors, rather than the PBIs themselves. For example, R&D expenditure in Computer Programming, Consultancy & Related Activities is responsible for £1.2bn worth of the growth of overall UK R&D spending (approximately 13% of the entire decade's growth), but has no overlap with the PBIs.

Figure 50 below presents the share of UK R&D conducted by the PBIs and physics-intensive industries separately across the decade., While the share of PBIs has witnessed a declining trend as discussed above, the share of R&D conducted by the physics-intensive industries has increased overall from 31.5% in 2010 to 34.2% in 2019 (albeit slightly below the mid-decade peak of 38.8%).

Figure 50: Share of UK R&D conducted by the PBIs and physics-intensive industries, 2010-2019



Source: ABS, ONS, Cebr analysis

6.2 The economic value of R&D investment

Beyond estimating the monetary value of R&D investment by the PBIs, this section focuses on the economic value generated by the R&D investment undertaken by PBIs.

A firm choosing to invest in R&D can expect to generate:

- Private returns in the form of higher profitability and/or efficiency. By investing in R&D, a firm expects to develop new ideas, intermediate goods, cost reduction mechanisms, and final consumer products.
- Social returns in terms of GDP growth, social and environmental benefits. In addition to the private benefits of R&D, positive spill-overs across firms, industries, and geographies can produce significant wider benefits. Since knowledge developed through R&D is non-rival, firms can benefit from the R&D investment of other firms.

In the attempt to offer a comprehensive overview of the economic value of R&D investment undertaken by PBIs, this section presents:

- A quantitative assessment of the private returns (measured as turnover and GVA) of PBI R&D investments, estimated through an econometric model
- A qualitative assessment of the social returns of PBI R&D investments - in other words, the wider economic contribution of R&D supported by PBIs to the UK economy

The return on R&D investment to PBIs

We developed two econometric models investigating the following relationships:

- PBI R&D and PBI turnover
- PBI R&D and PBI GVA

Details of the methodology and models' results can be seen in Appendix V**: R&D econometric model**.

Overall, we found that:

- The elasticity of PBI turnover to PBI R&D spending is 0.15, implying that for each 10% increase in R&D investment, turnover increases by 1.5%
- The elasticity of PBI GVA to PIB R&D spending is 0.27, implying that for each 10% increase in R&D investment, GVA increases by 2.7%

The estimated coefficients are broadly in line with the academic literature, although somewhat higher than some specific studies. This can be explained by two main factors. Firstly, R&D investment in PBIs is expected to produce greater-than-average economic contributions due to specific industry features. Secondly, the use of industry-level data instead of firm-level data enables us to capture the intra-industry spill-overs of R&D investment.

The below table outlines the findings of the few academic papers which looked at the relationship between firm-level R&D spending and economic output using a similar approach to the one developed in this study.

Table 11: Literature review of the relationship between R&D spending and economic output[21]

Paper	R&D variable(s)	Output measure	Sample	Elasticity estimate
Griffith et al. (2004)	R&D	Value added	188 manufacturing firms	0.026-0.029
Griffith et al (2006)	Investment intensity	Productivity (output per worker)	Firm-level data	0.059
Kafouros (2007)	R&D	Productivity (output per worker)	78 manufacturing firms, 1989–2002	0.035-0.11
Rogers (2009)	R&D	Value added	719 large UK firms, 1989-2000	0.04-0.234

By calculating the elasticity of turnover and GVA to R&D in the PBIs, we are able to estimate the likely contribution of future investment to economic output.

Assuming an increase in R&D in line with the UK Government target of 2.4%,[22] we estimate that R&D spending by PBIs could contribute £52 billion to industry turnover and £34 billion to

21 Whilst being slightly dated, the papers listed in the table represent some of the most relevant studies in this field.

22 https://www.gov.uk/government/publications/uk-research-and-development-roadmap/uk-research-and-development-roadmap

industry GVA by 2027. The below table presents a disaggregation of the impact by individual PBI categories.[23]

Table 12: Impact of an increase in PBI R&D in line with the UK Government target of 2.4%

Sub-sector	Assumed increase in R&D, £bn	Estimated impact on turnover, £bn	Estimated impact on GVA, £bn
Physics Manufacturing	3.9	19.8	10.8
Physics Science & Technology	4.3	12.6	10.0
Telecoms	0.4	5.5	4.9
Other	0.2	14.3	8.7
Total	8.8	52	34.3

Source: ABS, ONS, Cebr analysis

The wider economic contribution of PBI R&D investment

Recent economic growth theory has drawn attention to endogenous technological change as a key driver of economic growth. As emphasised by Romer (1986), technological innovation is created in the R&D sectors using human capital and the existing knowledge stock. It is then used in the production of final goods, leading to sustained increases in output growth rate. In other words, R&D drives the technological change needed for productivity growth and, consequently, long-term economic growth.

As outlined above, there is a strong positive relationship between PBIs' R&D investment and output, confirming that innovations generate large private returns. Empirical literature points in the direction of social rates of return to R&D being even higher than private rates, as a result of R&D spill-overs across the economy. Once invented, an idea can be reproduced by others because it is non-rival and only partially excludable. Non-rivalry means that consumption of a good by one person does not reduce the amount available for others, and non-excludability means that every single person can access a certain good.

A firm's new idea or process can be used by other firms to increase their own profit, generating positive externalities and wider social returns from investments. Furthermore, some knowledge investments can create benefits for the wider society in the form of 'public goods', while not having a direct benefit for the private sector e.g. health or environmental benefits.

To sum up, social returns on R&D investment, in terms of contribution to national GDP and wider social and environmental benefits, can be expected to be much larger than private returns to individual firms. In the case of R&D across PBIs, the expected GDP uplift as a result of a £8.8 billion increase in R&D spending is expected to be higher than £34 billion.

23 While the scope of this analysis did not extend to cover the returns to R&D investment in the physics-intensive industries, in order for the UK to meet this R&D target, R&D investment in the physics-intensive industries would need to increase by £4.9 billion.

7. Impact of the UK's PBIs relative to international comparators

This report so far has shown the significant contributions that PBIs make to the overall UK economy. This section shows that the role of PBIs is just as important in other major economies, and how the contribution of PBIs to these other countries differs from the UK.

A Cebr report commissioned by the European Physical Society (EPS) found that PBIs are worth more to the EU economy[24] than retail and financial services combined. The report found that in the EU, PBIs made a net contribution to the economy of at least €1.45 trillion per year, equivalent to 12% of total GVA – which is slightly higher than for the UK, where this figure stood at around 11% of the equivalent UK GVA in this report. This compares to 4.5%, 5.3% and 5.3% for the Retail, Construction and Financial Services sectors in the EU, respectively.[25] In addition, European PBIs contributed, on average, 44% of all exports from the EU28 during the period 2011-2016.

Germany's status as a leader in PBIs is reflected in the EPS report. In 2016, German PBIs contributed just over €396 billion of GVA, making the German physics-based sector the largest in Europe. As defined in this study, the UK comes in second to Germany with regards to GVA (approximately €252 billion of GVA in the UK in 2016)[26], followed by France, with over €182 billion in GVA from their PBIs in 2016. The fourth largest physics-based sector in Europe is Italy; PBIs contributed almost €140 billion of GVA in 2016.[27]

The relative sizes of the physics-based sectors in these four nations can be seen in Figure 51, which shows their growth over the 2011-2016 period. Figure 52 shows the relative contribution of PBIs to the respective nations' economies, by estimating the share of their GDP that is attributable to PBIs.

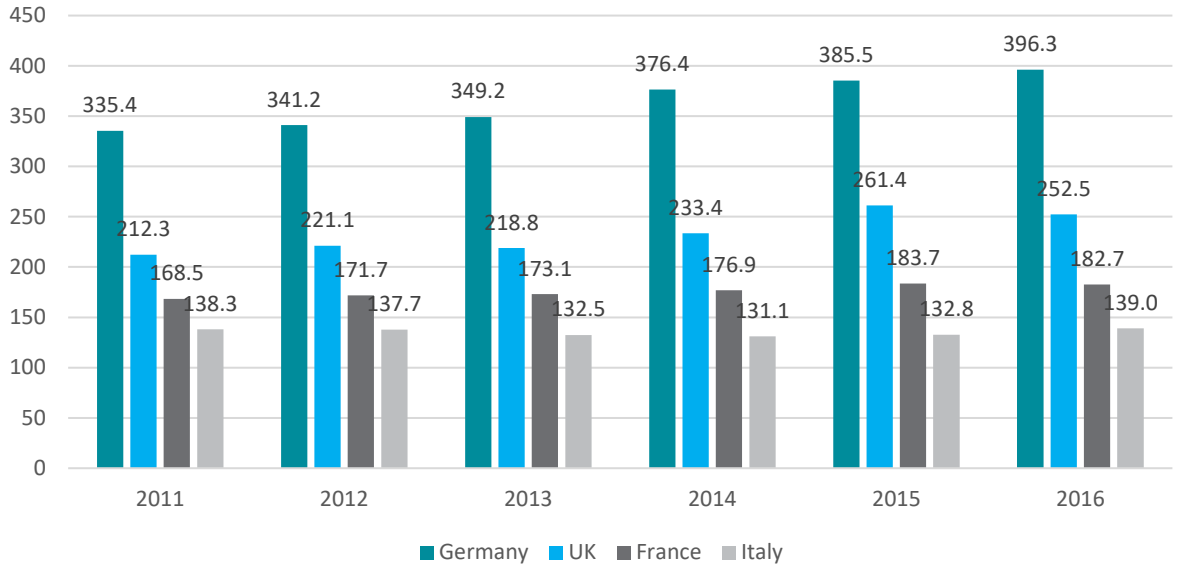
24 Note that this report was published in 2019 and looked at the 2011-2016 period, so the UK was still a member of the EU at the time of writing this report.

