The Royal Society of Chemistry

# Chemistry's Contribution: workforce trends and economic impact

cambridge econometrics
clarity from complexity

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# About the Royal Society of Chemistry

We are an international organisation connecting chemical scientists with each other, with other scientists, and with society as a whole. Founded in 1841 and based in London, UK, we have an international membership of over 50,000. We use the surplus from our global publishing and knowledge business to give thousands of chemical scientists the support and resources required to make vital advances in chemical knowledge. We develop, recognise and celebrate professional capabilities, and we bring people together to spark new ideas and new partnerships. We support teachers to inspire future generations of scientists, and we speak up to influence the people making decisions that affect us all. We are a catalyst for the chemistry that enriches our world.

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# Summary of key findings

- Chemistry using professionals play a significant role in the labour market. In 2019, there were an estimated 275,000 chemistry using professionals in employment in the UK, up from 272,000 in 2013. The largest shares are in London and the South East, with the North West also acting as an important regional hub.
- They also make an important economic contribution. Chemistry using professionals make a direct contribution to the economic output in the sectors in which they work, which also generates further rounds of impact throughout the economy. Over the period 2013-2019 chemistry using professionals are estimated to have generated an average of £83bn in economic output per year. They also contributed an estimated £3.2bn to the Exchequer in 2019, through tax and National Insurance payments.
- Chemistry using professionals encompass a wide range of occupations, from academic chemists in universities and professional chemical scientists in industry, through to chemistry teachers in schools and those in sales and marketing roles. The study has classified them into four distinct groups: Group 1 includes occupations where chemistry knowledge is of high importance (academics, professional chemists), while Group 4 includes those where chemistry knowledge is less important, but still a significant component of the role (sales, marketing, some engineering and science professionals).
- They are, overall, a highly qualified cohort, with most occupations classified under Major Groups 2 and 3 (Professional and Associate Professional and Technical occupations) in the Standard Occupational Classification 2010, which generally (but not necessarily) require a first degree or higher to enter.
- Chemistry using professionals share several similar characteristics, such as the ability to comprehend written and spoken word, knowledge of the English language and the skill to write and converse clearly. They are also highly analytical. They require not only chemistry subject knowledge, but often knowledge of other science subjects, alongside mathematics. As may also be expected of analytical occupations, critical thinking and complex problem-solving skills are also often required.
- Some occupations, that are perhaps not seen as 'traditional' roles for chemistry using professionals do require a significant level of chemistry knowledge to be undertaken successfully in chemistry using sectors. For example, many who undertake sales and marketing roles (Group 4) can be highly qualified: around 40% of respondents in sales and marketing roles hold a doctorate in a chemistry-related subject as their highest qualification, according to the Royal Society of Chemistry's (RSC) 2019 Pay and Reward Survey; and the overwhelming majority feel that their qualification has contributed positively towards their career progression.
- Although chemistry knowledge is an important requirement for Group 4 occupations, knowledge in other areas is equally, or more important than

chemistry knowledge in these roles. They are typically more general occupations, but with a significant chemistry component.

- The suite of evidence available suggests a strong link between, skills, innovation and productivity: higher skills are shown to be related to greater levels of innovation and both are associated with higher productivity and therefore, economic growth. Furthermore, firm-level evidence suggests that those holding higher degrees can have a significant impact on innovation and output.
- Taken together, the evidence suggests that chemistry using professionals make a significant contribution to innovation and economic growth, both through the nature of the occupations they undertake and because they tend to be highly qualified. Furthermore, several common characteristics shared by chemistry using professionals appear to be highly relevant to the ability to innovate. These include complex problem solving, critical thinking, coordination and troubleshooting skills.

# 1 Introduction

In 2018, the chemical and pharmaceutical sectors alone accounted for £18.3 billion in Gross Value Added (GVA) to the UK economy and employed 153,000 people[1]. Chemical sciences also contribute to the output of many other sectors, such as agriculture, energy, aerospace and the automotive industries.

A strong chemistry sector will play an important part in delivering each of the four Grand Challenges set out in the Government's Industrial Strategy (artificial intelligence and data-driven technology, clean growth, the ageing society and mobility), as well as other Government Strategies, such as the 25 year Environment Plan. Chemistry is therefore not just an important part of our economy in the UK, but it also plays a pivotal role in shaping our society and the environment we live in.

The Industrial Strategy also sets out the need to tackle shortages of STEM (Science, Technology, Engineering and Mathematics) skills, required across the economy. Skills are important for growth: skills improvements have accounted for one-fifth of UK labour productivity growth in recent decades (HM Government 2015) and skills shortages have a real impact on firms' day-to-day ability to do business (Department for Education, 2018).

The pivotal role that both chemistry and chemistry using professionals play in the Government's economic, environmental and skills strategies means that it is important to have as detailed an understanding as possible of the skills and knowledge that chemistry using professionals apply – and where they apply them – across the economy. This study aims to provide that understanding, by looking in some detail at what makes a chemistry using professional – informed by the job that they do, the sector they work in, the qualifications they hold and the importance of different attributes needed to undertake a range of occupations. This provides the basis for estimating the number of chemistry using professionals in employment over time and their economic contribution – capturing this across the economy as a whole and not just in 'traditional' chemistry using sectors.

This will help policymakers to better understand and value the important role that chemistry using professionals play, informing the continued implementation of the Industrial Strategy and future policy development.

*Research questions*

The aim of the study is to answer the research questions below:

- What skills and knowledge do chemistry using professionals typically apply in the workforce? What is the definition of a chemistry using professional? What other definitions can usefully describe the roles of chemistry using professionals in the workforce?
- Where in the UK economy do chemistry using professionals apply their skills?

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[1] Office for National Statistics Annual Business Survey.

- How does the chemistry using workforce contribute to UK economic activity and the public purse; and how does this vary by region and sector?
- How has this labour market and economic contribution changed over time?
- How can the innovative nature of chemistry using professionals be captured and what is the impact of this on these outputs?

This report is organised as follows. Chapter 2 is concerned with developing a robust definition of chemistry using professionals and looking at the knowledge, skills and abilities they apply in their day-to-day work. Chapter 3 uses the definitions developed in Chapter 2 and looks at where in the UK economy chemistry using professionals apply their skills, providing employment estimates by sector, region and over time.

An estimate of the contribution of chemistry using professionals to economic activity and the public purse is provided in Chapter 4. Chapter 5 discusses the importance of innovation, its links to economic growth and productivity and ways in which chemistry using professionals contribute to innovation. It also discusses the issue of professional development, skills and their economic benefits, with particular reference to the types of higher-level skills typically acquired by chemistry using professionals. Finally, Chapter 6 offers some concluding remarks.

# 2 Defining a chemistry using professional: What skills and knowledge do they typically apply in the workforce?

There is a dearth of definitions around chemistry using professionals in the literature. Those that do exist either focus narrowly on 'chemists' (i.e. those that are involved in the application of chemistry as a science); or, at the other extreme, everyone working in sectors dealing with the manufacture of chemical products. As neither of these extremes adequately captures the role of chemistry using professionals in the modern workforce, this section develops a more suitable definition of 'chemistry using professionals', for the purposes of this study, and identifies the knowledge, skills and abilities that they apply in the workforce.

The section begins by exploring the existing definitions as set out in the literature, before setting out how chemistry using professionals have been defined in this research and then identifying what knowledge, skills and abilities they apply in their work.

## 2.1 How are 'chemistry' and 'chemical sciences' defined in the literature?

The definitions provided in the literature can be broadly assigned to three categories: chemistry as a science; the manufacture of chemical products, and; the widest, which encompasses the chemical manufacturing and 'chemical using' industries.

*Chemistry as a science*

Chemistry can be defined as the science that studies, designs, and manipulates molecular structures. This strict definition excludes areas commonly attributed to the chemicals sector, such as pharmaceuticals and biotechnology. In general, this definition is recognised as being quite narrow, especially as multi-disciplinarity and cross-subject interspersion becomes more important. This results in several industries that would previously have been classed as "non-chemical" gaining a "chemical" component – see for example the field of chemo-informatics and the increased need for arts to play a role in the design process of chemistry related products (Royal Society of Chemistry n.d., Engineering and Physical Sciences Research Council 2009). With over 90% of respondents to a survey which was part of the Sciences Horizon inquiry by the Royal Society of Chemistry stating that they had collaborated with people outside their discipline, chemistry thus plays a significant linking role in the economy and is at the heart of the creation of new disciplines.

*The manufacture of chemical products*

The second, wider, definition (Oxford Economics 2019, Science Industry Partnership 2016) is based on an integrated statistical classification scheme of economic activities that facilitates sector comparisons across countries, as detailed in Division 20 (Manufacture of chemicals and chemical products ) of Eurostat's Statistical classification of economic activities in the European

Community (NACE Rev. 2[2]). It takes a manufacturing view of the chemical sciences, encompassing the following areas:

- Manufacture of basic chemicals, fertilisers and nitrogen compounds, plastics and synthetic rubber in primary forms
- Manufacture of pesticides and other agrochemical products
- Manufacture of paints, varnishes and similar coatings, printing ink and mastics
- Manufacture of soap and detergents, cleaning and polishing preparations, perfumes and toilet preparations
- Manufacture of other chemical products (explosives, glues, essential oils)
- Manufacture of man-made fibres

*The chemical manufacturing and chemical-using industries*

The broadest definition of the chemicals sector expands on Eurostat's definition by including chemistry-using industries. Sectors that manufacture chemical products are classified as the "upstream chemical industry", and 15 major chemistry-using industries make up the "downstream chemical industry". The latter include Aerospace, Textiles, Energy, and Food & Drink (Oxford Economics 2010).

However, even the broadest definition provided by the literature may not fully capture the breadth of how chemistry skills and knowledge are used in the modern economy. For example, chemistry using sectors also include service-based organisations, such as analytical testing services and contract research/consultancy. Furthermore, the definitions in the literature tend to be sector-based and say little about which occupations require chemistry knowledge; and how the use and level of chemistry knowledge required can vary across occupations. Thus in order to capture the breadth of chemistry usage throughout the economy, this research develops a more modern definition of chemistry using professionals (and the knowledge, skills and abilities they need to carry out the work of their occupations); and in a later section, establishes where in the economy they apply their skills.

## 2.2 Steps towards defining chemistry using professionals

### 2.2.1 The datasets

To identify the occupations that chemistry using professionals work in and the knowledge, skills and abilities that they apply in these occupations, the following key sources have been reviewed and combined to inform our definition of 'chemistry using professionals' and descriptions of occupational characteristics:

- RSC membership data
- Data from the RSC's Pay and Reward Survey
- The Standard Occupational Classification 2010 (SOC 2010) manual
- US Occupational Information Network (O*NET)

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[2] See https://ec.europa.eu/eurostat/documents/3859598/5902521/KS-RA-07-015-EN.PDF.

Firstly, the Society's membership database and data from the 2019 Pay and Reward Survey were examined, to gain an understanding of the types of occupations and sectors members work in. This information was then mapped to an equivalent SOC 2010 grouping at the Unit Group (4 digit) level.

The final list of SOC 2010 occupations were matched to their equivalents in O*NET, where the knowledge, skills and abilities required to undertake the occupations were analysed.

### *RSC membership and Pay and Reward Survey data*

The Society's membership data includes information provided by members about their job type (occupation) and company type (sector). However, this does rely on members keeping the RSC informed of any changes in their circumstances.

The Pay and Reward Survey is a biennial survey of RSC members and offers up-to-date insights into members' employment, having polled over 6,000 RSC members in 2019. Although the results are representative of the membership base, only around one-fifth of members respond to the survey (the RSC currently has around 50,000 members). Therefore, both datasets are used to inform the selection of relevant SOC 2010 classifications, alongside the characteristics of the occupations as detailed in the SOC 2010 manual – including typical tasks associated with the occupation, qualifications required, other entry requirements and alternative job titles. This was refined with input from the project Steering Group, to ensure adequate coverage of relevant occupations.

### *Standard Occupational Classification (2010)*

The Office for National Statistics' (ONS) SOC 2010[3] provides a detailed classification of UK occupations. Occupations are classified into Major (1 digit), Sub-Major (2 digits), Minor (3 digits) and Unit Group (4 digits) levels, with Major being the broadest and Unit Group being the most detailed.

SOC was first introduced in 1990 and has been updated every 10 years since, as technical and occupational changes can have a significant impact on the occupational structure – via the introduction of new jobs that didn't previously exist and changes in the scope of others. Occupational information serves a variety of purposes. It informs the job matching activities undertaken by employment agencies, it provides an organisational framework for the provision of career information for leavers from the educational sectors and other labour market entrants and, via statistical analysis of trends, yields guidance for the development of labour market policies – especially those which relate to the promotion of work-based training.

The aim of SOC is to classify jobs to occupational groups. Jobs in SOC 2010 are classified according to the concepts of skill level and skill specialisation. Skill specialisation is defined as the field of knowledge required for competent, thorough, and efficient conduct of the tasks. In some areas of the classification, it can also refer to the type of work performed (materials worked with, tools used, etc.).

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[3] See https://www.ons.gov.uk/file?uri=/methodology/classificationsandstandards/standardoccupationalclassificationsoc/soc2010/soc2010volume1structureanddescriptionsofunitgroups/soc2010volume1webtcm77181317.pdf

Skill levels reflect the approximate length of time required for a person to become fully competent in the performance of the tasks associated with the job, which is a function of the time taken to complete any necessary formal qualifications and any work-based training; plus experience required to acquire competence. Hence in SOC 2010, the classification roughly corresponds to the skills and qualifications required – with Managers (Major Group 1) being the highest skilled and Elementary occupations (Major Group 9) being the lowest.

The SOC 2010 manual provides a range of information that proved helpful when selecting chemistry using occupations. At Unit Group level, it provides an overview of the job types included, typical entry routes and associated qualifications, a list of tasks associated with jobs included in the classification and related job titles.