25 Science Business (2019). Physics worth more to EU economy than retail and financial services

26 Note that the industry definitions used in the report for the European Physical Society are different from the ones presented in this report. This means that the figures aren't directly comparable to the ones in this report using the new PBI definition; focus should be on the relative trends between countries where comparisons are consistent.

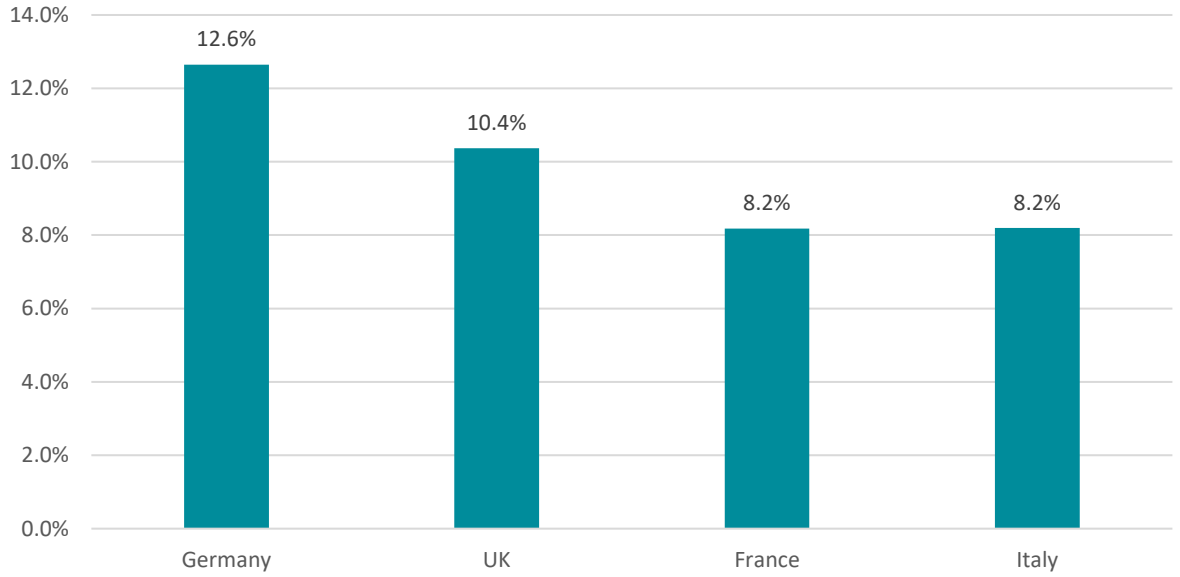
27 European Physical Society (2019). The importance of Physics to the economies of Europe

Figure 51: GVA by PBIs in four biggest economies in Europe, € billions, 2011-16



Source: Eurostat., (EPS-Cebr report)

Figure 52: Share of GDP attributable to PBIs, 2016[28]



Source: Eurostat., (EPS-Cebr report)

The contributions of PBIs in the USA are also significant. A report published by the American Physical Society found that physics-based companies directly contributed approximately $2.3 trillion to the U.S. economy (12.6% of GDP) and exported approximately $1.1 trillion of goods

28 Once again, this is based on the definitions used in the European Physical Society report carried out by Cebr in 2019.

in 2016.[29] In addition, value added in US PBIs between 1966 and 2016 grew by a factor of 22 reflecting the increasing value of the physics-based sector to the US economy. With regards to employment, U.S. physics-based companies employed 11.5 million people in 2016, which amounted to 6% of total employment in the USA. It was reported that this is significant due to them being innovative and pioneering, which attracts highly skilled and talented individuals from not only the USA, but also internationally.[30]

Although the US is still the biggest spender in terms of PPP-adjusted[31] R&D spending, it is expected that China will soon overtake the US to become the biggest spender in absolute terms. This is owed to the rapid development of China's science landscape, which has seen significant growth over the last four decades. It has also been highlighted as a top policy priority: 'innovation' was the main guiding principle in China's 13th Five Year Plan as the path to sustainable economic growth, which set the framework for government policies from 2016-2020. In 2019, China's R&D expenditure stood at approximately RMB 2.17 trillion (or £245 billion), of which 83% is spent on late-stage commercialisation.[32]

Japan is another major economy in which physics plays an important role and which actively invests into R&D. According to the Statistics Bureau of Japan, Japan's total expenditure on R&D during 2019 was ¥19.58 trillion (£130 billion[33]), equivalent to 3.5% as a share of Japan's GDP.[34] Many of the economic gains that Japan made since the last World War can be largely attributed to the contributions and growth of its Physics Science & Technology sub-sector. However, over the last few years, the physics sector in Japan has been experiencing a decline, and the number of people pursuing PhDs in the subject has been decreasing.[35]

India has also experienced rapid growth in the Physics Science & Technology sub-sector. Since the start of the century, there has been a significant increase in funding for research projects in India; its research base has expanded substantially, with several new institutions having been set up, and an increase in the number of people employed in research.[36] In 2013 India was ranked sixth in the world for scientific output (seventh for output directly related to

29 Note that due to the difference in source, the definition for the PBIs in the USA may differ to that used in this report.

30 American Physical Society (2019). Summary of Economic Impact Report

31 Purchasing Power Parity (PPP) is the measurement typically used in the context of international price comparisons. It uses the prices of specific goods to compare the absolute purchasing power of the countries' currencies. In other words, rather than simply using the exchange rate it calculates how much more (or less) relatively expensive a particular good, like bread or milk, is across different countries.

32 UK Science & Innovation Network (2020) Country Snapshot – China

33 Based on the exchange rate at the time of writing this report, where 1 JPY = 0.006656 GBP.

34 Note that this 3.5% figure for R&D expenditure as a percentage of GDP differs from the one presented in Figure 53, which is sourced from the OECD instead.

35 IOP Publishing: Physics World (2018). Revitalizing Japanese physics

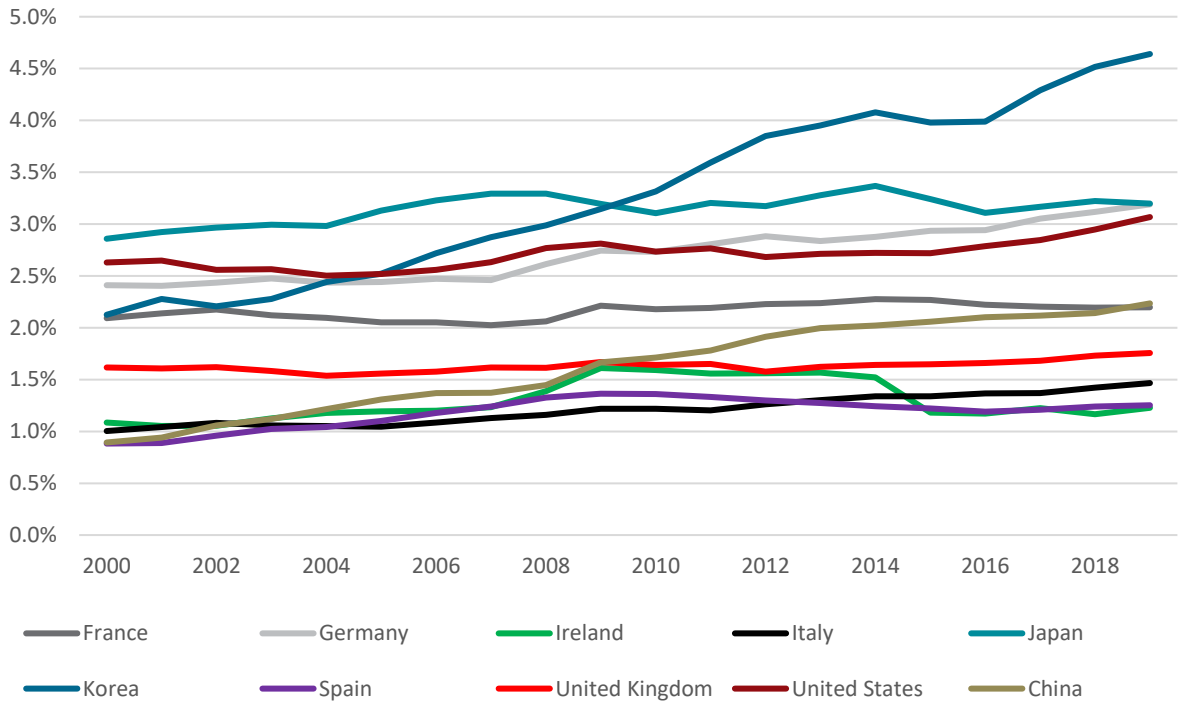
36 The Economic Times (2013). Will India be among the top 3 nations in science output by 2030?

physics research). Since 2004, India has increased its scientific output 3.8 times in the Scopus database.[37]

R&D spending as a share of GDP

Figure 53 looks at different countries' gross domestic expenditure on R&D (GERD) as a percentage of GDP. Although this is not an exact representation in absolute values of the physics-based sectors in these countries and thus not directly comparable, it could be looked at as illustrative of the relative performances of PBIs across regions. The top four countries are the Republic of Korea (which has gone from 2% to 4.5% GERD as a share of GDP across this time period), followed by Japan, Germany and the United States.

Figure 53: GERD as a percentage of GDP, 2000-2019



Source: OECD

37 Scopus is Elsevier's abstract and citation database of peer-reviews literature including scientific journals, books, and conference proceedings, and it provides a comprehensive overview of the world's research output.

8. The PBIs within the wider economic and political landscape

This section seeks to make links between the contributions and growth patterns of PBIs in the UK and occurrences in the political landscape.

Over the course of the 2010-2019 period, the UK PBIs experienced an overall increase of around 24% in turnover, which can be associated with several sectoral and national occurrences. In comparison, the same period saw an overall increase in PBI GVA of almost 21%, and an increase of just over 13% in FTE employment.

2011 saw a larger percentage increase in turnover than any other year, which is likely to be a result of the efforts exerted in recovering from the economic downturn following the global financial crisis of 2007-08. However, in 2012, and again in 2015, turnover fell. In 2012, most of the largest physics-based sub-sectors, except the Physics Science & Technology sub-sector, suffered a decline in turnover. The wider economy experienced a contraction at the end of 2012, and a significant portion of the overall economic growth of 1.4%[38] in that year was attributed to the Olympic Games.[39] Among the sub-sectors that saw low levels of growth in 2011-2012 was the Physics Manufacturing sub-sector, where weaker consumer demand, sluggish domestic orders and a conservative approach to inventory holdings likely played a part in its performance.[40]

In 2015, it was reported that UK manufacturers were affected by a strong exchange rate hitting industrial production and weak global demand, part of which was attributed to a fall in demand for extraction manufacturing products due to falling oil prices.[41] Certain industries in the Physics Manufacturing sub-sector are likely to have been affected by this, resulting in a lower GVA contribution in 2015, as shown by the data. However, the main two sub-sectors driving the decline in 2015 were the Oil & Gas Extraction sub-sector and the Energy Production, Transmission & Distribution sub-sector.

The decline in the Oil and Gas Extraction sub-sector could be associated with the Oil Price Plunge of 2014-2016 (one of the largest since World War II). Excess production and, therefore, supply of oil in 2014 was not met by the high levels of demand that were expected due to the low responsiveness of economic activity in key oil-importing emerging markets.[42] Consequently, reserves of oil increased and prices declined rapidly. The UK oil and gas supply chain services domestic activities, and exports about £12 billion worth of goods and services to the rest of the world, so the lack of demand for oil and resulting low prices would have impacted this industry greatly. This can be seen in the data from not only the decreasing level of GVA per worker, but also the substantial decrease in turnover.

38 World Bank (2020). Annual % change in GDP

39 UK Trade & Investment (2013). London 2012: delivering the economic legacy

40 BBC News (2011). UK manufacturing sector contracts in July

41 Financial Times (2015). UK manufacturing sector in recession

42 World Bank Blogs (2018). What triggered the oil price plunge of 2014-2016?

The decline in the Energy Production, Transmission & Distribution sub-sector could be associated with the fact that total energy consumption, and therefore demand for energy, has been falling over the last decade. Over the assessed decade, turnover generated by this sub-sector fell and can be attributed to, according to some experts, measures undertaken by the Government, utility companies and consumer side agencies to help conserve energy and improve efficiency.[43] In 2011, the Energy Act came into force, requiring energy providers to meet certain energy efficiency requirements when providing energy to consumers. Such measures increase costs of providers and impact the whole supply chain, thus reducing GVA. Another factor which likely exacerbated the low levels of growth in the Energy Production, Transmission & Distribution sub-sector is the gradual and consistent phasing out of coal as an energy source.[44]

The overall increase in output generated by PBIs, as measured by turnover, can be largely attributed to the contributions of both the Physics Manufacturing and Physics Science & Technology sub-sectors. Both of these sub-sectors make up a large share of the PBIs in the UK (approximately 39% and 22% respectively) and they both experienced significant growth during the last decade.

The growth in this sub-sector can perhaps be best exemplified by the performance of the manufacture of motor vehicles – one of its constituent sub-sectors – which saw an increase in turnover of over 70% across the 2010-2019 period. The industry experienced accelerated growth at the beginning of the decade, owing mostly to the recovery of the economy and the industry. Although the industry suffered from the Automotive Industry Crisis from 2008 to 2010, huge investments made by some of the biggest players such as Jaguar Land Rover, Nissan, and Toyota, in an effort to recover from the recent recession, fuelled this increase in GVA in this industry. In May 2011 it was announced that Jaguar Land Rover would be investing over £5 billion in product development over the next five years[45]. In the same year, both Nissan and Toyota announced they would be making respective investments of £192 million[46] and over £100 million,[47] and there were also substantial investments made in education.[48]

Another industry which contributed to the growth of PBIs was the Wireless Telecommunications sub-sector. The growth of this sub-sector can be attributed to the increased consumer demand for its services and products such as Wi-Fi or Bluetooth devices, as well as the widespread rollout of both 4G and 5G mobile wireless networks. This increase in consumer demand for Wi-Fi and mobile wireless networks can be represented by the increase in 'Household Internet Penetration' since 2010. In 2010, 73% of households had access to the internet, whereas 93% did in 2019. Evidently, demand for internet access has increased, as did demand for goods and services from the Wireless Telecommunications

43 Power Technology (2017). What's driving the fall in UK energy demand and can it last?

44 Department of Energy & Climate Change (2016). UK Energy Statistics, 2015 & Q4 2015

45 Reuters (2011). Tata's Jaguar Land Rover seeks China auto partner

46 Reuters (2011). Nissan to invest $315 million in UK Qashqai update

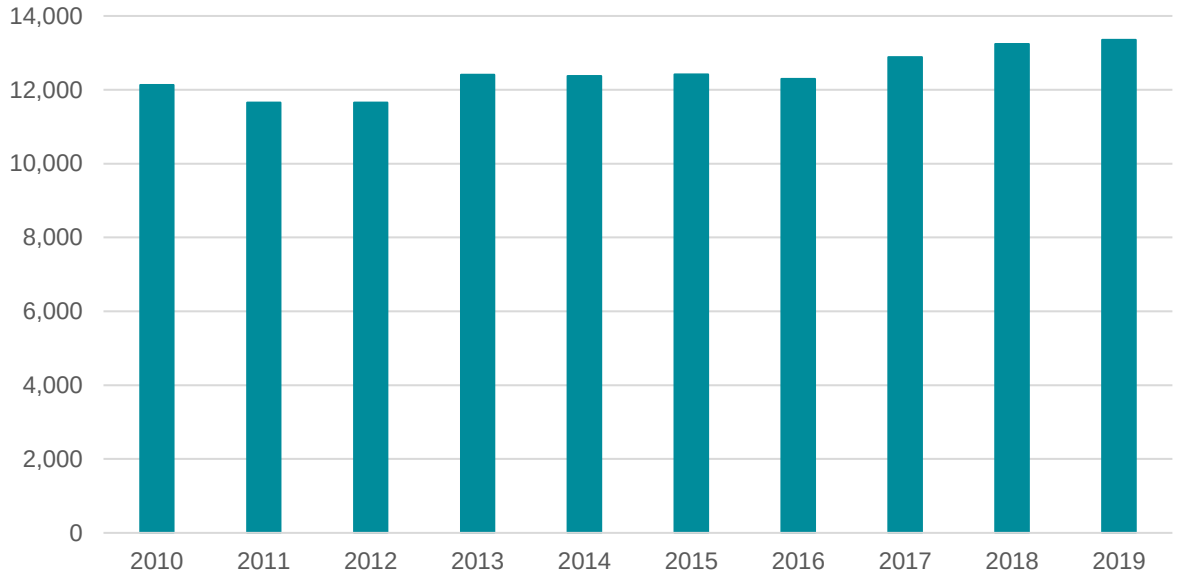
47 BBC News (2011). Toyota announces 1,500 new jobs for Burnaston factory

48 BBC News (2013). University of Warwick £100m car centre 'will secure jobs'

industry.[49] While the Wireless Telecoms industry is relatively small – about 15% of total Telecoms sub-sector GVA as of 2019 – this has increased from just 2.8% of GVA in 2010.

One of the most meaningful global trends over the past decade has been the increasing pressure to prepare for the biggest technological challenges that lie ahead, such as reaching net zero carbon and the transition to a low carbon economy. As a result, the UK Government has committed to providing funding for Science, Engineering and Technology (SET), now called the Government Expenditure on Research and Development Survey (GovERD). This is shown in Figure 54 (for R&D as well as knowledge transfer), which has likely played a role in not only an increase in turnover and GVA, but also the creation of jobs in the Physics Science & Technology sub-sector. As seen below, this funding has been strong over the entire assessed period.

Figure 54: UK Government net expenditure on SET, £ millions, 2010-19



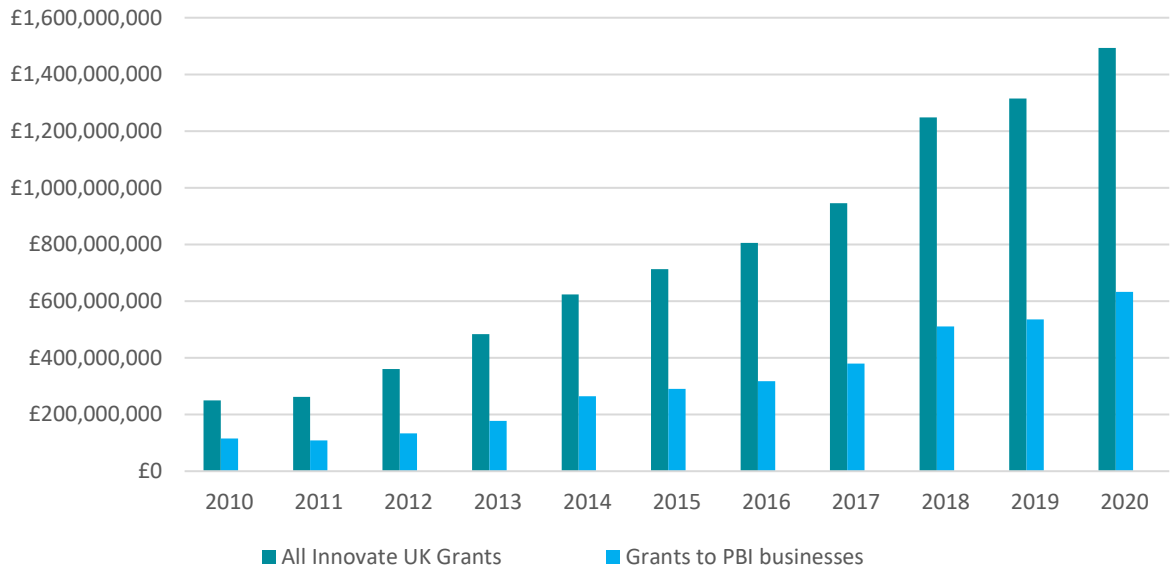
Source: ONS

Increased funding provided through the Innovate UK[50] grants over the last decade are likely to have further supported increased economic activity in the Physics Science & Technology sub-sector.