Using a combination of RSC data and the information in the SOC 2010 manual, a list of SOC 2010 occupations most likely to include chemistry using professionals was compiled at Unit Group (4 digit) level. These were then mapped to their equivalents in the O*NET database by hand, based on the occupation descriptions.

*The O*NET database*

The O*NET database was used to identify the key skills and abilities, as well as types of knowledge, that 'chemistry using professionals' apply in their respective occupations. The O*NET database contains information on hundreds of standardised and occupation-specific descriptors on almost 1,000 occupations, with data constructed by a combination of results from wide-scale surveys, occupation experts and analysts' judgement.

O*NET's underlying content model describes the distinguishing characteristics of occupations, based on key measures such as workers' knowledge, skills and abilities; as well as broader details. Each item is then given an importance score between 0 and 100. This is informed by responses to the O*NET survey and calibrated in a review process by O*NET analysts. This dataset forms the basis for the further analysis to come up with a clear definition of 'chemistry using professionals' and their knowledge, skills and abilities.

After the SOC 2010 to O*NET mapping process was completed, the characteristics of the relevant O*NET occupations were then analysed.

*Caveats*

It is important to note that although the occupational classifications are reasonably detailed, the mapping process is inherently imperfect: even at Unit Group level, some occupations may not perfectly reflect the job roles that chemistry using professionals undertake.

Also, whilst occupational characteristics are described in detail by O*NET, an element of judgement is required when mapping the US occupations used in O*NET to their UK equivalents. For instance, in some cases the same O*NET occupation could reasonably be matched to more than one SOC 2010 occupation. However, where this is the case, the SOC 2010 occupations tend to be in similar or related Unit Groups.

## 2.3 Analysing the characteristics of O*NET occupations: the approach

The aim of this part of the research was to analyse the characteristics of the occupations that chemistry using professionals undertake, to develop a definition of chemistry using professionals. This could be one, overarching, definition that captures all occupations selected; or several definitions encompassing different types of chemistry using professional, depending on the occupational characteristics.

Each O*NET occupation is characterised by 33 knowledge types, 34 skills and 31 abilities.  This means that each O*NET occupation has a total of 98 descriptive indicators across the 3 categories. The lead indicator, used to inform an initial ranking of occupations, is chemistry knowledge.

The chemistry knowledge score in O*NET is effectively a composite measure, representing both the level of knowledge and its importance. For example, high-scoring occupations (90 or more out of 100, say) are those that use a very high level of chemistry knowledge on a regular basis – such as academic chemists in universities. Occupations with a lower chemistry importance score may still require frequent application of chemistry knowledge, but at a lower level – laboratory technicians, for example.

Once ranked by their chemistry importance score, the occupations were sorted into 5 groups, as detailed in Table 1. Chemistry importance scores were not available in O*NET for teachers, marketing managers and sales representatives. These occupations represent an important part of RSC membership and the community as a whole. Although they have been excluded from the initial ranking exercise, their place among the groupings will be discussed later in this section.

Table 1 shows the initial occupation groupings for O*NET and SOC 2010 occupations. Food science technicians are placed in Group 4 alongside Environmental Engineering Technicians, since both are matched to SOC 2010 code 3119 (Science, engineering and production technicians not elsewhere classified (n.e.c)).

**Table 1: Initial groupings of occupations based on their chemistry importance score**

| Group | Chemistry importance score | O*NET occupation title | SOC 2010 occupation code | SOC 2010 occupation title |
|---|---|---|---|---|
| Group 1 | 94 | Chemist | 2111 | Chemical scientist |
| | 94 | Chemical Engineers | 2111 | Chemical scientist |
| | 94 | Chemistry Teachers Postsecondary | 2311 | HE Teaching Professionals |
| | 84 | Biochemists and Biophysicists | 2111 | Chemical scientist |
| | | | 2112 | Biological scientists and biochemists |
| | 87 | Material Scientist | 2111 | Chemical scientist |
| Group 2 | 74 | Biochemical Engineers | 2129 | Engineering professionals n.e.c. |
| | 75 | Chemical technician | 3111 | Laboratory technicians |
| | 75 | Quality Control Analysts | 2462 | Quality assurance and regulatory professionals |
| | | | 3115 | Quality assurance technicians |
| Group 3 | 67 | Chemical Plant and System Operators | 8129 | Plant and machine operatives n.e.c. |
| | | | 8114 | Chemical and related process operatives |
| | 61 | Environmental Scientists and Specialists, Including Health | 2463 | Environmental health professionals |
| | | | 2142 | Environment professionals |
| | 69 | Quality Control Systems Managers | 2127 | Production and process engineers |
| Group 4 | 59 | Environmental Engineering Technicians | 3119 | Science, engineering and production technicians n.e.c. |
| | 64 | Food Science Technicians | 3119 | Science, engineering and production technicians n.e.c. |
| | 58 | Industrial Safety and Health Engineers | 3567 | Health and safety officers |
| | | | 8124 | Energy plant operatives |
| | | | 1255 | Waste disposal and environmental services managers |
| | 52 | Natural Sciences Managers | 2119 | Natural and social science professionals n.e.c. |
| No chemistry importance score in O*NET | | Career/Technical Education teacher | 2312 | Further education teaching professionals |
| | | Secondary School Teacher | 2314 | Secondary education teaching professionals |
| | | Marketing Managers | 3543 | Marketing associate professionals |
| | | Sales Representative, Wholesale and Manufacturing, | 3542 | Business sales executives |

| | |
|---|---|
| | Technical and Scientific Products |

### Analysis of the knowledge, skills and abilities associated with each occupation

Once this initial ranking was completed, the next step was to analyse the wider set of characteristics related to each occupation, to understand whether particular traits exist across occupations in the same group, and also across the groups – i.e. are common to all chemistry using professionals.

Similarly to chemistry knowledge, each indicator is given a score from 0 to 100 in O*NET to reflect its importance to an individuals’ ability to undertake that occupation. With up to 98 knowledge, skills and ability indicators to analyse for each occupation, a set of decision rules is required to distil the common knowledge, skills and ability indicators within groups of occupations.

An indicator is considered as *in scope* if its score lies within 1 standard deviation of the median score for that indicator across occupations in the same group. If the standard deviation is larger than 10, indicators are only included if their score lies within 10 points of the median. This is imposed since such large standard deviations are likely to be driven by outliers. Furthermore, occupations that are scored more than 10 points apart on the same characteristic are unlikely to make use of that knowledge, skill or ability in the same way. If the standard deviation is less than 2, the indicator is regarded as a common indicator across all occupations, since such a small difference in scores is unlikely to represent a material difference in the importance of an attribute across occupations.

If an indicator has a similar importance score across most occupations in a group, it is defined as a common indicator.

The list of knowledge, skills and ability indicators included was agreed with the project Steering Group. As a rule, most indicators with a score below 50 were excluded, except where the Steering Group felt that a characteristic would be particularly relevant to chemistry using professionals.

### 2.3.1 Results: the characteristics of occupations and groups

### Group 1

Common knowledge, skills and ability indicators for group 1 occupations are shown in Table 2, below.

**Table 2: Common knowledge, skills and ability indicators for Group 1 occupations**

| Knowledge | Skills | Abilities |
|---|---|---|
| Biology | Active Learning | Arm-hand Steadiness |
| Chemistry | Active Listening | Deductive Reasoning |
| Clerical | Complex Problem Solving | Far Vision |
| Computers and Electronics | Coordination | Fluency of Ideas |
|  | Critical Thinking | Inductive Reasoning |
| Engineering and Technology | Equipment Maintenance | Information Ordering |
|  | Equipment Selection | Manual Dexterity |
| English Language | Instructing | Mathematical Reasoning |
|  | Judgement and Decision Making | Near Vision |
| Mathematics | Mathematics | Number Facility |
| Physics | Monitoring | Oral Comprehension |
|  | Operations Analysis | Oral Expression |
|  | Operation and Control | Perceptual Speed |
|  | Persuasion | Selective Attention |
|  | Science | Speech Clarity |
|  | Social Perceptiveness | Speech Recognition |
|  | Speaking | Visual Colour Discrimination |
|  | Systems Analysis | Visualization |
|  | Time Management | Written Comprehension |
|  | Troubleshooting | Written Expression |

Source: Cambridge Econometrics analysis of O*NET knowledge, skills and abilities.

Group 1 occupations have a high chemistry importance score (greater than 80) and include Chemical Scientists, Higher Education Teaching Professionals and Biological scientists and biochemists. Their SOC 2010 equivalents are professional science occupations that require specialist knowledge at first degree level or above. The relatively large number of common indicators suggests that they share many similar characteristics.

Although they are chemistry-focused, some knowledge of other sciences is also needed to undertake these professions, as biology and physics are also common knowledge indicators in this group. Biology knowledge is a relatively low-scoring common indicator, whereas physics knowledge is scored more highly (and is therefore more important). The exception is for biochemists, who have a biology knowledge importance score of 83, which is the same as that for physics and almost equal to that for chemistry (which is 84). Mathematics is also a high-scoring, common indicator in this group.

As might be expected in a group of analytical professions, complex problem-solving and critical thinking are high-scoring common skills indicators. This is also the case for general science skills (particularly high scoring for biochemists), reading comprehension and mathematics.

Oral and written comprehension are high-scoring ability indicators in this group, alongside inductive and deductive reasoning. Manual dexterity[4] is a low scoring common indicator, with a median score of 28 out of 100 amongst O*NET occupations in this group. This suggests that this attribute is not integral to carrying out the tasks required in Group 1 occupations.

## Group 2

Table 3 below, shows the common knowledge, skills and ability indicators identified for Group 2 occupations.

**Table 3: Common knowledge, skills and abilities identified for Group 2 occupations**

| Knowledge | Skills | Abilities |
|---|---|---|
| Chemistry<br>Computers and Electronics<br>English Language<br>Mathematics | Active Learning<br>Active Listening<br>Coordination<br>Critical Thinking<br>Equipment Maintenance<br>Equipment Selection<br>Instructing<br>Judgement and Decision Making<br>Learning Strategies<br>Monitoring<br>Operation and Control<br>Operation Monitoring<br>Quality Control Analysis<br>Reading Comprehension<br>Science<br>Social Perceptiveness<br>Speaking<br>Time Management | Arm-hand Steadiness<br>Category Flexibility<br>Deductive Reasoning<br>Far Vision<br>Flexibility of Closure<br>Inductive Reasoning<br>Information Ordering<br>Manual Dexterity<br>Mathematical Reasoning<br>Near Vision<br>Oral Expression<br>Perceptual Speed<br>Problem Sensitivity<br>Selective Attention<br>Speech Clarity<br>Speech Recognition<br>Written Comprehension<br>Written Expression |

Source: Cambridge Econometrics analysis of O*NET knowledge, skills and abilities.

Group 2 consists of professional and technical occupations with chemistry importance scores between 70 and 80. Chemistry knowledge is still an important component of these occupations, but it is not necessarily used at the same level or frequency as Group 1 occupations.

Occupations in Group 2 share fewer common knowledge indicators compared to those in Group 1. In common with Group 1 however, knowledge of computers and electronics and mathematics are important common indicators. Knowledge of biology and physics is important for biomedical engineers, but much less so for the other occupations in this group – hence why these are not defined as common knowledge indicators for Group 2 occupations.

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[4] In O*NET, manual dexterity is "The ability to quickly move your hand, your hand together with your arm, or your two hands to grasp, manipulate, or assemble objects". This was included following consultation with the RSC project Steering Group.

Active listening is a high-scoring common skill required for Group 2 occupations, as is reading comprehension and critical thinking, (in common with Group 1). Science skills are relatively more important for technicians, as are equipment maintenance and selection skills; though they are not particularly high-scoring indicators in terms of their absolute performance (no occupation has a score of over 50[5]).

As is also the case with Group 1 occupations, oral and written comprehension are high-scoring common ability characteristics for occupations in Group 2. Information ordering and inductive reasoning are also important, common characteristics. Manual dexterity and hand-arm steadiness are also common ability characteristics of these occupations, but in common with Group 1 occupations, have a score of 50 or below – suggesting that these abilities are less integral to carrying out the tasks required in Group 2 occupations compared to others shown in Figure 2.

## Group 3

The common knowledge, skills and ability indicators for Group 3 occupations are shown in Table 4.

**Table 4: Common knowledge, skills and abilities identified for Group 3 occupations**

| Knowledge | Skills | Abilities |
|---|---|---|
| Biology<br>Chemistry<br>Clerical<br>Computers and Electronics<br>Customer and Personal Service<br>English Language<br>Mathematics<br>Production and Processing | Active Learning<br>Active Listening<br>Complex Problem Solving<br>Coordination<br>Instructing<br>Judgement and Decision Making<br>Learning Strategies<br>Mathematics<br>Monitoring<br>Persuasion<br>Quality Control Analysis<br>Reading Comprehension<br>Social Perceptiveness<br>Speaking<br>Troubleshooting<br>Time Management | Category Flexibility<br>Deductive Reasoning<br>Far Vision<br>Flexibility of Closure<br>Fluency of Ideas<br>Inductive Reasoning<br>Information Ordering<br>Mathematical Reasoning<br>Near Vision<br>Number Facility<br>Oral Comprehension<br>Oral Expression<br>Originality<br>Perceptual Speed<br>Selective Attention<br>Speech Clarity<br>Speech Recognition<br>Visual Colour Discrimination<br>Written Comprehension<br>Written Expression |

Source: Cambridge Econometrics analysis of O*NET knowledge, skills and abilities.

Group 3 occupations are those that have chemistry importance scores between 60 and 70 in O*NET, and correspond to professional occupations and some process operative occupations in the SOC 2010 classifications. Chemistry knowledge is still an important part of these occupations, but it may

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[5] They were included following consultation with the project Steering Group.

not necessarily be the case that everyone undertaking these occupations will be educated to degree level.