49 ONS (2020). Internet access - households and individuals

50 Innovate UK is a non-departmental public body, operating at arm's length from the UK Government's Research and Innovation organisation. It provides money and support to organisations to make new products and services, describing itself as the UK's innovation agency.

Figure 55: Innovate UK grant commitment (total and PBI-only grants), split by year (to nearest £1 million), 2010-2020



Source: Innovate UK, IOP analysis

Appendix I: SIC-based definitions of PBIs and sectoral alignment

Code	Description	Code	Description
Oil & Gas Extraction			
06.1	Extraction of crude petroleum	06.2	Extraction of natural gas
Physics Manufacturing			
13.95	Manufacture of non-wovens and articles made from non-wovens, except apparel	26.511	Manufacture of electronic instruments and appliances for measuring, testing, and navigation, except industrial process control equipment
13.96	Manufacture of other technical and industrial textiles	26.512	Manufacture of electronic industrial process control equipment
13.99	Manufacture of other textiles nec[51]	26.513	Manufacture of non-electronic instruments and appliances for measuring, testing and navigation, except industrial process control equipment
18.129	Printing (other than printing of newspapers and printing on labels and tags) nec	26.514	Manufacture of non-electronic industrial process control equipment
20.12	Manufacture of dyes and pigments	26.52	Manufacture of watches and clocks
20.13	Manufacture of other inorganic basic chemicals	26.6	Manufacture of irradiation, electromedical and electrotherapeutic equipment
20.17	Manufacture of synthetic rubber in primary forms	26.701	Manufacture of optical precision instruments
20.301	Manufacture of paints, varnishes and similar coatings, mastics and sealants	26.702	Manufacture of photographic and cinematographic equipment
20.302	Manufacture of printing ink	26.8	Manufacture of magnetic and optical media
20.51	Manufacture of explosives	27.11	Manufacture of electric motors, generators and transformers
20.59	Manufacture of other chemical products nec	27.12	Manufacture of electricity distribution and control apparatus
23.11	Manufacture of flat glass	27.2	Manufacture of batteries and accumulators
23.12	Shaping and processing of flat glass	27.31	Manufacture of fibre optic cables
23.13	Manufacture of hollow glass	27.32	Manufacture of other electronic and electric wires and cables
23.14	Manufacture of glass fibres	27.33	Manufacture of wiring devices
23.19	Manufacture and processing of other glass, including technical glassware	27.4	Manufacture of electric lighting equipment
23.2	Manufacture of refractory products	27.51	Manufacture of electric domestic appliances
23.31	Manufacture of ceramic tiles and flags	27.9	Manufacture of other electrical equipment
23.43	Manufacture of ceramic insulators and insulating fittings	28.11	Manufacture of engines and turbines, except aircraft, vehicle and cycle engines
23.44	Manufacture of other technical ceramic products	28.21	Manufacture of ovens, furnaces and furnace burners
23.49	Manufacture of other ceramic products	28.23	Manufacture of office machinery and equipment (except computers and peripheral equipment)
24.1	Manufacture of basic iron and steel and of ferro-alloys	28.25	Manufacture of non-domestic cooling and ventilation equipment

51 Where n.e.c. means 'not elsewhere classified

24.2	Manufacture of tubes, pipes, hollow profiles and related fittings, of steel	28.41	Manufacture of metal forming machinery
24.31	Cold drawing of bars	28.49	Manufacture of other machine tools
24.32	Cold rolling of narrow strip	28.91	Manufacture of machinery for metallurgy
24.33	Cold forming or folding	28.922	Manufacture of earthmoving equipment
24.34	Cold drawing of wire	28.94	Manufacture of machinery for textile, apparel and leather production
24.41	Precious metals production	28.95	Manufacture of machinery for paper and paperboard production
24.46	Processing of nuclear fuel	28.96	Manufacture of plastics and rubber machinery
25.11	Manufacture of metal structures and parts of structures	28.99	Manufacture of other special-purpose machinery nec
25.12	Manufacture of doors and windows of metal	29.1	Manufacture of motor vehicles
25.21	Manufacture of central heating radiators and boilers	29.31	Manufacture of electrical and electronic equipment for motor vehicles
25.29	Manufacture of other tanks, reservoirs and containers of metal	29.32	Manufacture of other parts and accessories for motor vehicles
25.3	Manufacture of steam generators, except central heating hot water boilers	30.11	Building of ships and floating structures
25.4	Manufacture of weapons and ammunition	30.12	Building of pleasure and sporting boats
25.5	Forging, pressing, stamping and roll-forming of metal; powder metallurgy	30.2	Manufacture of railway locomotives and rolling stock
25.61	Treatment and coating of metals	30.3	Manufacture of air and spacecraft and related machinery
25.62	Machining	30.4	Manufacture of military fighting vehicles
26.11	Manufacture of electronic components	30.91	Manufacture of motorcycles
26.12	Manufacture of loaded electronic boards	30.92	Manufacture of bicycles and invalid carriages
26.2	Manufacture of computers and peripheral equipment	30.99	Manufacture of other transport equipment nec
26.301	Manufacture of telegraph and telephone apparatus and equipment	32.5	Manufacture of medical and dental instruments and supplies
26.309	Manufacture of communication equipment (other than telegraph and telephone apparatus and equipment)	32.99	Other manufacturing nec
26.4	Manufacture of consumer electronics	33.16	Repair and maintenance of aircraft and spacecraft
Physics Machine Services			
33.11	Repair of fabricated metal products	33.17	Repair and maintenance of other transport equipment
33.12	Repair of machinery	33.19	Repair of other equipment
33.13	Repair of electronic and optical equipment	33.2	Installation of industrial machinery and equipment
33.14	Repair of electrical equipment	33.15	Repair and maintenance of ships and boats
Energy Production, Transmission & Distribution			
35.11	Production of electricity	35.13	Distribution of electricity
35.12	Transmission of electricity	35.22	Distribution of gaseous fuels through mains
Physics Waste & Recovery			
38.12	Collection of hazardous waste	38.32	Recovery of sorted materials
38.22	Treatment and disposal of hazardous waste	39	Remediation activities and other waste management services
38.31	Dismantling of wrecks		
Physics Machine Sales			
46.14	Agents involved in the sale of machinery, industrial equipment, ships and aircraft		

Medical Equipment Sales			
47.741	Retail sale of hearing aids in specialised stores	47.749	Retail sale of medical and orthopaedic goods (other than hearing aids) nec, in specialised stores
Space Transport & Air Transport Services			
51.22	Space transport	52.23	Service activities incidental to air transportation
Telecoms			
61.1	Wired telecommunications activities	61.3	Satellite telecommunications activities
61.2	Wireless telecommunications activities	61.9	Other telecommunications activities
Physics Science & Technology			
71.121	Engineering design activities for industrial process and production	72.19	Other research and experimental development on natural sciences and engineering
71.122	Engineering related scientific and technical consulting activities	74.1	Specialised design activities
71.129	Other engineering activities (not including engineering design for industrial process and production or engineering related scientific and technical consulting activities)	74.9	Other professional, scientific and technical activities nec
71.2	Technical testing and analysis	82.99	Other business support service activities nec
72.11	Research and experimental development on biotechnology		
Defence			
84.22	Defence activities		

Appendix II: SIC-based definitions of Physics-intensive industries and sectoral alignment

Code	Description	Code	Description
Physics Manufacturing			
13.95	Manufacture of non-wovens and articles made from non-wovens, except apparel	26.51	Manufacture of instruments and appliances for measuring, testing and navigation
13.96	Manufacture of other technical and industrial textiles	26.511	Manufacture of electronic instruments and appliances for measuring, testing, and navigation, except industrial process control equipment
13.99	Manufacture of other textiles n.e.c.	26.512	Manufacture of electronic industrial process control equipment
18.129	Other printing	26.513	Manufacture of non-electronic instruments and appliances for measuring, testing and navigation, except industrial process control equipment
20.12	Manufacture of dyes and pigments	26.514	Manufacture of non-electronic industrial process control equipment
20.13	Manufacture of other inorganic basic chemicals	26.52	Manufacture of watches and clocks
20.17	Manufacture of synthetic rubber in primary forms	26.6	Manufacture of irradiation, electromedical and electrotherapeutic equipment
20.3	Manufacture of paints, varnishes and similar coatings, printing ink and mastics	26.7	Manufacture of optical instruments and photographic equipment
20.301	Manufacture of paints, varnishes and similar coatings, mastics and sealants	26.701	Manufacture of optical precision instruments
20.302	Manufacture of printing ink	26.8	Manufacture of magnetic and optical media
20.51	Manufacture of explosives	27.11	Manufacture of electric motors, generators and transformers
20.59	Manufacture of other chemical products n.e.c.	27.12	Manufacture of electricity distribution and control apparatus
23.11	Manufacture of flat glass	27.2	Manufacture of batteries and accumulators
23.12	Shaping and processing of flat glass	27.32	Manufacture of other electronic and electric wires and cables
23.13	Manufacture of hollow glass	27.33	Manufacture of wiring devices
23.14	Manufacture of glass fibres	27.4	Manufacture of electric lighting equipment
23.19	Manufacture and processing of other glass, including technical glassware	27.51	Manufacture of electric domestic appliances
23.2	Manufacture of refractory products	27.9	Manufacture of other electrical equipment
23.31	Manufacture of ceramic tiles and flags	28.11	Manufacture of engines and turbines, except aircraft, vehicle and cycle engines
23.43	Manufacture of ceramic insulators and insulating fittings	28.21	Manufacture of ovens, furnaces and furnace burners
23.44	Manufacture of other technical ceramic products	28.23	Manufacture of office machinery and equipment (except computers and peripheral equipment)
23.49	Manufacture of other ceramic products	28.25	Manufacture of non-domestic cooling and ventilation equipment
24.1	Manufacture of basic iron and steel and of ferro-alloys	28.41	Manufacture of metal forming machinery
24.2	Manufacture of tubes, pipes, hollow profiles and related fittings, of steel	28.49	Manufacture of other machine tools
24.31	Cold drawing of bars	28.91	Manufacture of machinery for metallurgy

24.32	Cold rolling of narrow strip	28.922	Manufacture of machinery for mining, quarrying and construction
24.33	Cold forming or folding	28.94	Manufacture of machinery for textile, apparel and leather production
24.34	Cold drawing of wire	28.95	Manufacture of machinery for paper and paperboard production
24.41	Precious metals production	28.96	Manufacture of plastics and rubber machinery
24.46	Processing of nuclear fuel	28.99	Manufacture of other special-purpose machinery
25.11	Manufacture of metal structures and parts of structures	29.1	Manufacture of motor vehicles
25.12	Manufacture of doors and windows of metal	29.31	Manufacture of electrical and electronic equipment for motor vehicles
25.21	Manufacture of central heating radiators and boilers	29.32	Manufacture of other parts and accessories for motor vehicles
25.29	Manufacture of other tanks, reservoirs and containers of metal	30.11	Building of ships and floating structures
25.3	Manufacture of steam generators, except central heating hot water boilers	30.12	Building of pleasure and sporting boats
25.4	Manufacture of weapons and ammunition	30.3	Manufacture of air and spacecraft and related machinery
25.5	Forging, pressing, stamping and roll-forming of metal; powder metallurgy	30.4	Manufacture of military fighting vehicles
25.61	Treatment and coating of metals	30.92	Manufacture of bicycles and invalid carriages
25.62	Machining	30.99	Manufacture of other transport equipment
26.11	Manufacture of electronic components	32.5	Manufacture of medical and dental instruments and supplies
26.3	Manufacture of communication equipment	32.99	Other manufacturing
26.309	Manufacture of communication equipment (other than telegraph and telephone apparatus and equipment)		
Physics Machine Services			
33.13	Repair of electronic and optical equipment	33.17	Repair and maintenance of other transport equipment
33.14	Repair of electrical equipment	33.19	Repair of other equipment
33.15	Repair and maintenance of ships and boats	33.2	Installation of industrial machinery and equipment
33.16	Repair and maintenance of aircraft and spacecraft		
Energy Production, Transmission & Distribution			
35.11	Production of electricity	35.22	Distribution of gaseous fuels through mains
35.13	Distribution of electricity		
Physics Waste & Recovery			
38.31	Dismantling of wrecks	39	Remediation activities and other waste management services
38.32	Recovery of sorted materials		
Physics Machine Sales			
46.14	Agents involved in the sale of machinery, industrial equipment, ships and aircraft		
Medical Equipment Sales			
47.741	Retail sale of hearing aids in specialised stores	47.749	Retail sale of medical and orthopaedic goods (other than hearing aids) nec, in specialised stores
Space Transport & Air Transport Services			
51.22	Space transport	52.23	Service activities incidental to air transportation

Physics Science & Technology			
71.12	Engineering activities and related technical consultancy	71.2	Technical testing and analysis
71.121	Engineering design activities for industrial process and production	74.1	Specialised design activities
71.122	Engineering related scientific and technical consulting activities	82.99	Other business support service activities n.e.c.
Defence			
84.22	Defence activities		
Other			
13.91	Manufacture of knitted and crocheted fabrics	35.23	Trade of gas through mains
20.52	Manufacture of glues	42.21	Construction of utility projects for fluids
20.53	Manufacture of essential oils	42.22	Construction of utility projects for electricity and telecommunications
23.7	Cutting, shaping and finishing of stone	43.999	Specialised construction activities (other than scaffold erection) nec
24.45	Other non-ferrous metal production	46.52	Wholesale of electronic and telecommunications equipment and parts
25.71	Manufacture of cutlery	46.69	Wholesale of other machinery and equipment
25.72	Manufacture of locks and hinges	46.71	Wholesale of solid, liquid and gaseous fuels and related products
25.73	Manufacture of tools	46.711	Wholesale of petroleum and petroleum products
25.91	Manufacture of steel drums and similar containers	46.719	Wholesale of fuels and related products (other than petroleum and petroleum products)
25.92	Manufacture of light metal packaging	46.76	Wholesale of other intermediate products
25.93	Manufacture of wire products, chain and springs	46.9	Non-specialised wholesale trade
25.94	Manufacture of fasteners and screw machine products	77.39	Renting and leasing of other machinery, equipment and tangible goods nec
25.99	Manufacture of other fabricated metal products nec	80.1	Private security activities
27.52	Manufacture of non-electric domestic appliances	82.92	Packaging activities
32.12	Manufacture of jewellery and related articles	84.25	Fire service activities
32.3	Manufacture of sports goods	86.102	Medical nursing home activities
35.14	Trade of electricity		

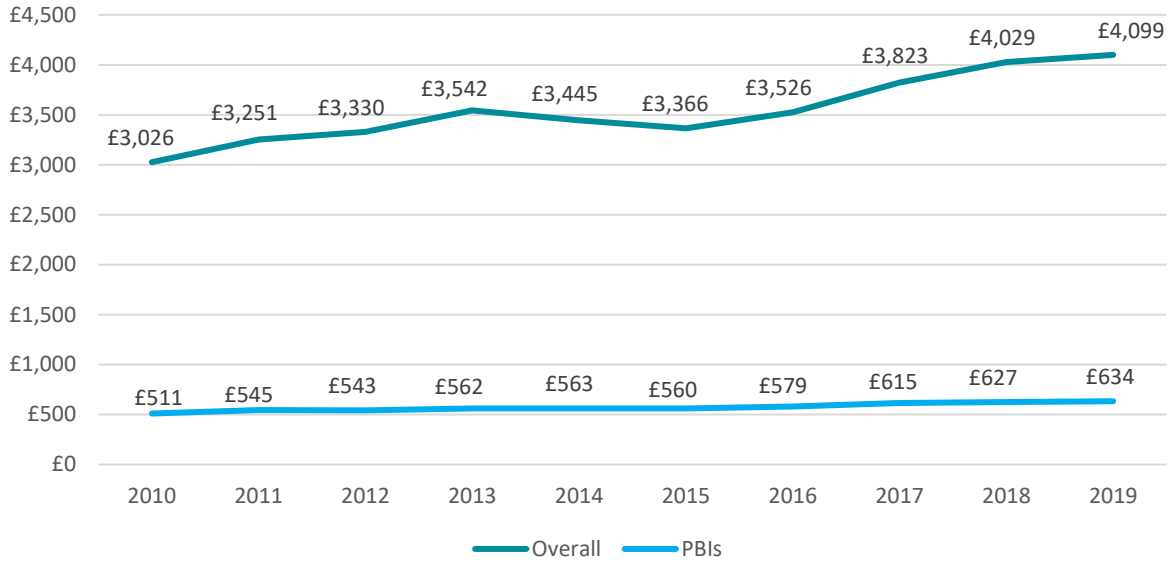
Appendix III: Supplementary figures and tables

Table 13: Turnover in the different sub-sectors of UK PBIs, £ billions, 2010-2019

Sub-sector	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Oil & Gas Extraction	37	42	37	35	27	22	17	19	22	24
Physics Manufacturing	189	204	202	210	213	216	230	242	243	240
Physics Machine Services	12	12	14	16	16	17	17	19	18	18
Energy Production, Transmission & Distribution	91	98	100	101	104	97	99	100	100	104
Physics Waste & Recovery	8	10	9	9	9	8	8	10	10	10
Physics Machine Sales	3	3	3	3	2	2	2	2	2	3
Medical Equipment Sales	1	1	1	1	1	1	1	1	1	1
Space Transport & Air Transport Services	6	7	7	8	8	9	9	10	10	11
Telecoms	66	66	63	63	61	64	65	66	66	66
Physics Science & Technology	92	98	102	114	118	122	128	143	149	153
Defence	6	5	4	5	5	4	4	4	5	4
Physics Total	511	545	543	562	563	560	579	615	627	634

Source: ABS, Cebr analysis

Figure 56: Turnover in the UK[52], £ billions, 2010-2019



Source: ABS, Cebr analysis

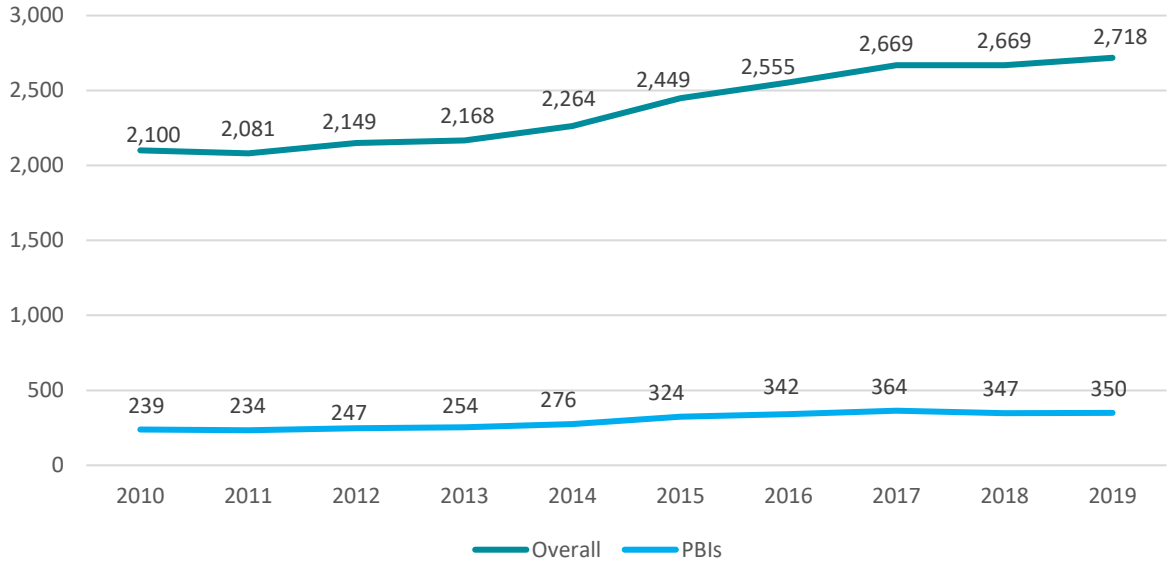
Table 14: Number of enterprises in the different sub-sectors of PBIs in the UK, thousands, 2010-2019