In this group, 'Chemical Plant and System Operators' are somewhat of an outlier, sharing relatively few common indicators with the other two occupations in this group. English language and production and processing knowledge are the only common knowledge indicators that apply to this occupation. Mathematics knowledge is an important common indicator across the other occupations in this group, as is customer and personal service knowledge.

Active listening, reading comprehension and speaking skills are amongst the most important that are required for occupations in Group 3. Written comprehension and expression are particularly high scoring ability indicators, as are problem sensitivity, oral expression and near vision.

## Group 4

The common knowledge, skills and ability indicators for Group 4 occupations are shown in Table 5.

**Table 5: Common knowledge, skills and abilities identified for Group 4 occupations**

| Knowledge | Skills | Abilities |
|---|---|---|
| Biology<br>Clerical<br>Computers and Electronics<br>Customer and Personal Service<br>Mathematics | Active Learning<br>Active Listening<br>Complex Problem Solving<br>Coordination<br>Critical Thinking<br>Learning Strategies<br>Mathematics<br>Operation and Control<br>Quality Control Analysis<br>Reading Comprehension<br>Science<br>Speaking<br>Time Management<br>Troubleshooting<br>Writing | Deductive Reasoning<br>Inductive Reasoning<br>Information Ordering<br>Mathematical Reasoning<br>Near Vision<br>Number Facility<br>Oral Comprehension<br>Oral Expression<br>Originality<br>Perceptual Speed<br>Problem Sensitivity<br>Selective Attention<br>Speech Clarity<br>Speech Recognition<br>Written Comprehension<br>Written Expression |

Source: Cambridge Econometrics analysis of O*NET knowledge, skills and abilities.

Group 4 contains the occupations with the lowest chemistry importance scores. These are mostly Professional or Associate Professional and Technical occupations (SOC 2010 Major Group 2 and 3), where, although chemistry knowledge remains important, knowledge of other areas becomes equally or more important to the ability to undertake these occupations proficiently.

Food science technicians are included in Group 4 despite their higher chemistry importance score because they are matched to occupation 3119 *Science, engineering and production technicians n.e.c.* (not elsewhere classified) in SOC 2010, alongside Environmental Engineering Technicians.

Chemistry knowledge is not captured as a common knowledge indicator in Group 4, as only Environmental Engineering Technicians and Industrial Safety and Health Engineers have chemistry importance scores that lie within one standard deviation of the median score in the group. Food Science Technicians have a relatively high score (64) and Natural Science Technicians a relatively low score (52); which are too far apart to be regarded as similar scores in this analysis.

One characteristic of Group 4 occupations is that chemistry knowledge is less of a 'lead indicator': other knowledge indicators become more important than chemistry knowledge when undertaking these occupations. This is particularly the case for Industrial Safety and Health Engineers, where the importance of chemistry knowledge ranks as the 12th most important knowledge characteristic. English language is one of the highest scoring common knowledge indicators for this group: the importance score for English language is significantly higher than that for chemistry and biology knowledge for Industrial Safety and Health Engineers and Natural Sciences managers. In common with the other groups, mathematics is also a common knowledge indicator for occupations in Group 4.

Active listening, critical thinking and reading comprehension are all relatively high-scoring skills indicators for occupations in Group 4. Operation and control and troubleshooting are also common indicators, but are relatively low-scoring, with no occupation scoring above 50 in these characteristics.

Deductive and inductive reasoning are high-scoring common ability indicators in Group 4 occupations, as is oral comprehension and expression. Written comprehension and expression is also important, as is problem sensitivity.

## *Conclusions on the initial grouping exercise*

Chemistry using professionals are overall a highly qualified cohort, with most occupations classified under Major Groups 2 and 3 (Professional and Associate Professional and Technical occupations) in the SOC2010 classification, which generally (but not necessarily) require a first degree or higher to enter.

There are several knowledge, skills, and ability indicators that are common across the groups. The importance of communication, such as the ability to comprehend written and spoken word, knowledge of the English language and the skill to write and converse clearly, are common characteristics. Chemistry using professionals are highly analytical. They require not only chemistry subject knowledge, but often knowledge of other science subjects, alongside mathematics. As may also be expected of analytical occupations, critical thinking and complex problem-solving skills are also often required, as is the ability to make inductive and deductive reasonings.

Although many of the groups share these common indicators, knowledge indicators in Group 1 tend to be scored more highly. For instance, although mathematics knowledge is required for most chemistry using professionals, the importance score for Group 1 occupations is noticeably higher, with a median score of 83, compared to median scores of 60-65 for the other groups.

Whilst Group 1 can be differentiated by its higher-scoring knowledge characteristics, there are few discernible differences between the skills and abilities required by chemistry using professionals: the skills and abilities – and the level required – are similar across occupations. This is perhaps unsurprising, as most of the occupations selected are grouped together in the SOC 2010 classification.

For Group 4 occupations, chemistry knowledge is less of a lead indicator. It is still an important requirement, but knowledge in other areas becomes equally, or more important than chemistry knowledge. Group 4 occupations could arguably be viewed as more general science occupations, with a significant chemical component. In that sense, those undertaking these occupations are still chemistry using professionals, who also rely on a broad, but less detailed knowledge of other areas to undertake their work.

## 2.4 Sales and marketing professionals and teachers

This section discusses sales and marketing professionals and teachers, and their characteristics, before making a recommendation as to where they are best placed amongst Groups 1-4, based on the evidence.

Those in sales and marketing roles, as well as chemistry teachers in secondary schools and the Further Education sector, are part of the RSC's membership and can reasonably be expected to be classified as chemistry using professionals, yet have no chemistry knowledge score in the set of O*NET indicators. This is because these roles are not chemistry specific and O*NET only classifies the knowledge, skills and abilities required for these roles in general.

*Sales and marketing professionals*

In the RSC's 2019 Pay and Reward Survey, members in sales and marketing roles are categorised as one group for the purpose of reporting. Evidence from the survey suggests that there are RSC members in sales and marketing roles who should be regarded as chemistry using professionals.

Around 40% of Survey respondents in sales and marketing roles have a doctorate as their highest qualification, with a further 15% holding a Master's degree and 27% holding a First degree as their highest. Furthermore, around 87% said that their qualification contributed either 'somewhat' to their career progression or 'to a great extent'. This suggests that certainly amongst RSC members, those in sales and marketing occupations do make use of their chemistry knowledge, potentially at a high level.

In O*NET, *Marketing Managers* and *Sales Representative, Wholesale and Manufacturing, Technical and Scientific Products* have been selected as comparable occupations for this analysis.

Customer and personal service and English language are important knowledge indicators for both Marketing Managers and Sales Representatives, as is mathematics knowledge. Communications and media is another high-scoring knowledge indicator.

Active listening is a particularly high-scoring skill for both occupations; social perceptiveness and speaking skills are also very important, the latter particularly so for Sales Representatives. Perhaps unsurprisingly, Sales Representatives also score highly for persuasion skills, while judgement and decision-making is important for Marketing Managers.

Oral and written comprehension and expression are all high-scoring abilities required for both occupations. Speech clarity and speech recognition are also important.

To determine where sales and marketing professionals might fit in the above groupings, the full range of knowledge, skills and ability indicators were analysed for all occupations of interest, to establish with which occupations sales and marketing professionals have the most in common. A characteristic is deemed as similar if a given knowledge, skill or ability indicator has a score within 10 points of the score for the same indicator for Marketing Managers and Sales Representatives. The number of similar indicators is added up for each occupation and the occupations are then ranked in turn, beginning with Marketing Managers.

*Marketing Managers*

The result of this ranking exercise for Marketing Managers is shown in Table 6.

In O*NET, marketing managers share 23 common characteristics with Industrial Safety and Health Engineers (Group 4), Quality Control Systems Managers (Group 3) and Material Scientists (Group 1). Natural Sciences Managers (Group 4), Environmental Scientists and Specialists (Group 3) and Chemistry Teachers Postsecondary (Group 1), all share 22 common characteristics with Marketing Managers.

**Table 6: Number of common characteristics shared with Marketing Managers, by O*NET occupation**

| O*NET occupation | Knowledge | Skills | Ability | Total characteristics |
|---|---|---|---|---|
| Industrial Safety and Health Engineers | 4 | 6 | 13 | 23 |
| Quality Control Systems Managers | 4 | 6 | 13 | 23 |
| Material Scientist | 4 | 5 | 14 | 23 |
| Natural Sciences Managers | 3 | 4 | 15 | 22 |
| Environmental Scientists and Specialists, Including Health | 4 | 5 | 13 | 22 |
| Chemistry Teachers Postsecondary | 3 | 5 | 14 | 22 |
| Food Science Technicians | 3 | 3 | 13 | 19 |
| Biochemists and Biophysicists | 3 | 5 | 11 | 19 |
| Environmental Engineering Technicians | 2 | 4 | 11 | 17 |
| Quality Control Analysts | 3 | 2 | 11 | 16 |
| Chemical Engineers | 2 | 4 | 10 | 16 |
| Chemists | 2 | 4 | 10 | 16 |
| Biochemical Engineers | 1 | 5 | 8 | 14 |
| Chemical Technicians | 1 | 3 | 10 | 14 |
| Chemical Plant and System Operators | 0 | 1 | 8 | 9 |

Source: Cambridge Econometrics analysis of O*NET knowledge, skills and abilities.

It appears that Marketing Managers would represent the best fit with **Group 4** occupations. It is unlikely that Marketing Managers will use their chemistry knowledge to the same degree or frequency as Group 1 occupations. Although they share many common characteristics with some Group 3 occupations, the fact that Marketing Managers score highly on a number of non-science knowledge indicators suggests that they would best suit a group where chemistry knowledge is an important – but not the most important – knowledge aspect.

*Sales Representatives*

The result of this same ranking exercise for Sales Representatives is shown in Table 7.

Sales Representatives would appear to have less in common with the other occupations compared to Marketing Managers, as the total number of common characteristics is generally lower.

**Table 7: Number of common characteristics shared with Sales Representatives, by O*NET occupation**

| O*NET occupation | Knowledge | Skills | Ability | Total characteristics |
|---|---|---|---|---|
| Quality Control Systems Managers | 3 | 8 | 8 | 19 |
| Chemistry Teachers Postsecondary | 2 | 4 | 11 | 17 |
| Natural Sciences Managers | 3 | 7 | 6 | 16 |
| Industrial Safety and Health Engineers | 4 | 7 | 5 | 16 |
| Marketing Managers | 2 | 5 | 9 | 16 |
| Environmental Scientists and Specialists, Including Health | 1 | 7 | 6 | 14 |
| Quality Control Analysts | 3 | 6 | 5 | 14 |
| Environmental Engineering Technicians | 1 | 7 | 5 | 13 |
| Food Science Technicians | 2 | 6 | 5 | 13 |
| Material Scientists | 3 | 6 | 4 | 13 |
| Chemists | 2 | 6 | 5 | 13 |
| Biochemical Engineers | 2 | 6 | 4 | 12 |
| Chemical Technicians | 1 | 4 | 6 | 11 |
| Biochemists and Biophysicists | 1 | 4 | 5 | 10 |
| Chemical Plant and System Operators | 1 | 4 | 4 | 9 |
| Chemical Engineers | 2 | 5 | 2 | 9 |

Source: Cambridge Econometrics analysis of O*NET knowledge, skills and abilities.

Sales Representatives share the highest number of common characteristics with Quality Control Systems Managers (Group 3), followed by Chemistry Teachers Postsecondary (Group 1), Natural Sciences Managers (Group 4) Industrial Safety and Health Engineers (Group 4) and Marketing Managers (Group 4).

Although Sales Representatives share the highest number of common Characteristics with occupations in Group 3 and Group 1, the rationale for placing Marketing Managers into Group 4 also applies to Sales Representatives. Therefore, they are classified as a **Group 4** occupation. In common with Marketing Managers, it is unlikely that Sales Representatives will use their chemistry knowledge to the same degree or frequency as Group 1 occupations. Similarly, the fact that Sales Representatives score highly on several non-science knowledge indicators suggests that this is an occupation where chemistry knowledge is an important – but not the most important – knowledge aspect.

Furthermore, sales and marketing occupations are closely related in the SOC 2010 classifications, which also suggests that the two occupations should be placed in the same group.

*Teachers*

Teachers represent a significant group of RSC members in employment. According to the 2019 Pay and Reward Survey data, 36% of teachers who responded have a doctorate as their highest qualification and 23% have a Master's degree (though it is not known whether this is chemistry-based and could include those holding postgraduate teaching qualification). 92% said that their highest qualification contributed either 'somewhat' to their career progression or 'to a great extent'. Whilst it is unclear whether respondents are referring to chemistry-based qualifications, chemistry knowledge and application is an important part of the role, for both chemistry specialists and general science teachers.

The comparable O*NET occupations selected are Secondary School Teachers and Career/Technical Education Teachers. Unsurprisingly, education and training is a high-scoring knowledge indicator for teachers, as is English language; and to a lesser extent, knowledge of psychology and computers and electronics are also important.

Active listening, critical thinking, instructing and learning strategies are all high-scoring skills for teachers, as are reading comprehension, social perceptiveness and writing skills.

Oral and written comprehension and expression are high-scoring ability measures, as are problem sensitivity and speech clarity.

To help determine the most appropriate group for teachers, a similar ranking exercise to that for sales and marketing occupations was performed.

The result of this ranking exercise for teachers is shown in Table 8. For this exercise, the ranking scores for Secondary School Teachers and Career/technical education teachers are combined. Although chemistry is taught in different settings (secondary schools and the Further Education sector in UK), the skills required to do so are very similar and it therefore makes sense to consider both O*NET occupations together.

**Table 8: Number of common characteristics shared with Teachers, by O*NET occupation**

| O*NET occupation | Knowledge | Skills | Ability | Total characteristics |
|---|---|---|---|---|
| Chemistry Teachers Postsecondary | 8 | 17 | 31 | 56 |
| Industrial Safety and Health Engineers | 6 | 20 | 29 | 55 |
| Environmental Scientists and Specialists, Including Health | 6 | 18 | 30 | 54 |
| Natural Sciences Managers | 3 | 21 | 29 | 53 |
| Quality Control Systems Managers | 2 | 22 | 28 | 52 |
| Biochemists and Biophysicists | 5 | 16 | 27 | 48 |
| Material Scientist | 5 | 13 | 27 | 45 |
| Chemist | 5 | 14 | 25 | 44 |
| Marketing Managers | 6 | 9 | 27 | 42 |
| Environmental Engineering Technicians | 3 | 10 | 27 | 40 |
| Biochemical Engineers | 3 | 16 | 19 | 38 |

| | | | | |
|---|---|---|---|---|
| Chemical Engineers | 7 | 10 | 21 | 38 |
| Quality Control Analysts | 2 | 9 | 26 | 37 |
| Sales Representative, Wholesale and Manufacturing, Technical and Scientific Products | 6 | 14 | 17 | 37 |
| Chemical Technicians | 2 | 9 | 24 | 35 |
| Food Science Technicians | 2 | 7 | 23 | 32 |
| Chemical Plant and System Operators | 3 | 5 | 10 | 18 |

Source: Cambridge Econometrics analysis of O*NET knowledge, skills and abilities.

Chemistry Teachers Postsecondary (Group 1) share the largest number of common characteristics with teachers. This is perhaps not surprising, as many academic staff in universities will have teaching responsibilities. Industrial Safety and Health Engineers (Group 4), Environmental Scientists and Specialists, Including Health (Group 3), Natural Sciences Managers (Group 4) and Quality Control Systems Managers (Group 3) also share many common characteristics with teachers.

Although it is an integral part of the role, teachers do not need to use chemistry knowledge at the same high level as academic chemists, or other Group 1 occupations.

There is no real case for including teachers in Group 2 (alongside Biochemical Engineers, Chemical Technicians and Quality Control Analysts), since they are more closely related in terms of their characteristics to occupations in the other Groups.

The case for including teachers in Group 3 or Group 4 is not clear, since they are closely related to some occupations in each group, but also share little in common with others in each Group.

An argument can be made for either allocation, but teaching occupations are allocated to Group 3. Although they share many common characteristics with some Group 4 occupations, the importance of chemistry knowledge required to perform the duties associated with the occupation, is, on balance, likely to be higher than in Group 4 occupations.

*Further research*

Both the O*NET and SOC 2010 classifications provide detailed information on a wider variety of occupations. Whilst this has enabled occupations to be classified for the purpose of this research, further research could build on this work to validate these final classifications. For example, qualitative research would be helpful to determine the extent and depth of chemistry knowledge and its usage amongst chemistry using professionals in sales and marketing occupations. In a similar vein, O*NET scores, by definition, capture information about characteristics across occupations in general; and chemistry using professionals may place a different level of importance on some of the characteristics discussed here.

## 2.5 Final groupings

The final occupational groupings are shown in Table 9, below. Although the groupings generally reflect the chemistry importance scores in O*NET, they are not hierarchical and are not intended to suggest that any group of occupations is more important than any other; nor are the occupations within groups listed in any order of importance. Each occupation, and the people who work in them, have their own important role to play as part of the chemistry using workforce. Chapter 3 takes the occupations identified in Table 9 and estimates the number of chemistry using professionals in the workforce.

**Table 9: Final occupational group classification**

| Group | O*NET occupation title | SOC 2010 code | SOC 2010 title |
|---|---|---|---|
| Group 1 | Chemist | 2111 | Chemical scientist |
| | Chemical Engineers | 2111 | Chemical scientist |
| | Chemistry Teachers Postsecondary | 2311 | HE Teaching Professionals |
| | Biochemists and Biophysicists | 2111 | Chemical scientist |
| | | 2112 | Biological scientists and biochemists |
| | Material Scientist | 2111 | Chemical scientist |
| Group 2 | Biochemical Engineers | 2129 | Engineering professionals n.e.c. |
| | Chemical technician | 3111 | Laboratory technicians |
| | Quality Control Analysts | 2462 | Quality assurance and regulatory professionals |
| | | 3115 | Quality assurance technicians |
| Group 3 | Chemical Plant and System Operators | 8129 | Plant and machine operatives n.e.c. |
| | | 8114 | Chemical and related process operatives |
| | Environmental Scientists and Specialists, Including Health | 2463 | Environmental health professionals |
| | | 2142 | Environment professionals |
| | Quality Control Systems Managers | 2127 | Production and process engineers |
| | Career/Technical Education teacher | 2312 | Further education teaching professionals |
| | Secondary School Teacher | 2314 | Secondary education teaching professionals |
| Group 4 | Environmental Engineering Technicians | 3119 | Science, engineering and production technicians n.e.c. |
| | Food Science Technicians | 3119 | Science, engineering and production technicians n.e.c. |
| | Industrial Safety and Health Engineers | 3567 | Health and safety officers |
| | | 8124 | Energy plant operatives |
| | | 1255 | Waste disposal and Environmental services managers |
| | Natural Sciences Managers | 2119 | Natural and social science professionals n.e.c. |
| | Marketing Managers | 3543 | Marketing associate professionals |
| | Sales Representative, Wholesale and Manufacturing, Technical and Scientific Products | 3542 | Business sales executives |

Source: Cambridge Econometrics analysis of O*NET knowledge, skills and abilities.
Note: n.e.c – not elsewhere classified.

# 3 Where in the UK economy do those with a chemistry background apply their skills? How has this changed over time?

This chapter estimates the number of chemistry using professionals in the UK, by sector, across time and by region.

## 3.1 Methodology

To estimate the number of chemistry using professionals in employment, the share of chemistry using professionals employed in each sector, based on data from the UK Labour Force Survey (LFS), is applied to the UK Office for National Statistics' (ONS) Workforce Jobs (WFJ) estimates. This includes both employees and the self-employed in each sector. The WFJ series is compiled mainly from surveys of businesses and is the preferred source of statistics on jobs by industry, since it provides a more reliable industry breakdown than the LFS. However, the WFJ data offers no occupational breakdown, hence the use of the LFS to develop the employment shares of chemistry using professionals. The WFJ figures provide a measure of jobs in the economy, rather than a measure of people in employment, and so the final estimates of chemistry using professionals in the economy in this chapter are also a measure of jobs rather than people. Figures for the number of jobs in an economy can be higher than the number of people in employment, because one person can have more than one part-time job.

*Calculating employment shares*

Simply calculating the total number of people in employment in each SOC 2010 occupation included in Groups 1-4 in the previous section would risk overestimating the number of chemistry using professionals, since not everyone who is assigned to an occupation will work in a chemistry using sector. For example, SOC 2010 group 2112 includes both biological scientists and biochemists.

In order to develop a more precise estimate of the number of chemistry using professionals, the Standard Industrial Classification (SIC) 2007 was examined in detail to determine the subsectors (at industry class level) that were most likely to employ chemistry using professionals. Subsequently, only those who are employed in a) occupations in Groups 1-4 above, and b) subsectors most likely to employ chemistry using professionals, are included in the employment estimates. Employment of chemistry using professionals as a share of industry employment is calculated at industry division (2 digit) level, to provide more reliable estimates and avoid disclosure issues. As the LFS is a quarterly survey, employment shares are derived by taking an average estimate across all four quarters in each year.

This may still represent an overestimate of the share of chemistry using professionals, as even at industry class level, it is not always possible to be sure that everyone employed in an occupation-industry combination will use chemistry knowledge as a significant part of their job. The possibility of overestimating the share of chemistry using professionals is more likely to be the case with occupations in Groups 3 and 4, where the chemistry importance scores are lower, than with occupations in Groups 1 and 2.

For this reason, and to reduce the risk of significantly overestimating the number of chemistry using professionals in employment, sales and marketing occupations have been excluded from the employment calculations.

The LFS shares are then applied to the WFJ figures in each sector, to derive estimates of the number of chemistry using professionals in employment.

## 3.2 Estimates of chemistry using professionals across time

This section presents estimates of the employment of chemistry using professionals in the UK economy, by sector, across time. The analysis is split into two parts: the first part deals with employment estimates calculated using the LFS and WFJ estimates from the Office for National Statistics; while the second part looks at employment patterns of teachers and academics, which are derived using separate data sources.

*LFS/WFJ employment estimates*

In total, there are estimated to have been around 228,000 chemistry using professionals in employment in 2019 (excluding academic staff and teachers). As Figure 1 shows, this varies considerably by sector, with the largest number in sector 72 (Scientific research and development), followed by non-teaching staff in the education sector (85) and sector 71 (Architectural and engineering activities; technical testing and analysis).

Figures for sector 85 (Education) exclude occupations 2311 (HE teaching professionals), 2314 (Secondary education teaching professionals) and 2312 (Further education teaching professionals). The remainder of those employed in this sector is overwhelmingly represented by chemistry using professionals in occupation 2119 (Natural and social science professionals n.e.c.).

Table 10 shows the change in the employment level of chemistry using professionals over time, in each sector of employment. Estimates are not presented for some sector-year combinations, due to very low numbers of chemistry using professionals in employment in these instances.

Since 2013, the number of chemistry using professionals in employment (excluding academics and teachers) has remained relatively stable, fluctuating between 211,000 and 234,000.

Over this time period, employment in most sectors has also remained stable, with some exceptions. Employment in sector 72 (scientific research and development has grown, reaching 50,000 in 2019, up from 42,000 in 2013. In contrast, employment in sector 20 (Manufacture of chemicals) and sector 21 (Manufacture of pharmaceuticals), has fallen slightly over the same period, by around 5,000 in each.

**Table 10: Change in employment levels of chemistry using professionals in selected sectors over time, LFS/WFJ**

| Sector | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|
| 19 Manufacture of coke and refined petroleum products | 2,585 | 1,740 | 2,063 | 702 | 608 | 2,040 | 2,529 |
| 20 Manufacture of chemicals and chemical products | 22,972 | 26,467 | 19,410 | 15,967 | 15,604 | 18,530 | 17,492 |
| 21 Manufacture of basic pharmaceutical products and pharmaceutical preparations | 16,071 | 12,608 | 12,461 | 13,513 | 14,719 | 13,748 | 10,446 |
| 22 Manufacture of rubber and plastic products | 6,829 | 8,406 | 11,485 | 9,272 | 7,632 | 4,329 | 6,239 |
| 23 Manufacture of other non-metallic mineral products | 236 | 869 | 584 | 900 | 1,211 | 297 | 1,616 |
| 24 Manufacture of basic metals | 2,035 | 1,940 | 3,327 | 1,973 | 2,502 | 2,867 | 3,660 |
| 26 Manufacture of computer, electronic and optical products | 2,863 | 3,077 | 2,430 | 5,236 | 3,218 | 3,717 | 3,577 |
| 27 Manufacture of electrical equipment | 8,865 | 5,812 | 6,428 | 5,867 | 11,853 | 6,342 | 2,827 |
| 28 Manufacture of machinery and equipment n.e.c. | 831 | 432 | 1,100 | 489 | 822 | 1,262 | 1,744 |
| 32 Other manufacturing | - | - | - | - | 644 | 305 | 891 |
| 35Electricity, gas, steam and air conditioning supply | 5,876 | 5,525 | 6,716 | 3,659 | 4,978 | 6,793 | 6,739 |
| 36 Water collection, treatment and supply | 3,504 | 3,087 | 2,961 | 2,112 | 3,505 | 5,796 | 4,027 |
| 37 Sewerage | - | - | - | - | - | 305 | 4,127 |
| 38 & 39 Waste collection, treatment and disposal activities; materials recovery; Remediation activities and other waste management services. | 379 | 987 | 612 | 1,445 | 4,257 | 908 | 2,250 |
| 46 Wholesale trade, except of motor vehicles and motorcycles | 16,593 | 16,902 | 11,289 | 11,565 | 7,920 | 10,125 | 12,505 |
| 70 Activities of head offices; management consultancy activities | 5,394 | 5,558 | 7,768 | 8,791 | 2,815 | 6,410 | 10,720 |
| 71 Architectural and engineering activities; technical testing and analysis | 27,325 | 33,343 | 32,606 | 33,003 | 32,363 | 33,522 | 29,945 |
| 72 Scientific research and development | 41,973 | 37,928 | 47,758 | 45,249 | 43,689 | 45,644 | 50,331 |
| 74 Other professional, scientific and technical activities | 16,340 | 14,141 | 13,147 | 12,439 | 10,848 | 10,475 | 13,153 |
| 84 Public administration and defence; compulsory social security | 330 | 129 | 162 | - | 248 | 398 | 318 |
| 85 Education (excluding teachers and academic staff) | 45,962 | 47,521 | 52,155 | 50,614 | 41,660 | 52,647 | 43,232 |
| **Total** | 226,963 | 226,471 | 234,463 | 222,795 | 211,096 | 226,460 | 228,367 |

Source: Cambridge Econometrics estimates based on LFS and WFJ data.

*Academics and teachers*

Employment numbers for academic staff in the higher education sector are available and broken down by cost centre via the Higher Education Statistics

Agency (HESA) Staff Record. The number of classroom teachers in schools are provided in the Department for Education's School Workforce Census (SWC), which gives a snapshot of school staffing levels (as a headcount) in November of each year.

Table 11 shows the number of academic staff and teachers in employment, according to these two data sources, from the 2013/14 academic year to the 2019/20 academic year[6].