Sub-sector	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Oil & Gas Extraction	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2
Physics Manufacturing	58.6	55.4	54.8	53.4	54.2	55.6	56.2	56.7	57.3	57.3
Physics Machine Services	5.5	6.6	9.1	13.1	12.1	11.7	13.0	14.1	13.7	14.2
Energy Production, Transmission & Distribution	0.4	0.6	1.0	1.6	2.2	3.0	3.9	4.2	4.5	4.5
Physics Waste & Recovery	2.2	2.3	2.6	2.7	2.8	2.8	2.9	2.9	2.9	2.9
Physics Machine Sales	2.5	2.4	2.4	2.4	2.3	2.2	2.2	2.1	2.1	2.2
Medical Equipment Sales	1.2	1.1	1.2	1.2	1.2	1.2	1.3	1.3	1.4	1.4
Space Transport & Air Transport Services	0.8	0.8	0.7	0.7	0.8	0.8	0.8	0.8	0.9	1.0
Telecoms	6.2	6.5	7.3	7.7	7.7	7.9	8.0	8.4	8.4	8.4
Physics Science & Technology	161.8	157.9	168.2	171.4	192.2	238.7	253.8	273.4	255.2	258.1
Overall	239.1	233.7	247.5	254.2	275.7	324.1	342.2	364.1	346.6	350.1

Source: Nomis, Cebr analysis

52 Note that 'Overall' turnover here, is the sum of total turnover reported in the Annual Business Survey. This covers only the UK non-financial business economy which accounts for approximately two thirds of the UK economy in terms of Gross Value Added.

Figure 57: Number of enterprises in the UK, thousands, 2010-19



Source: BRES, Cebr analysis

Table 15: Division of enterprises in UK PBIs, distinguished between size, 2019

Sub-sector	Micro	Small	Medium	Large
Oil & Gas Extraction	110	15	10	15
Physics Manufacturing	45,845	8,965	2,240	295
Physics Machine Services	12,940	1,070	165	40
Energy Production, Transmission & Distribution	4,150	360	10	10
Physics Waste & Recovery	2,265	550	75	5
Physics Machine Sales	1,995	165	10	-
Medical Equipment Sales	1,335	95	5	-
Space Transport & Air Transport Services	780	95	50	25
Telecoms	7,460	690	155	45
Physics Science & Technology	245,375	10,985	1,435	300
Total	**322,255**	**22,990**	**4,155**	**735**
Overall in the UK	**2,431,990**	**233,960**	**42,000**	**10,480**

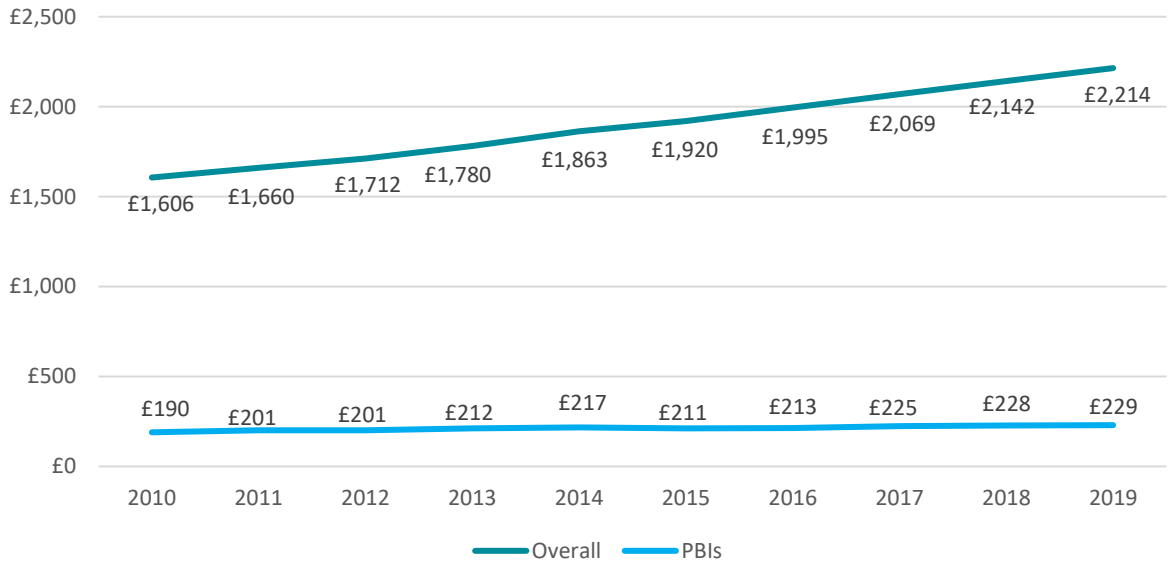
Source: Nomis, Cebr analysis

Table 16: GVA in the different sub-sectors of UK PBIs, £ billions, 2010-2019

Sub-sector	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Oil & Gas Extraction	22	25	20	17	13	11	8	13	14	16
Physics Manufacturing	61	66	66	70	70	70	70	75	73	72
Physics Machine Services	5	6	7	8	7	7	7	7	7	7
Energy Production, Transmission & Distribution	20	21	22	23	21	18	21	20	20	22
Physics Waste & Recovery	2	2	2	2	2	2	3	3	3	3
Physics Machine Sales	1	1	1	1	1	1	1	1	1	1
Medical Equipment Sales	0	0	0	0	0	0	0	0	0	0
Space Transport & Air Transport Services	4	5	5	6	6	6	7	7	7	7
Telecoms	25	26	26	26	31	30	29	32	33	33
Physics Science & Technology	45	47	50	57	62	63	66	65	67	67
Defence	3	3	2	3	3	2	2	2	3	3
Physics Total	190	201	201	212	217	211	213	225	228	229

Source: ABS, Cebr analysis

Figure 58: GVA in the UK, £ billions, 2010-2019



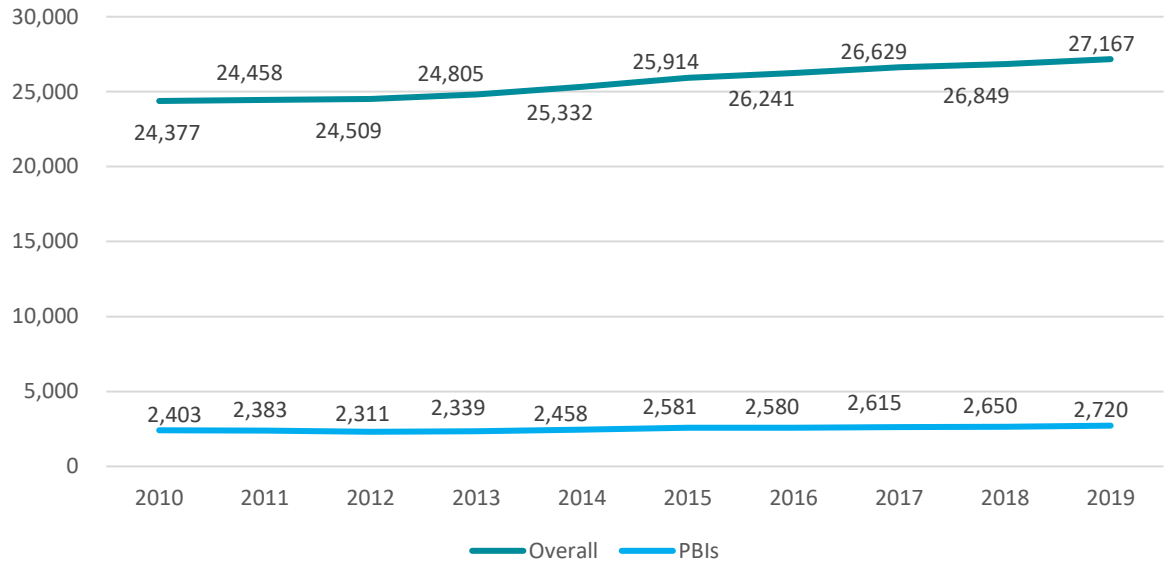
Source: Annual Population Survey, ABS, Cebr analysis

Table 17: FTEs in the different categories of UK PBIs, thousands, 2010-2019

Sub-sector	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Oil & Gas Extraction	12	13	15	16	17	16	15	12	13	13
Physics Manufacturing	1,030	1,046	1,000	992	1,011	1,037	1,006	1,033	1,048	1,006
Physics Machine Services	110	91	110	110	114	111	123	117	121	129
Energy Production, Transmission & Distribution	102	106	109	99	101	87	85	95	108	101
Physics Waste & Recovery	33	36	39	37	38	42	34	40	37	38
Physics Machine Sales	8	7	8	8	9	8	7	6	6	8
Medical Equipment Sales	6	5	5	6	5	6	6	6	6	8
Space Transport & Air Transport Services	43	41	42	44	45	47	48	50	54	54
Telecoms	208	201	188	209	199	213	199	207	195	210
Physics Science & Technology	776	772	731	762	866	965	1,013	1,005	1,012	1,102
Defence	74	64	64	55	53	49	45	45	49	50
Physics Total	2,403	2,383	2,311	2,339	2,458	2,581	2,580	2,615	2,650	2,720