**Table 11: Number of academic staff in universities and teaching staff in schools, 2013/14 - 2018/19**

| | 2013/14 | 2014/15 | 2015/16 | 2016/17 | 2017/18 | 2018/19 | 2019/20 |
|---|---|---|---|---|---|---|---|
| Academic staff | 4,725 | 5,210 | 5,415 | 5,535 | 5,625 | 5,720 | 5,825 |
| Chemistry teachers | 7,400 | 7,500 | 7,500 | 7,500 | 7,600 | 7,700 | 7,800 |
| General/Combined Science teachers | 32,900 | 32,300 | 32,100 | 32,700 | 32,600 | 32,800 | 33,100 |

Source: DfE School Workforce Census and HESA staff record[7]. Numbers of teachers in 2018/19 have been rounded to the nearest 100.

In Table 11, academic staff include those in both the chemistry and chemical engineering cost centres in UK universities. Chemistry specialists are included alongside general science teachers in schools, since the latter group is likely to also include those with a chemistry background, as well as those from another science background, but who also teach chemistry.

The SWC covers state-funded secondary schools in England. As such, teachers in independent schools are not included in the figures presented in Table 11. Teachers are counted against each science subject taught and may teach more than one science subject. Thus, teachers recorded as teaching chemistry may also teach general/combined sciences and so could be counted more than once.

Whilst the figures in Table 11 are likely to overestimate the number of chemistry using professionals in teaching, only including chemistry teachers is likely to lead to a significant underestimate

*Teachers in the rest of the UK*

Numbers of teachers by subject taught are not published for Wales and Northern Ireland. Figures for Scotland are available from the Scottish Government, though they are calculated on a different basis to those for England. Scottish figures show that 967 full-time equivalent teachers in Scottish secondary schools taught chemistry as their main subject in 2019. This rises to 1,121 full-time equivalents when those who have taught chemistry as an additional subject are included in the figures.

As figures for Scotland are calculated on a different basis to those for England, they have not been included in the totals presented here. In this respect it should be noted that the final figures may underrepresent UK totals.

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[6] 2019/2020 figures are estimated by inflating 2018/19 numbers by the average change over the previous three years.

[7] See https://www.gov.uk/government/collections/statistics-school-workforce and https://www.hesa.ac.uk/data-and-analysis/staff/chart-6.

*Total number of chemistry using professionals in the workforce*

Table 12 shows the total number of chemistry using professionals in the workforce, estimated over 2013-2019. In 2019, it is estimated that there were a total of approximately 275,000 chemistry using professionals in the workforce, compared to 272,000 in 2013.

Although the figures presented in Table 12 have been calculated using cautious assumptions, the methodology is likely to produce overestimates rather than underestimates, for reasons outlined above. However, it is difficult to say to what extent the estimates may be too high and to some extent, opposing effects may balance out at a UK level. For example, general science teachers are included in the estimates, but only for England. Also, while the number of chemistry using professionals in individual industry classes may be overestimates, sales and marketing professionals (one of the most likely groups to produce overestimates) have been excluded in an effort to make the overall total more robust.

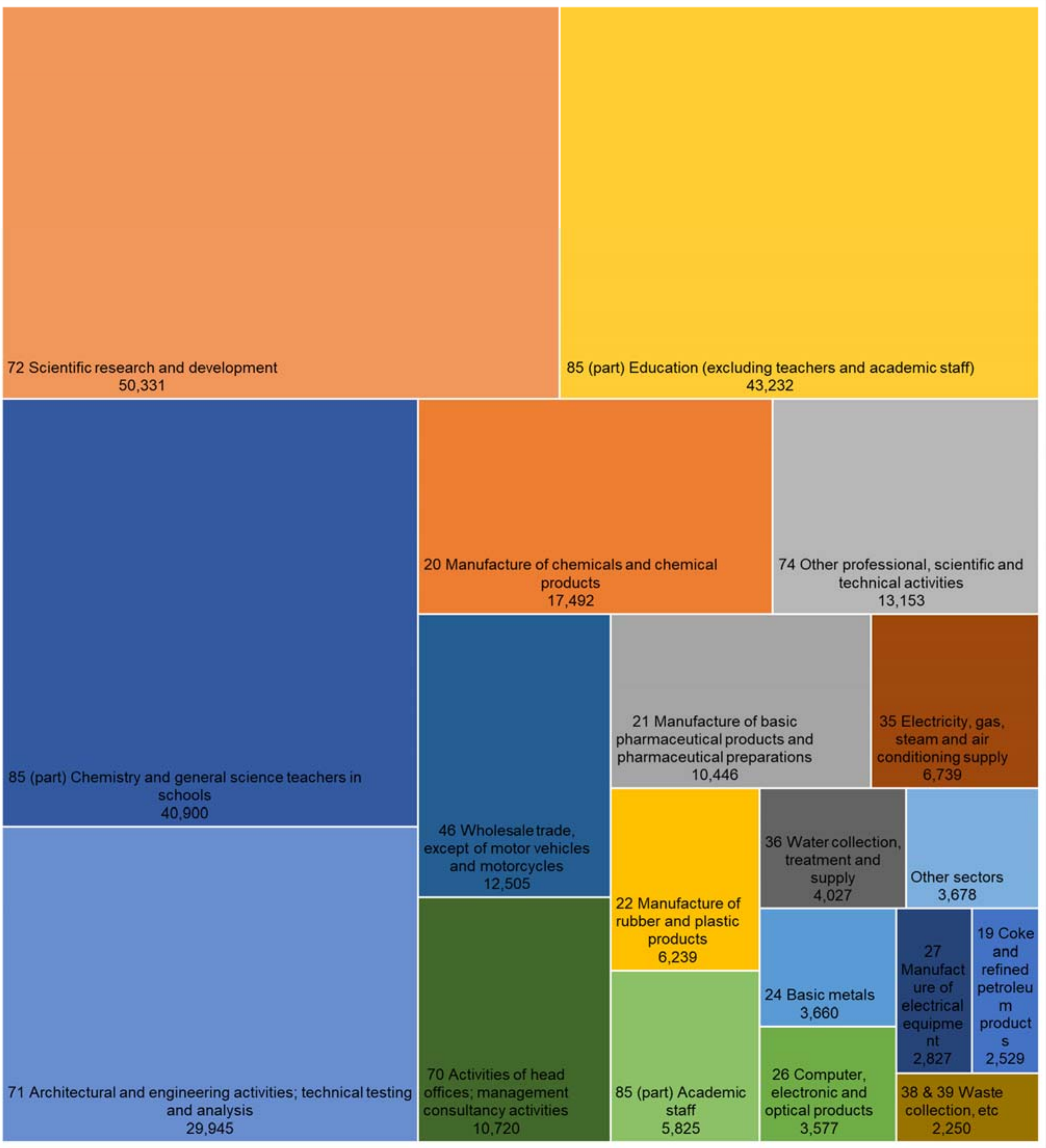
**Table 12: Total number of chemistry using professionals in the workforce, 2013-2019**

| | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|
| Academic staff | 4,725 | 5,210 | 5,415 | 5,535 | 5,625 | 5,720 | 5,825 |
| Chemistry and general science teachers in schools | 40,300 | 39,800 | 39,600 | 40,200 | 40,200 | 40,500 | 40,900 |
| WFJ/LFS employment totals | 226,963 | 226,471 | 234,463 | 222,795 | 211,096 | 226,460 | 228,367 |
| **Grand total** | **271,988** | **271,481** | **279,478** | **268,530** | **256,921** | **272,680** | **275,092** |

Source: Cambridge Econometrics estimates based on LFS and WFJ data, DfE School Workforce Census and HESA staff record.

Figure 1 shows the final estimated number of chemistry using professionals in employment in 2019, by sector.

**Figure 1: The estimated number of chemistry using professionals in employment in 2019**



Source: Cambridge Econometrics estimates based on LFS and WFJ data, DfE School Workforce Census and HESA staff record.

## 3.3 Regional analysis

An analysis of employment by region is undertaken by applying the share of chemistry using professionals in each region from the LFS, to the totals based on WFJ shown above.

In 2019, 29% are in the South of England, particularly in the South East and London where there are around 51,000 and 30,000 chemistry using professionals, respectively. Northern Ireland has the lowest number of chemistry using professionals, with around 5,000. A full regional breakdown of the estimates over time is provided in Table 13[8].

**Table 13: Total chemistry using professionals in UK regions 2013 – 2019**

| Regions | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|
| South East | 36,988 | 38,764 | 45,748 | 47,467 | 39,968 | 50,658 | 51,093 |
| London | 31,218 | 26,196 | 17,409 | 34,175 | 32,588 | 30,091 | 30,349 |
| North West | 41,444 | 46,520 | 36,787 | 36,738 | 33,382 | 29,849 | 30,105 |
| East of England | 22,435 | 30,747 | 38,507 | 33,653 | 23,325 | 28,649 | 28,895 |
| Scotland | 23,433 | 23,957 | 25,445 | 19,862 | 24,142 | 27,618 | 27,855 |
| South West | 20,448 | 18,707 | 24,792 | 17,627 | 22,872 | 23,381 | 23,582 |
| Yorkshire & the Humber | 23,763 | 17,522 | 20,691 | 22,901 | 16,059 | 21,891 | 22,079 |
| East Midlands | 14,563 | 18,785 | 15,960 | 8,418 | 25,630 | 18,550 | 18,710 |
| West Midlands | 22,273 | 17,203 | 17,431 | 19,980 | 17,061 | 14,183 | 14,305 |
| North East | 16,133 | 15,445 | 13,543 | 14,814 | 11,022 | 12,147 | 12,251 |
| Wales | 14,881 | 12,758 | 17,040 | 6,890 | 7,690 | 10,792 | 10,885 |
| Northern Ireland | 4,408 | 4,877 | 6,126 | 6,006 | 3,182 | 4,938 | 4,981 |

Source: Cambridge Econometrics estimates based on LFS data.
Note: total may differ to that for 2019 in previous tables due to rounding.

Table 13 illustrates that chemistry using professional employment in UK regions has varied across the period 2013 to 2019. Northern Ireland and Wales have consistently accounted for the lowest number of chemistry using professionals. In 2013, the largest number of chemistry using professionals were employed in the North West; but in 2019, it had only the third largest number. The chemistry using workforce in the North West has fallen by 27% over this period, while in the South East it has increased by 38%.

Across all regions, the share of chemistry using professionals in total regional employment ranges between 0.5-1.4%. In the North West, the share of chemistry using professionals has decreased by 0.5 percentage points (pp) over 2013-19, while the South East has experienced an increase of 0.2 pp. In most of the other regions, the share of chemistry using professionals has remained stable (see Table 17).

Between 2013 and 2019, Wales, the North East and the West Midlands have seen their employment of chemistry using professionals decline by an average of 30%. The largest increase in employment has occurred in the South East but employment has also increased in the East of England (by around 6,000 jobs) and in the East Midlands (where employment rose by around 4,000 jobs).

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[8] The Office for National Statistics provides local authority breakdowns in each region of England and other parts of the UK. Readers interested in understanding which local authorities are included in particular regions can see: https://geoportal.statistics.gov.uk/datasets/local-authority-district-to-region-april-2019-lookup-in-england and https://geoportal.statistics.gov.uk/datasets/0fa948d8a59d4ba6a46dce9aa32f3513_0

Despite not having the highest number of chemistry using professionals in 2019, the North West is arguably one of the most dependent on them. 38% of employment in the region's chemistry using sectors is accounted for by chemistry using professionals. In contrast, the remaining regions see between 2% and 5% of employment in the chemistry using sectors accounted for by chemistry using professionals. The North West therefore, would appear to be an important hub for chemistry in the UK despite only accounting for the third largest absolute employment of chemistry professionals.

### *Sectoral employment of chemistry using professionals, by region*

Most chemistry using professionals employed in the Waste collection, treatment, and disposal activities sector (SIC 38) are employed in the North East of England, however this is not the case for all employees (i.e. not just chemistry using professionals) in this sector. Similarly, the West Midlands accounts for most chemistry using professionals employed in the manufacture of fabricated metal products sector (SIC 25) while the East Midlands' manufacture of food products industry employs the majority of UK based chemistry using professionals working in that sector (SIC10). Chemistry using professionals employed in the manufacture of machinery and equipment n.e.c industry (SIC 24) are mostly based in the South East, South West and Wales.

The manufacture of pharmaceutical products (SIC 21) industry employs most chemistry using professionals in the East of England, North West and the South East of England. The manufacture of chemical products industry (SIC 20) is more evenly distributed, with the East of England again as the key employer of the chemistry using workforce, accounting for 18% of total employment, but most other regions except Scotland, London and the East accounting for a roughly equal share.

Over 50% of all chemistry using professionals working in scientific research and development activities (SIC 72) are located in the South East, London and the East of England. This is perhaps not surprising, given the large amount of chemistry using professionals working in the South East in general, as well as the high concentration of research universities in the East of England.

Scotland is strong in the wholesale trade (SIC 46) sector, employing over a quarter of all chemistry using professionals in that sector, in addition to water collection, treatment and supply (SIC 36) and remediation activities and other waste management services (SIC 39), where it accounts for an average of 21% of total UK employment of chemistry using professionals. With many strong universities located in the country, a significant amount (15%) of UK chemistry using professionals in research and related sectors (SIC 71 and SIC 72) is also located in Scotland. Wales on the other hand is less strong in research activities, but records nearly 60% of UK chemistry using professional employment in the manufacture of basic metals (SIC 24) and is one of the few regions outside the South East and North West, where a significant share of chemistry professionals work in the manufacture of computer, electronic and optical products (SIC 26) – 14%.

The full breakdown is provided in Table 17 in Appendix A.

# 4 How does the chemistry workforce contribute to UK economic activity and the public purse; and how does this vary by region and sector?

## 4.1 Methodology

Chemistry using professionals contribute towards economic activity through three channels. Firstly, they contribute directly to the economic output in the sectors they are employed in – this is called the direct impact. Purchases from elsewhere in the economy are required to facilitate this production, such as raw materials, IT and other equipment, etc. This is known as the supply-chain impact or the indirect impact. Lastly, chemistry using professionals spend at least part of their income in the UK, which in turn generates further rounds of spending. This is known as an induced impact. To capture all these impacts in terms of GDP, GVA and employment, CE's Input-Output (I-O) tool is used. It is based on the ONS' UK I-O tables which show the structure of the UK economy in terms of interlinkages between industries. It thus measures the historical purchases of goods and services from each industry within the economy.

To estimate the contribution of chemistry using professionals to the economic output of sectors in which they work, it is assumed that their economic contribution is in line with their share of employment. For example, if chemistry using professionals make up 30% of those employed in a sector, it is assumed that they will contribute towards 30% of that sector's output.

This assumes that the productivity of chemistry using professionals reflects average productivity levels in the sectors that they work in. If they are more productive than average, then the output effects produced in this analysis will be an underestimate. If they are less productive, then the analysis presented here will overestimate the economic impact.

A comparison of the average qualification levels of chemistry using professionals against the average qualification level of the remaining workforce in each sector using LFS data suggests that the former are slightly more skilled than the latter. This implies that the above stated assumption is likely to lead to an underestimate of the true effect.

To measure the economic impact of chemistry using professionals, a counterfactual scenario is created, to provide an illustration of what the economic output of each industry would look like if chemistry using professionals were not included in the workforce. This is a somewhat stylised approach, as if there were no chemistry using professionals in employment at all the structure of the economy could well look very different. However, in the absence of a truly observable counterfactual, this is the next best approach.

Our analysis traces this impact across the years 2013 to 2019, based on the employment numbers calculated in Chapter 3 above. The ONS provides I-O analytical tables, the basis for our own I-O tool, only up to 2015. For this reason, to create a time series of impact shocks, 2015 gross output values have been inflated using the GDP deflator with base year 2015. This is a simplification, however, as we are implicitly assuming that the inherent productive structure has not changed since 2015.

*The I-O tool background*

As mentioned above, economic impact can be broken down into three main components, described in further detail below.

In our case, the direct impact refers to the activity (and jobs) immediately lost by the absence of chemistry using professionals in the economy. In this context it is the reduced output in sectors that rely directly on chemistry using professionals, such as the manufacturing of chemicals and chemical products and others identified in the previous section.

Indirect and induced effects are the knock-on impacts of the reduced output in each industry as a consequence of the absence of chemistry using professionals, once the effects have fully circulated through the economy. This includes:

- the impact on the wider supply chain considering upstream providers (indirect impacts); and,
- the impact on household spending considering that reduced employment leads to lower aggregate household incomes (induced effects).

Indirect impacts occur through the relationship between demand for inputs to production and output. When output decreases in a sector, so too does its demand for components and support services. If these inputs are sourced domestically, this leads to a further decrease in overall national output, which then leads to reduced demand for inputs, and so on.

Induced effects relate to the relationship between wages/salaries paid by firms to employees and the goods and services purchased by households. As output falls, firms require less labour and therefore the total wage bill falls. As, in aggregate, households are paid less, they then spend a smaller amount on products and services. The reduced household demand in the economy then pushes output further down, which depresses employment, wages and spending further. The nature of this feedback loop depends on the typical spending patterns of consumers, and the spending patterns of industries on employees.

*Caveats*

The I-O tool is a simple mechanism to capture a wide range of effects stemming from a shock, be it negative or positive, to the economy. It contains detailed inter-industry linkages and allows a wide range of analytical techniques to be applied. However, due to its simplicity, there are some caveats associated with it: for example, it is linear in structure and its coefficients are rigid, meaning that the underlying production relationships among industries are fixed. Furthermore, the results are driven by the assumption that the employment shares of chemistry using professionals in each industry sector are representative of their contribution to the output of that sector, which, as discussed earlier, may not necessarily be the case.

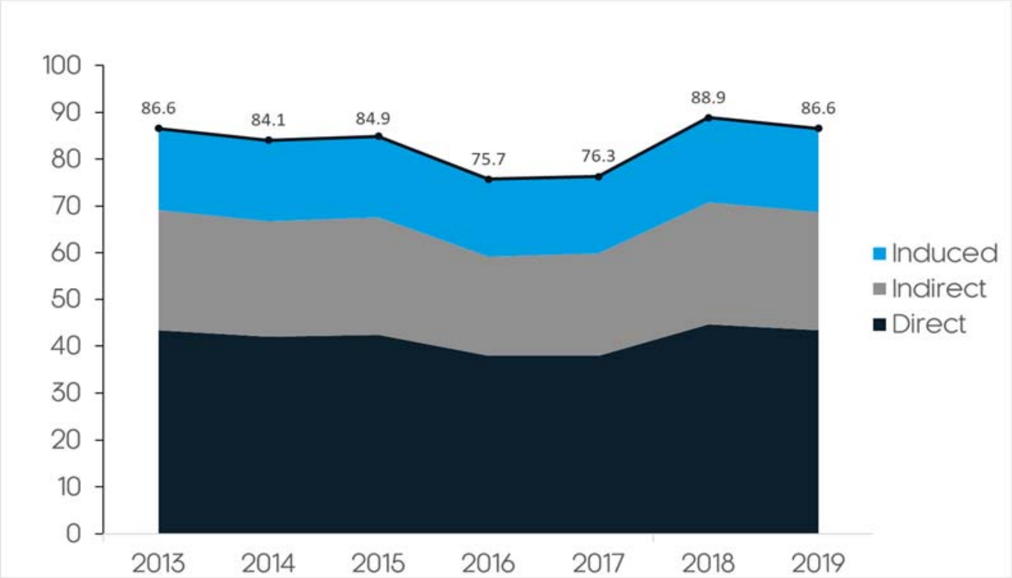
It should also be noted that the employment (jobs) figures in the I-O tool are measured as full-time equivalent (FTE), which means that part-time jobs have been converted to a full-time basis, taking into account the average number of hours worked in a part time job compared to a full-time job[9]. The direct employment impacts shown in section 4.2 will therefore be lower than those calculated in section 3.2 above.

## 4.2 Contribution to the UK economy

*Analysis of impacts over time*

Figure 2 shows that over the period of 2013 to 2019 the total impact – direct, indirect and induced effects – of chemistry using professionals on UK economic output (or Gross Domestic Product - GDP) averaged around £83bn per year. Between 2013 and 2016 there appears to have been a small decrease in the impact of chemistry using professionals for the overall UK industry, as the total gross output impact accounted for by the presence of chemistry using professionals in the economy fell to £76bn. There was then a recovery period up until 2018, but total output effects then subsequently decreased slightly back to 2013 levels of around £87bn. In general, these estimates suggest that chemistry using professionals contributed around 2.2%-2.7% of total output in the UK economy over this period, detailed figures can be found in Table 24.

**Figure 2: Impact of chemistry using professionals on UK gross output (£bn)**



Source: Cambridge Econometrics.

In terms of Gross Value Added (GVA)[10], the pattern over time looks similar – see Figure 3. In 2017 the contribution of chemistry using professionals to total GVA in the UK economy was at its lowest (during the period covered), they accounted for £37bn. Again, 2018 saw the biggest contribution of chemistry using professionals to total GVA in the UK, accounting for £41.5bn.

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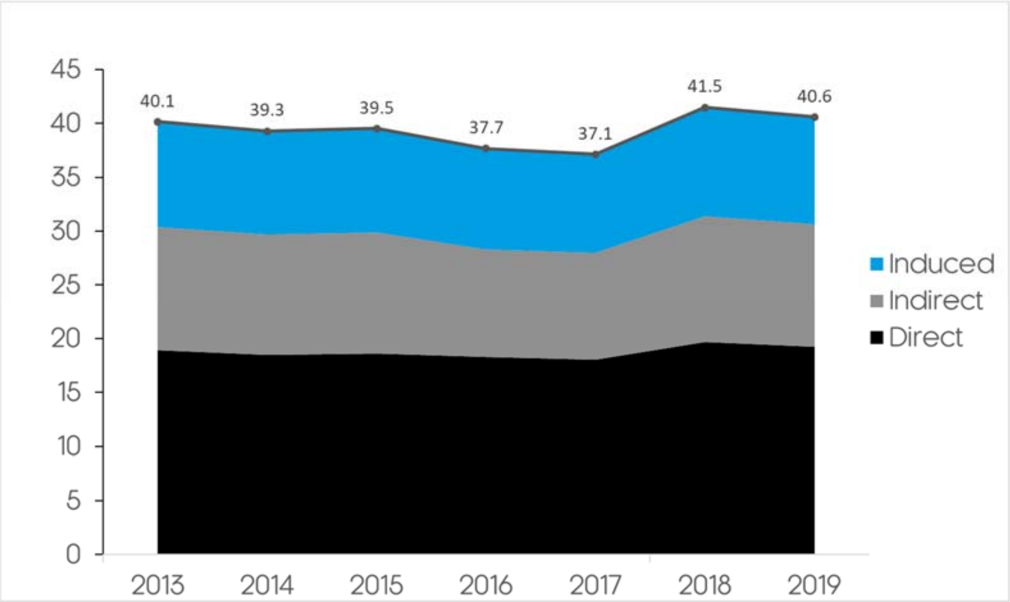
[9] Using data from the Annual Survey of Hours and Earnings (ASHE).

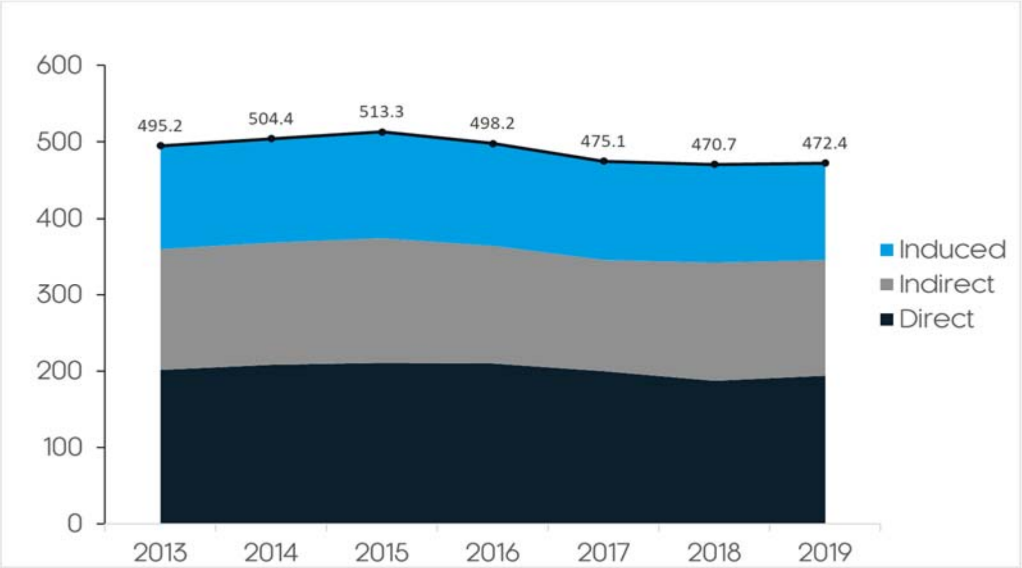
[10] The relationship between GVA and GDP is defined as: GVA= GDP + Subsidies on products - Taxes on products

**Figure 3: Impact of chemistry using professionals on UK GVA (£bn)**



In terms of the overall impact of chemistry using professionals on employment, Figure 4 illustrates how, over 2013 to 2019, the combined direct, indirect and induced impacts remained relatively stable, with an average of 490,000 FTE jobs per year. The impact was lowest in 2018, picking up slightly in 2019.

**Figure 4: Impact of chemistry using professionals on employment ('000s)**



Source: Cambridge Econometrics.

Source: Cambridge Econometrics.

However, the total impact of 472,000 jobs estimated to be due to chemistry using professionals’ presence in the workforce in 2019 is somewhat lower than the high of 513,000 seen in 2015. The driver of the pick-up in 2019 is a slightly larger direct impact of chemistry using professionals’ presence in the overall economy which offset slight decreases in the indirect and induced effects (with the changes in the different components of the total impact due to changes in the industry mix of the direct impact). Since 2013, chemistry using professionals are estimated to account, directly, for around 0.7%-0.8% of employment in the UK economy, with a further 0.5%-0.6% accounted for through indirect and induced impacts (see Table 22 in Appendix A). The impact values for each year are summarized in Appendix A, Table 19 to Table 21.

*Spotlight on 2019*

Focusing on 2019, the following impacts with regards to output, GVA, and employment are noteworthy.

In 2019, the sector with the highest output due to chemistry using professionals working in the UK economy was Electricity, gas, steam and air conditioning supply (SIC 35). Around £12.7bn of output or £3.3bn of GVA in this sector was accounted for by chemistry using professionals from the combination of direct, indirect and induced effects. It is followed by more "traditional", chemistry using industries such as Scientific research and development (SIC 72), Manufacture of pharmaceuticals (21) and Manufacture of coke and refined petroleum products (SIC 19). These industries also experienced the largest *direct* output impact of chemistry using professionals. As a consequence of supply chain, or *indirect* effects, the Electricity and gas sector (SIC 35) accounted for roughly £6.3bn and £1.6bn in GVA from the presence of chemistry using professionals in the workforce in 2019. The second and third most dependent industries on chemistry using professionals in terms of indirect effects are Wholesale trade services and Financial services, SIC 46 and SIC 64 respectively. The Extraction of crude petroleum and mining of metal ores sectors (SIC 6, 7) are similarly dependent, this is because the classical manufacturing industry of chemical products is deeply intertwined with the latter and relies on their goods as intermediate inputs. Similarly, the electricity sector in the UK is heavily fossil-fuel dependent and hence relies on the extraction of crude petroleum to generate its own output. Unsurprisingly, when it comes to induced effects, i.e. higher consumer expenditure in the UK economy because of the presence of chemistry using professionals in the workforce, the main impact is felt by service sectors, which include retail (SIC 47), real estate (SIC 68), food and beverage (SIC 56) and financial services (SIC 64). Together, these sectors see nearly £7bn of their output accounted for by the higher spending in the UK economy due to the presence of chemistry using professionals.