Source: BRES, Cebr analysis

Figure 59: Employment in the UK, FTEs, thousands, 2010-19



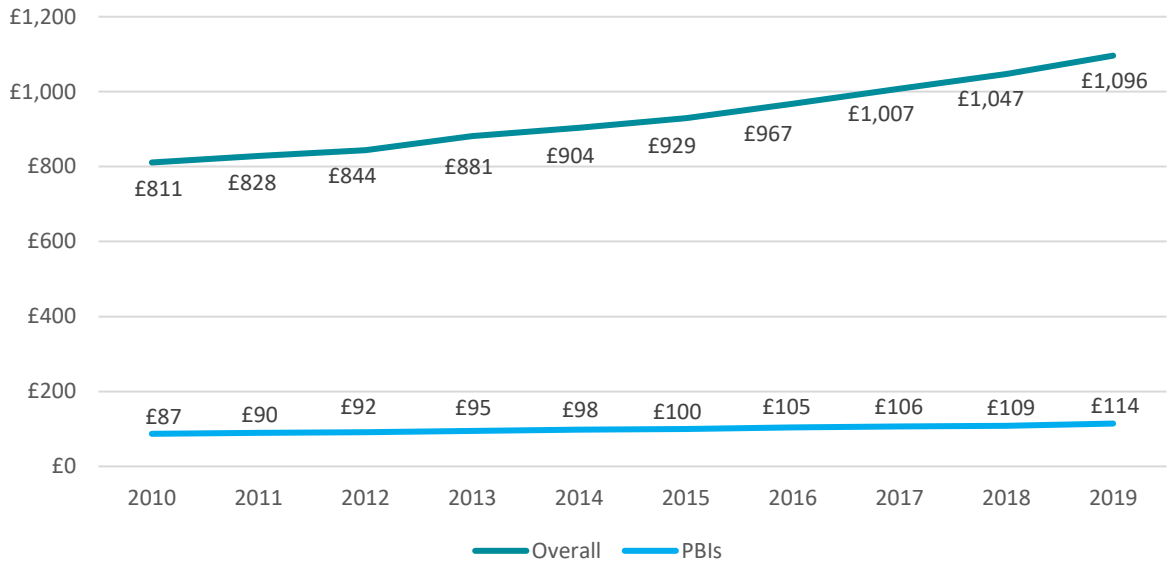
Source: Annual Population Survey, BRES, Cebr analysis

Table 18: COE in the different sub-sectors of UK PBIs, £ billions, 2010-2019

Sub-sector	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Oil & Gas Extraction	1.9	2.1	2.4	2.8	2.8	2.5	2.1	2.1	2.0	1.9
Physics Manufacturing	34.2	34.4	35.3	37.0	37.3	39.2	41.1	41.4	42.6	44.0
Physics Machine Services	2.9	3.0	3.4	3.8	3.7	3.7	3.7	4.1	4.0	3.9
Energy Production, Transmission & Distribution	5.0	5.8	5.8	4.6	4.2	4.2	4.2	5.0	5.3	5.4
Physics Waste & Recovery	0.8	0.9	0.9	1.0	1.2	1.0	1.3	1.3	1.4	1.6
Physics Machine Sales	0.7	0.5	0.4	0.4	0.4	0.4	0.2	0.2	0.3	0.3
Medical Equipment Sales	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2
Space Transport & Air Transport Services	1.6	1.6	1.9	2.1	2.1	2.1	2.2	2.4	2.6	2.7
Telecoms	9.7	9.9	10.0	10.2	10.5	10.4	10.4	11.0	10.8	11.2
Physics Science & Technology	27.7	29.5	29.7	30.9	33.7	35.0	37.6	37.0	37.7	41.3
Defence	2.4	2.0	1.8	1.8	1.8	1.6	1.4	1.6	1.8	1.8
Physics Total	87.0	89.7	91.6	94.7	97.8	100.2	104.5	106.2	108.7	114.3

Source: ABS, Cebr analysis

Figure 60: COE in the UK, £ billions, 2010-19



Source: Eurostat, Annual Population Survey, Cebr analysis

Table 19: R&D in the different sub-sectors of UK PBIs and physics-intensive industries, £ thousands, 2010-2019

Sub-sector	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Defence	-	-	-	-	-	-	-	-	-	-
Energy Production, Transmission & Distribution	12	21	56	72	64	65	49	44	56	140
Physics Machine Sales	11	7	6	7	5	5	4	6	7	7
Physics Machine Services	156	77	83	105	131	159	153	160	143	127
Medical Equipment Sales	2	2	2	2	2	2	2	3	4	5
Oil & Gas Extraction	88	124	93	118	104	96	87	93	89	98
Physics Manufacturing	4,154	4,551	4,927	5,326	5,683	6,143	7,054	6,725	7,234	6,957
Physics Science & Technology	5,997	6,522	5,942	6,245	6,549	6,821	6,629	6,669	7,046	7,636
Telecoms	826	719	701	730	798	691	748	734	780	801
Space Transport & Air Transport Services	3	3	-	2	3	3	3	5	6	5
Physics Waste & Recovery	2	2	3	5	3	8	9	19	12	7
PBI Total	11,252	12,029	11,814	12,611	13,342	13,993	14,739	14,456	15,378	15,784
Physics-Intensive Industries	5,056	5,526	6,416	6,901	7,469	8,028	8,753	8,475	9,059	8,882

Source: ABS, ONS, Cebr analysis

Appendix IV: Methodology

The following section lays out our methodology, broken down by our approach to the overall impacts and the regional impacts.

Direct impacts

In order to provide a well-rounded summary of the PBIs in the UK, we worked with the turnover, GVA, total FTE employees and COE, as well as with the number of enterprises. For these, we used the Annual Business Survey (ABS) from the Office of National Statistics (ONS), the Business Register and Employment Survey (BRES) from Nomis and the UK business counts from Nomis. Since BRES only has data on Great Britain, and thus does not include Northern Ireland, we modelled the total UK FTE employment by adjusting the GB value to the yearly share of Northern Ireland FTE workers to the UK:

$$UK\ FTE_i = GB\ FTE_i \times (1 + Share\ of\ NI\ FTE_i)$$

Where FTE_i is the number of full-time employees in year *i*.

ABS has a very granular database on economic variables at a four/five-digit SIC level, however there are some cases when some of the values were missing. When this occurs, we estimated the data we needed in order to provide a more accurate summary and not simply omit the footprint of some SICs. If an employment data was missing, we used the average of the employment in the industry one year earlier and one year later. In cases where the turnover, GVA or COE was missing, the turnover-FTE, the GVA-FTE or the COE-FTE ratio for the previous year where we had the full data was used to extrapolate estimates for the missing year. Whenever we encountered a SIC 5-digit level industry, where ABS had no data, we used the 3- or 4-digit SIC values and the ratio of the 5- and 3-digit level BRES FTE values in order to estimate the specific data on these:

$$5\ digit\ GVA_i = 3\ digit\ GVA_i \times \frac{5\ digit\ FTE_i}{3\ digit\ FTE_i}$$

Where again GVA_i is the gross value added in year *i,* and $FTE_i$is the number of full-time employees in year *i.*

Once we had all the data, we aggregated the industries into 11 sub-sectors. These are: Oil & Gas Extraction; Physics Manufacturing; Physics Machine Services; Energy Production, Transmission & Distribution; Physics Waste & Recovery; Physics Machine Sales; Medical Equipment Sales; Space Transport & Air Transport Services; Telecoms; Physics Science & Technology; and lastly, Defence. Appendix I**: SIC-based definitions of PBIs and sectoral alignment** shows which industries belong to which sub-sector.

Aggregate impacts

After collation and interrogation, the direct economic impacts for PBIs have then been embedded within Cebr's economic impacts models of the UK economy, to estimate the wider economic footprint supported by the PBIs. These models are built upon the framework provided by the ONS' supply-use tables. This is the most detailed official record of how the industries of the economy interact with other industries, consumers and international markets in producing the nation's GDP and national income.

To model the relationships that exist between these impact layers, we use bespoke input-output models. These models examine the structure of a firm, industry or sector's supply-chain (in this case that of the PBIs), allowing us to quantify the economic activity supported along

them. In addition, by considering the typical distribution of household spending, the model allows us to calculate the output and employment associated with the induced impact layer.

Our modelling produces multipliers, which calculate the total footprint supported for a given level of direct contributions. For example, if the GVA multiplier turned out to be 2.5, this would translate as 'for every £1 directly generated by the PBIs, a further £1.50 is supported elsewhere in the economy, producing an aggregate GVA supported of £2.50'. We have calculated these multipliers based upon the direct economic impacts calculated for 2019.

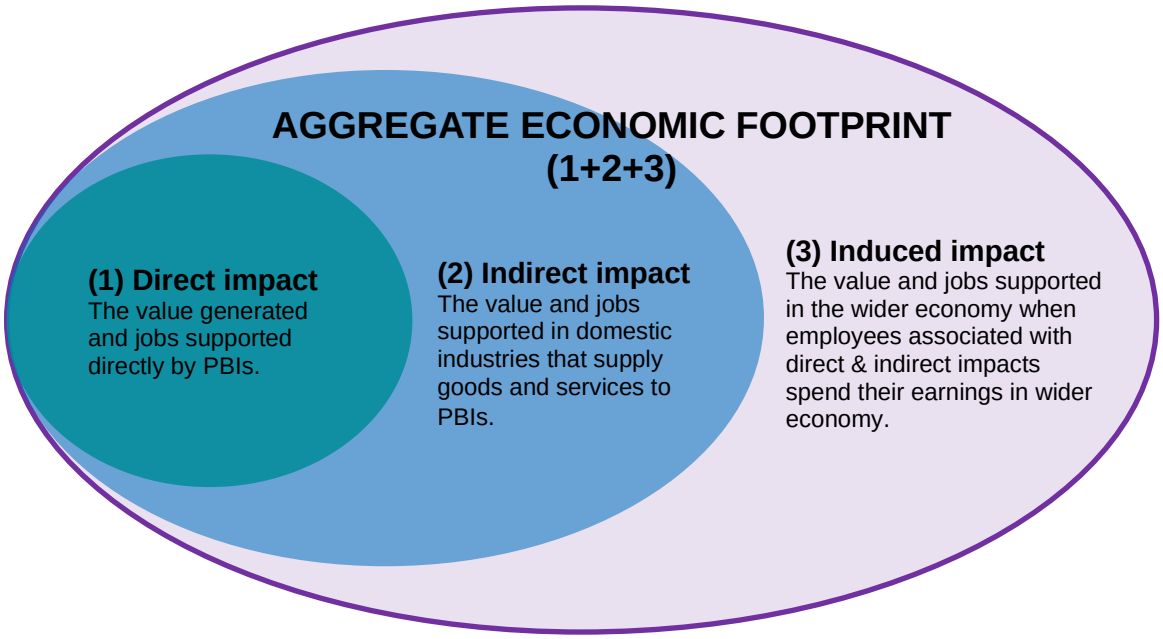
By combining these multipliers with the calculated direct impacts, we form our estimates for the aggregate footprint supported by the PBIs.

The models produce three types of impact for four indicators – turnover, GVA, employment and COE. The three types of impact are:

- **Direct impact**: this is the value generated and jobs supported directly by the economic activities of the UK PBIs.
- **Indirect impact**: this is the value and jobs supported in industries that supply inputs to the UK PBIs.
- **Induced impact**: this is the value and jobs supported in the wider economy when the direct and indirect employees of the sector spend their wages and salaries on final goods and services.

These three impacts are then combined to convey the aggregate impact associated with each industry and activity within PBIs in terms of turnover, GVA, employment, and COE, which can be seen in the figure below.

Figure 61: Illustration of economic and social impact layers



Removal of 'double-counting' effects

As this report considers the activities of the entire physics-based industry (as defined in Section 1), when quantifying the associated aggregate economic impacts, it is necessary to consider and account for the crossovers or interlinkages that will exist between each of the constituent industries. So, if we were to simply apply multipliers to each industry and combine

the resulting aggregate impacts, we would in effect be double-counting some of the economic contributions, and would by extension overstate the aggregate impacts of the sector.[53]

To avoid double-counting it has therefore been necessary to remove these surplus interlinkages from our analysis. In practice, this involves removing coefficients relating to affected industries within Cebr's input-output models which would otherwise feature as part of the PBI multipliers.

Regional impacts

After modelling the data of the UK impacts, we estimated the share attributable to each UK nation and region. First, we used BRES employment data to estimate the share of FTEs in each region in a given industry. We modelled the GVA by using the UK industrial GVA/FTE ratio, adjusting for regional productivity differentials (from ONS) and the number of employees in the region. In order to estimate the COE and the turnover, we used the ABS 2-digit level regional data to find the COE-GVA and the GVA-turnover ratios in a given year. After that, we were able to estimate both from the GVA and the relevant ratio, and scaling figures were necessary to ensure the regional estimates summed to that of the UK direct impacts.

In some cases, ABS was missing one of the regional values we needed to calculate the ratios underpinning the analysis. If there were only one or two years of data missing, we averaged the earlier and later years to estimate the value of the missing year. If the lack of data was more frequent, we used the UK-level ratios to estimate the regional values.

In a few cases we had the ABS values, but the ratios were highly volatile - an unfortunate challenge associated with very granular industry and regional economic data. In order to control for this, we have adjusted the methodology in such cases, using UK-level variable ratios to estimate regional impacts, with regional distributions solely driven by the regional distribution of employment within a particular industry.

53 For example, where a business in the PBIs purchases goods or services from another business in the PBIs, we do not want to include this as both a direct and indirect impact.

Appendix V: R&D econometric model

The empirical relationship between R&D and private returns has been extensively studied in the academic literature. A review of studies adopting an approach comparable to the one used in this report is presented in Section 7. Most studies draw on an equation which reproduces a production function, augmented with R&D expenditure as a proxy for knowledge. Following the academic literature, we adopt a Cobb-Douglas production function as a particular functional form of the production function which reproduces the technological relationship between the amounts of the inputs and the amount of output that can be produced by those inputs. The function can be expressed as follows:

$$Y = AN^{\alpha}K^{\beta}R^{\gamma}$$

Where Y is some measure of economic output (turnover, sales or value added), N is labour, K is tangible capital (assets), R is R&D investment and A is a constant.

Taking natural logarithms (denoted using lower case letters) of the above equation variables, we can derive the following empirical model:

$$y_{i,t} = a + \alpha n_{i,t} + \beta k_{i,t} + \gamma r_{i,t} + \mu_{i,t}$$

Where i indicates a firm or industry and t indicates a year and μ is the residual error term.

Using data for PBIs at a four- and five-digit SIC level over the period 2010-2019, we have estimated two regression models based on the above equation. One model has turnover as dependent variable (or left-hand variable of the equation), and the other model has GVA. Independent variables (right-hand variables of the equation) of both models include data on employment, gross fixed capital formation and R&D spending.

Regression analysis enables us to estimate the relationship between the dependent and the independent variables. In this case, we are interested in the strength of the relationship between R&D spending and turnover/GVA, expressed by the R&D spending coefficient. Since we use logarithms, coefficients can be interpreted as elasticities.

Using panel data (which is data for a set of subjects – 100+ specific PBI SICs, in this case – over time) implies that we estimate one coefficient of the impact of R&D investment on turnover/GVA which is valid across all PBI sub-sectors. As opposed to time series, panel data models produce estimates for all sub-sectors at once and have the main advantage of minimizing estimation biases. We have then applied these coefficients to estimates for the increase in PBI R&D investment required to meet wider Government targets for R&D. A time series approach would have enabled us to calculate a bespoke coefficient for each sub-sector. However, the regressions would have relied on only ten observations (2010-2019), raising concern about the robustness of the approach.

As commonly done in panel data analysis to choose between fixed-effects and random-effects model, we performed a Hausman test. Results of the test demonstrates that fixed-effects should be preferred for both models.

Outputs of the regressions are presented below.

The models' results tell us that, for PBIs, turnover elasticity to R&D spending is 14.7% and GVA elasticity to R&D spending is 26.8%.

To assess the overall fit of a fixed-effects regression model, the within R-squared is typically of main interest. The first model explains 80% of the turnover variance while the second model explains 61% of the GVA variance. Both values are relatively high, indicating that a large percentage of the data variance is explained by the model. Furthermore, whilst the R-squared

gives us a sense of the overall fit of the model, evaluation of the estimated coefficients (investigating their statistical significance, sign, magnitude and stability across different models) and diagnostic tests are equally important. In addition to performing a Hausman test to choose between fixed effects and random effects, we tested for the presence of multicollinearity[54] and heteroskedacity[55]. Comparing the coefficients estimated in this study with academic literature and having run all the necessary diagnostic tests, the model proves to be robust.

Figure 62: Turnover regression outputs

```
Fixed-effects (within) regression               Number of obs      =      1146
Group variable: id                              Number of groups   =       115

R-sq:  within  = 0.8018                         Obs per group: min =         9
       between = 0.9330                                        avg =      10.0
       overall = 0.9285                                        max =        10

                                                F(3,1028)          =   1385.82
corr(u_i, Xb)  = -0.4939                        Prob > F           =    0.0000

------------------------------------------------------------------------------
  log_Turnover |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
       log_RnD   .1477312   .0115147    12.83   0.000     .1251362    .1703263
     log_GFCF2   .8201941   .0206253    39.77   0.000     .7797215    .8606667
log_Employment   .1012963   .0208893     4.85   0.000     .0603057    .1422869
         _cons   2.322462   .1674655    13.87   0.000     1.993849    2.651075
-------------+----------------------------------------------------------------
       sigma_u  .54643164
       sigma_e   .1355752
           rho   .9420111   (fraction of variance due to u_i)
------------------------------------------------------------------------------
F test that all u_i=0:     F(114, 1028) =    89.65           Prob > F = 0.0000
```

54 Multicollinearity occurs when two or more independent variables in a multiple regression model are highly intercorrelated. If not addressed, multicollinearity can lead to skewed coefficient estimates.

55 Heteroskedasticity occurs when the error variance is nonconstant. Whilst regression analysis using heteroscedastic data provides an unbiased estimate for the relationship between the predictor variable and the outcome, standard errors of the coefficients and therefore inferences obtained from data analysis could be biased.

Figure 63: GVA regression outputs

```
Fixed-effects (within) regression               Number of obs      =      1146
Group variable: id                              Number of groups   =       115

R-sq:  within  = 0.6126                         Obs per group: min =         9
       between = 0.8887                                        avg =      10.0
       overall = 0.8780                                        max =        10

                                                F(3,1028)          =    541.77
corr(u_i, Xb)  = -0.3320                        Prob > F           =    0.0000

------------------------------------------------------------------------------
       log_GVA |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
---------------+--------------------------------------------------------------
       log_RnD |   .2683574   .0187085    14.34   0.000     .2316461    .3050686
     log_GFCF2 |   .6988523    .033511    20.85   0.000     .6330946    .7646101
log_Employment |   .0335074   .0339399     0.99   0.324    -.0330919    .1001068
         _cons |   2.122932    .272089     7.80   0.000     1.589018    2.656845
---------------+--------------------------------------------------------------
       sigma_u |  .64703903
       sigma_e |  .22027538
           rho |  .89614032   (fraction of variance due to u_i)
------------------------------------------------------------------------------
F test that all u_i=0:     F(114, 1028) =    38.94           Prob > F = 0.0000
```

Cebr