In 2019, chemistry using professionals are estimated to have accounted for a total of 472,000 jobs in the UK economy, as a result of direct, indirect and induced effects. The largest total effects occurred in research-linked sectors, with 37,000 jobs in Scientific research and development services (SIC 72) and another 33,000 in Technical testing and analysis services (SIC 71). Technical testing and analysis services experienced a high direct, but also a significant indirect employment effect. This is unsurprising, given the considerable number of chemistry using professionals employed in those sectors and the fact that they are deeply intertwined. Most-reliant on the supply chain effects from chemistry using professionals' presence in the workforce are however employment services (SIC 78) and wholesale trade (SIC 46) when it comes to employment effects. The higher circulation of household income and thus higher demand for products in the UK economy resulting from chemistry using professionals also led to induced effects. These impacted upon the nonchemicals services sectors the most. Sectors significantly benefitting from chemistry using professionals' presence in the workforce in terms of employment are retail trade services (SIC 47), food and beverage services (SIC 56) and wholesale trade services (SIC 46), but also construction (SIC 41-43).

In summary, the estimates of the direct, supply chain and induced, or household spending related, effects of the presence of chemistry using professionals in the UK economy provide a lower bound for their actual impact, given that, as mentioned above, the productivity of chemistry using professionals is likely to be higher, on-average, than the remainder of the workforce in each sector. Although it is difficult to measure and correct for any underestimate, the evidence suggests that in general, higher skills are positively associated with increased productivity (HM Government 2015). Induced effects mainly occur in service sectors, while significant indirect effects are captured by sectors that provide intermediate inputs for the "key" chemical using industries. These include electricity generation as well as research and testing sectors.

## 4.3 Contribution to the public purse

The contribution of chemistry using professionals to the public purse – also known as the Exchequer impact – is an important element of their overall economic impact. Chemistry using professionals pay tax on their earnings; and they and their employers also contribute National Insurance (NI) payments. They are also likely to contribute to the public purse through payment of indirect taxes, for example, Value Added Tax on purchases, council tax, Vehicle Excise Duty (road tax) and so on.

This analysis will focus on the contribution of chemistry using professionals to the public purse via income tax and NI contributions. The amount of and type of indirect tax paid depends very much on individuals' lifestyle choices, which cannot be captured easily here.

Firstly, the median gross earnings of chemistry using professionals, by sector are calculated. These earnings are then applied to the relevant Income Tax and NI thresholds, to determine how much the average chemistry using professional and their employers will pay in Income Tax and NI contributions. Finally, to generate an aggregate impact, these figures are multiplied by the employment estimates shown in Section 3, above.

*Estimating the gross earnings of chemistry using professionals*

The first step in estimating the Exchequer impact is to estimate the gross earnings of chemistry using professionals. This is done using the 2019 Labour Force Survey, to capture the median gross weekly pay of chemistry using professionals, in the relevant sectors. Gross weekly pay estimates are then multiplied by 52 to derive annual pay estimates.

The RSC's Pay and Reward Survey also collects information on the average pay of respondents. However, the occupation and sector categories in the Pay and Reward Survey do not align well with the Standard Occupational and Industrial Classifications (SOC 2010 and SIC 2007). Many occupations and sectors cannot be easily matched between the two sources, making it difficult to apply sectoral employment estimates to estimate aggregate effects. However, since employment estimates are calculated separately for teachers and university academics, median earnings from the Pay and Reward Survey in 2019 have been used for these occupations.

*Income Tax and National Insurance Assumptions*

Employer and Employee NI contributions are modelled assuming that employees are in NI category A[11]. Income tax rates for the 2019-20 financial year are used for income tax calculations. This assumes a tax-free personal allowance of up to £12,500, a basic rate of 20% on income earned between £12,501 and £50,000; and a higher rate of 40% on income earned between £50,001 and £150,000.

*Estimating the aggregate contribution to the public purse by chemistry using professionals*

To estimate the total contribution to the public purse by chemistry using professionals, the average employee and employer NI contributions, and income tax contributions, are multiplied by the total number of chemistry using professionals estimated to be employed in each sector in 2019. The estimated median annual pay of chemistry using professionals, the associated tax and NI contributions and the total aggregate impact, are shown in Table 14 for each sector.

**Table 14: Average median pay of chemistry using professionals, employer and employee NI contributions and income tax contributions, by sector, in 2019**

| Sector | Median pay | Total average annual contribution to Exchequer | Aggregate annual contribution to Exchequer |
|---|---|---|---|
| 19 Manufacture of coke and refined petroleum products | £67,496 | £34,950 | £88,398,487 |
| 20 Manufacture of chemicals | £31,876 | £9,872 | £172,679,733 |
| 21 Manufacture of pharmaceuticals | £37,128 | £12,278 | £128,246,443 |
| 22 Manufacture rubber plastic products | £35,997 | £11,760 | £73,366,313 |
| 23 Manufacture non-metallic mineral products | £41,743 | £15,240 | £24,632,988 |
| 24 Manufacture of basic metals | £34,580 | £11,111 | £40,662,867 |
| 26 Manufacture of computer, electronic and optical products | £35,828 | £11,682 | £41,790,411 |
| 27 Manufacture of electrical equipment | £18,980 | £3,966 | £11,212,602 |
| 28 Manufacture of machinery and equipment n.e.c. | £36,296 | £11,897 | £20,745,530 |
| 32 Other manufacturing | £24,973 | £6,711 | £5,976,070 |
| 35 Electricity, gas and air conditioning supply | £47,255 | £18,867 | £127,137,027 |
| 36 Water collection, treatment and supply | £30,121 | £9,068 | £36,519,660 |
| 37 Sewerage | £33,592 | £10,658 | £43,990,992 |
| 38 & 39 Waste collection, treatment and disposal activities; materials recovery; Remediation activities and other waste management services. | £36,933 | £12,188 | 27,429,663 |
| 46 Wholesale trade, except vehicles | £26,832 | £7,562 | £94,560,883 |
| 70 Activities of head offices; management consultancy activities | £29,484 | £8,777 | £94,082,120 |
| 71 Architectural and engineering activities; technical testing and analysis | £37,427 | £12,415 | £371,752,337 |
| 72 Scientific research and development | £33,319 | £10,533 | £530,135,904 |

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[11] Full details can be found here: https://www.gov.uk/guidance/rates-and-thresholds-for-employers-2019-to-2020.

| | | | |
|---|---|---|---|
| 74 Other professional, scientific and technical activities | £39,130 | £13,520 | £177,828,542 |
| 84 Public administration and defence; compulsory social security | £35,035 | £11,319 | £3,601,406 |
| 85 Education (excluding teachers and academic staff) | £31,252 | £9,586 | £414,435,053 |
| Teachers | £40,000 | £14,093 | £576,359,131 |
| Academic staff in universities | £50,300 | £20,918 | £121,845,859 |
| **Grand total** | | | **£ 3,227,390,022** |

Source: Cambridge Econometrics estimates based on the Labour Force Survey, income tax rates and National Insurance categories.

In total, chemistry using professionals are estimated to have contributed around £3.2bn to the public purse through income tax and NI contributions in 2019.

## 4.4 Foreign Direct Investment

Any discussion around the economic impact of chemical scientists necessarily involves consideration of foreign direct investment (FDI). FDI is an important contributor to economic growth due to its potential to enhance productivity and innovation and therefore economic growth, to create employment and to lead to several other social benefits (Girma and Wakelin 2007, Latreille and Manning 2000, Love, Roper and Du 2009). However, these effects vary by country and region, and are neither necessarily positive nor vast. The empirical literature suggests that the economic impact and spillover effects of FDI depend on the motivation behind it (technology sourcing vs exploiting)[12] , the general sector, the time period during which FDI takes place, as well as the underlying economic conditions in terms of absorptive capacity[13] in the FDI-receiving country. Some conditions that generate the greatest returns to FDI revolve around agglomeration and embeddedness – referring to firm clusters with a common high skill base, good infrastructural capacity, as well as efficiently integrated supply-chain networks.

Inward foreign direct investment can be interpreted as a positive shock to the economy, which results in direct and indirect impacts. In this case, the indirect impact captures the impact the FDI has had on all other firms in that sector, for example through competition or demonstration effects. The former refers to FDI raising competitive pressure in the domestic market and hence encouraging some sort of reactionary behaviour from competing firms. Demonstration effects occur when domestic firms are encouraged to imitate or to develop their own innovation in response to superior technology brought in through the FDI. As Hejazi and Pauly (2003) highlighted, the competitive effect of inward FDI flows could result in domestic firms cutting output and reducing investment – in this case, FDI has the indirect effect of crowding out domestic investment.

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[12] Technology sourcing refers to FDI undertaken with the aim of accessing technology and transferring it from the host economy to the investing multinational company, while technology exploiting does not encompass such a transfer.

[13] Absorptive capacity is defined as the ability of an organisation to identify, assimilate and apply knowledge that exists outside of the organisation itself for its own purposes.

With regards to innovation and R&D, Driffield et al (2010) showed that while the direct effect of FDI on R&D is positive, because Multinational Enterprises (MNEs) tend to have higher expenditure than domestic firms, the indirect effect need not be. There are two factors resulting from increased competition that pull the net effect of FDI on domestic investment in opposite directions: on the one hand, domestic firms may increase their investment in R&D to attempt to remain competitive, constrained by the increased cost of R&D as a result of bidding up researcher's wages, while; on the other hand, domestic firms may recognise that R&D produced by MNEs is available at a lower cost and will thus seek to obtain technology this way, whereby net R&D expenditure is decreased (they are essentially free-riding). Absorptive capacity in the industry determines the overall net effect of FDI inflows towards R&D budgets that heighten technological capabilities of firms.

For the UK, however, the overall evidence points towards less of a crowding out effect: Driffield and Hughes (2003) reported that FDI inflows boosted manufacturing investment in the domestic sector, while for the Manchester City Region there was no clear evidence that foreign investment did crowd-out domestic investment (2008). In terms of productivity effects, the evidence points towards these being of minimal size: studies have found that there are no significant productivity growth effects arising from FDI, but employment effects are often positive  (Department of International Trade 2018).

A  (2018) study by the Department for Trade found that extramural FDI, defined as FDI outside a firm's own sector had an overall positive effect on firms directly affected, as well as indirectly through spillover effects and encouragement of expenditure on outsourced R&D on firms in the same industry. On the other hand, intramural R&D, referring to research undertaken by dedicated research departments within domestic companies, is negatively affected by FDI – as FDI crowds out domestic R&D spending. They find that between 2010 and 2014 in most cases FDI had a net positive effect on the UK economy. Each additional £1m of FDI spending was estimated to lead to an average net increase in national GVA levels of around £69,000, create an additional 1.3 jobs, and raise R&D expenditure by £1,700 over the period 2010 to 2014. Their paper however suffers from a lack of distinction between different forms of investment, grouping together greenfield, expansion, Mergers and Acquisitions (M&A) and joint venture investment projects.

## *FDI in the chemistry-using industries*

Detailed data on FDI flows into the UK at sectoral level is very sparse. The most recent FDI figures by broad industrial group are for 2018, while a user request led to the ONS publishing FDI inward flows and positions disaggregated at two-digit industrial level for 2015. For these reasons, this section will first look at 2015 data for the chemistry using industries selected, and subsequently refer to more recent (2018) data for the broad industrial groups.

In 2015, the UK received a total inflow of £21.6bn in FDI funding for various activities. At a sectoral level, financial services accounted for the largest share. With regards to the identified sectors employing chemistry using professionals, the following table summarizes their investment inflows for 2015. Unsurprisingly, Scientific research and development (sector 72) accounted for the highest share of FDI inflows amongst the selected industries, with £1.985bn it is also the 8th largest sector receiving inward FDI in the UK. Others with high inflow rates are Manufacturing of machinery and equipment n.e.c. (28) as well as Electricity, gas, steam and air conditioning supply (35). For 9 out of the 19 selected sectors, FDI flows in 2015 were negative, implying a net outflow of investment.

In terms of FDI net positions[14], in 2015 the UK held stock of investment worth £950bn – this value reflects the stock of investment in the UK controlled by foreign companies. Similar to inflows, companies involved in financial activities come out on top UK-wide. Amongst chemistry using industries, as Table 15 illustrates, it is Electricity, gas, steam and air conditioning supply, Activities of head offices; management consultancy activities, as well as Wholesale trade, except of motor vehicles and motorcycles where the investment shares held by the direct foreign investor (parent company) are highest. Interestingly, the *Scientific research and development* sector (72) that accounts for the majority of inflows, has a total of £1.6bn of its value in the hands of foreign investors – reflecting the national interest in the protection of innovation and newly developed technologies.[15]

**Table 15: FDI Flows and Position in the UK for 2015 (£ million)**

| Industry group | Industry name | Flows | Position |
|---|---|---|---|
| 72 | Scientific research and development | 1,985 | 1,653 |
| 28 | Manufacture of machinery and equipment n.e.c. | 1,556 | 17,216 |
| 35 | Electricity, gas, steam and air conditioning supply | 1,555 | 45,205 |
| 26 | Manufacture of computer, electronic and optical products | 1,016 | 20,695 |
| 71 | Architectural and engineering activities; technical testing and analysis | 963 | 14,524 |
| 20 | Manufacture of chemicals and chemical products | 429 | 18,050 |
| 38 | Waste collection, treatment and disposal activities; materials recovery | 1555 | 1935 |
| 21 | Manufacture of basic pharmaceutical products and pharmaceutical preparations | 358 | 5,084 |
| 25 | Manufacture of fabricated metal products, except machinery and equipment | 292 | 3,589 |
| 32 | Other manufacturing | 252 | 4,702 |
| 36 | Water collection, treatment and supply | 121 | 981 |
| 39 | Remediation activities and other waste management services. | 2 | 8 |

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[14] Position refers to the value of the stock of investment held at a point in time. The ONS defines FDI positions as net values for the investments held by the direct investor (parent company) minus reverse investment by direct investment enterprises.

[15] See: https://www.ons.gov.uk/economy/nationalaccounts/balanceofpayments/adhocs/006923inwardforeigndirectinvestmentbyindustryforearningsflowsandpositions2014to2015

| | | | |
|---|---|---|---|
| 85 | Education | -40 | 1,354 |
| 74 | Other professional, scientific and technical activities | -148 | 2120 |
| 10 | Manufacture of food products | -232 | 10,606 |
| 24 | Manufacture of basic metals | -635 | 3,193 |
| 70 | Activities of head offices; management consultancy activities | -691 | 32,553 |
| 29 | Manufacture of motor vehicles, trailers and semi-trailers | -705 | 7,864 |
| 22 | Manufacture of rubber and plastic products | -1,044 | 6,985 |
| 27 | Manufacture of electrical equipment | -1,458 | 6,903 |
| 23 | Manufacture of other non-metallic mineral products | -2,286 | 18,190 |
| 46 | Wholesale trade, except of motor vehicles and motorcycles | -7,849 | 55,362 |
| 19 | Manufacture of coke and refined petroleum products | .. | 2,871 |
| 37 | Sewerage | - | 4 |
| 84 | Public administration and defence; compulsory social security | - | - |
| .. refers to disclosive data | | | |

Note: '..' indicates value is disclosive, '-' indicates either nil or < £500,000.
Source: Office for National Statistics (2017)

By broad industrial group over the years 2015-2018, the *petroleum*, chemicals, pharmaceuticals, rubber *and* plastic products industry's share of total inward investment has increased (see Table 16). In 2015, the sector saw considerable disinvestment, while in 2018 it received the 6th largest inward investment flow in the UK, worth £1.7 billion. The table shows the picture by source country for this industry.

**Table 16: FDI flows in petroleum, chemicals, pharmaceuticals, rubber and plastic products (£ million)**

| Country | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|
| World total | -493 | 4,721 | 3,045 | 1,730 |
| Europe | .. | 761 | 1,873 | 689 |
| EU | -132 | 1,009 | 952 | 428 |
| The Americas | -562 | 3,470 | -1,033 | -926 |
| USA | -601 | 2,098 | -191 | -1,148 |
| Asia | 94 | .. | .. | 1,374 |
| Africa | .. | .. | -14 | .. |
| Australasia & Oceania | 2 | 7 | .. | .. |

Note: '..' indicates value is disclosive, '-' indicates either nil or < £500,000.
Source: Office for National Statistics (2020)

After significant net disinvestment in this sector in 2015 of £493 million, 2016 saw a surge in investment totalling £4.7 billion, which subsequently followed a downward trend and fell to one third of this value in 2018, possibly reflecting Brexit uncertainty. It is noteworthy that this industry was particularly dependent on inflows from Asia in 2018, accounting for £1.3bn of FDI in that year. The share of FDI flows stemming from the Americas has been negative for three out of the last four years of data, implying disinvestment.

# 5 How can the innovative nature of chemical scientists be captured and what is the link between innovation, productivity and economic growth?

Innovation has been linked in various studies to personal wage premia, firm-level productivity increases and nationwide economic growth. However academic understanding of its link with particular skills and occupations is severely restricted due to data limitations and econometric estimation problems that lead to biases. These constraints are illustrated in the subsequent section, which also defines innovation. Subsequent sections offer academic evidence on the link between skills, innovation and economic growth. Furthermore, the relevance of Continuing Professional Development (CPD) and higher degrees for innovation is delineated.

## 5.1 Innovation: a definition and measurement issues

According to the Oslo Manual (OECD/Eurostat 2019), innovation can be defined as:

> *"new or improved product or process (or combination thereof) that differs significantly from the unit's previous products or processes and that has been made available to potential users (product) or brought into use by the unit (process)"*

This definition uses the generic term "unit" to describe the actor responsible for innovations. It can be any institutional unit in any sector, including academia.

It implicitly makes use of two types of innovation – product and process – which can be thought of as the following (HM Government 2016):

- Product innovation: defined as either the introduction of a new product or the significant improvement of an existing product
- Process innovation: defined as new or improved forms of organisation, business structures or marketing concepts

There has been a recent rise in the use of Contract Research Organisations (CROs), to which firms outsource research. While academic research has been lagging behind industry when it comes to identifying the role CROs play in innovation, they play a particular role in the automotive industry and are seeing more frequent use by the biopharma and food industries. These organisations change the nature of the traditional innovative process; hence it is likely that the aforementioned two types of innovation will be supplemented in the near future by a third type related to contractual innovation (PharmaTimes Magazine 2019).

*Measuring innovation*

Within the literature, there is an ongoing debate around the correct measurement of innovation. Traditional proxies include scientific publications, stock of scientists, and patents and trademarks registered. Other studies have used R&D expenditure as a guide to the innovative capability of firms. Some limitations of these measures include, for example, that not all innovations are patented and that not all patents actually have a significant innovative component. In addition, there is a plethora of analysis that is unable to find a statistically significant link between R&D spending and firms' sustained financial performance.

This perspective equates innovation to the use of R&D by manufacturing firms to develop technical inventions, it is characterised by a linear science-push model view. Although useful, these indicators hence fail to capture the diversity and complexity of innovation processes, particularly in the majority of sectors where innovation rarely requires R&D. These days most innovation is generated through services, business models, entrepreneurial start-ups, and often Mergers and Acquisitions (M&A) whose contributions cannot be easily captured by these traditional indicators. In addition, the fluid nature of innovation and the fact that it very easily crosses organisational boundaries make it hard to recoup the point of origin and hence its accurate measurement. For this reason, Eurostat's Community Innovation Survey attempts to use survey data to provide the opportunity to construct innovation metrics that can on the one hand substantially deepen the understanding of R&D and related activities and on the other hand broaden the understanding of other types of innovative activities (Arundel et al. 2018, Eurostat 2020).

*UK Innovation Survey*

The UK Innovation Survey is the main source of information on firm-level innovation activity in the UK (UK Government 2019). The 2017 survey showed that roughly half of UK firms had engaged in some form of innovation activity (labelled as 'broad innovators') – this is down to 38% in the headline findings for the 2019 survey vintage. The figure rises to almost 57% (46% in 2019 headline findings) of firms in the 'Manufacture of fuels, chemicals, plastic, metals and minerals' sector. The survey also shows that broad innovators were more likely to employ people with an engineering or applied sciences background than firms that did not engage in innovation activity (15% versus 5%), with the equivalent figures for the 'Manufacture of fuels, chemicals, plastic, metals and minerals' sector being around 36% for broad innovators and 10% for non-innovators respectively.

Broader innovators also have a higher proportion of employees that hold a degree or higher than non-innovators (15% versus 5%). In addition, an experimental regression analysis undertaken by the survey's authors suggests that engagement in innovation activities and employing STEM graduates were both positively associated with increased turnover and employment growth.

## 5.2 The link between skills, innovation and economic indicators

In the academic literature, several cross-country studies have attempted to identify and subsequently quantify a causal relationship between innovation and economic growth or productivity. Most studies use R&D investment, volume of high-tech exports, or number of patents registered per industry as measures of innovation.

A study by Griffith, Redding and Van Reenen (2004) for example finds that through R&D expenditure's effect on facilitating the absorption and transfer of new technologies in companies, i.e. innovation, it stimulates the industry's overall productivity and thereby contributes to economic growth. Their results are robust to different specifications and measurements of the variables used. Taking a firm-level perspective, a study by the OECD (2009) later confirms that innovation raises labour productivity. In the case of the UK, a one percent increase in innovation sales per worker[16] raises productivity at firm-level by 0.55 percent. In addition, in an extended model for the UK, it is found that novel innovation (sales from products new to market) plays a stronger role than incremental innovation (sales from products new to firm) to firms’ productivity growth.

More recently, Mason et al. (2014) have also shown that the innovative capability of industries and ultimately their economic success depends on their ability to effectively use knowledge, ideas and technologies. As this is closely related to the skills of the workforce, the next logical step is to link skills to innovation and growth. The analysis here is complicated by the lack of reliable skills measures, which has led the academic literature to develop several proxies. These most commonly include measures of qualifications such as average years of schooling or the proportion of the workforce who hold qualifications at broad qualification levels. Some studies choose school/university enrolment rates, monetary investment in education or standardised test scores instead. Studies have been undertaken across countries, at national level and at firm level.

*International studies*

The relationship between skills and economic growth has been found to persist across time and across countries. Hanushek and Woessmann (2012) use data from a series of international tests of the maths and science skills of secondary school children from 50 countries over the period 1960-2000 (the OECD’s Programme for International Student Assessment (PISA) data). They find that a one standard deviation improvement in test scores is associated with a 1.2-2.0 percentage points higher average annual growth rate in GDP per capita across the countries in their sample. The main advantage in using PISA data is that the tests are standardised across countries. However, maths and science skills of secondary school children can only be considered as a very general proxy of the education level of those in the labour force.

*National level studies*

At national level, growth accounting approaches have attempted to measure the contribution of skills to productivity growth over time. Mason, Holland et al (2014) developed a five-category skills measure based on the 1997 international standard classification of education (ISCED) scale and found that 18 percent of productivity growth in the UK between 1981 and 2007 could be explained by improvements in labour quality, with the key driver recently being higher-level skills.

Sianesi and Van Reenen (2003) provide a thorough review of the empirical literature that applies econometric techniques to measure the impact of years of education as a proxy for skills on macroeconomic performance. They find

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[16] Innovation sales per worker is based on firms’ replies to the Community Innovation Survey questionnaire and hence is defined as the ratio of sales generated from new products to the number of employees for each firm.

that a one-year increase in average years of schooling raises output per worker by 3-6 percent, depending on the country under consideration.

Others use the share of a country's workforce educated to degree level to proxy for skills, and find that a one percent increase raises productivity levels by 0.2-0.5 percent in the long-run (HM Government 2013). Disaggregating further, several studies have confirmed that the number of graduates holding STEM degrees is associated with increased innovation, productivity and growth in the economy (HM Government 2015, UKCES 2013).

All of the previously mentioned studies lacked taking into account uncertifiable skills, such as those acquired through on-the-job training and experience. To overcome this deficiency, Mason, Vecchi and O'Leary (2012) construct their own skills measure. They add relative earnings data to certified qualifications in order to capture differences in relative productivity between qualification groups. The authors find that a one percent increase in hours worked by those with degree level qualifications is associated with a 0.12 percent increase in labour productivity.

*Firm level studies*

At firm-level, there are several influential studies, all using vintages of the Community Innovation Survey to look at the relationship between skills, innovation and growth.

Firstly, a study by (Leiponen 2005) for Finland establishes that high technical skills, measured by the share of employees with postgraduate degree, complements R&D collaboration and innovation and raises firms' profits.

Secondly, Brandenburg, Guenther and Schneider (2007) use a very detailed linked employer-employee dataset for Germany to find evidence that sectors with a higher share of workers with tertiary level education engage in product innovation at above-average levels. Their results only hold if this highly qualified workforce is involved directly in R&D activities (as opposed to having a more highly-educated workforce in general). Nevertheless, the study convincingly concludes that degree-level education is a driver of innovation which has been linked to economic growth.

Thirdly, studies by the UK government suggest that a 10% increase in the share of the workforce educated to degree level can raise industry productivity by up to 2% (HM Government 2015). Further, they found that an increase in the share of STEM graduates raises industry turnover and employment growth (HM Government 2018b). Previously, the government (HM Government 2014) undertook a "big data approach" and found that when distinguishing between highly and less innovative firms there exists a beneficial impact of hiring STEM graduates in terms of innovation. Highly innovative firms, defined as the top 20% of firms in terms of R&D spending and the top 20% of firms with sales from new-to-market processes, were found to have a higher share of total employment accounted for by STEM graduates. In addition, these firms conducted more R&D, brought more new products to market, and cooperated more externally than less innovative firms.

## Case study: skills, innovation and economic growth

Croda is the name behind the sustainable, high performance ingredients and technologies in some of the world's most successful brands: creating, making and selling speciality chemicals that are relied on by industries and consumers everywhere. Using their Smart Science to Improve Lives™, the ingredients Croda make are used in applications ranging from crop protection to health care and beauty actives to anti-static additives.

Croda has 19 principal manufacturing sites in Western Europe, North America, EEMAE, Asia-Pacific and Latin America, and 36 research facilities in 17 countries. The company employ 4,580 people and today has a turnover of £1.38 bn. Between 2006-2019, Croda saw phenomenal growth of almost 500%, as a result of strategic acquisitions and continuous innovation.

Croda's business model is based on engaging with customers, creating, making and selling sustainable and innovative speciality ingredients that meet unmet needs of consumers around the world. They measure innovation by looking at the global contribution from products which are new, patented and protected (NPP) which currently stands at 28.1%. Croda is the world leader in sustainable Plant Cell Culture technology that enables the development and production of plant based active ingredients without the use of land, freeing up that land for food production. Croda prides itself on a strong sustainability and R&D focus, with around two thirds of its organic raw materials coming from bio-based sources. This year the company launched its ambitious Commitment to become Climate, Land and People Positive by 2030.

Croda's successful innovation-driven model has created significant economic impact, this is in part thanks to employing highly skilled chemists who match up to Croda's own aspirations as well as those of its customers. The company actively seeks people who are problem solvers and can 'think outside the box'. Croda sponsors many PhD students and short-term post-Doctorate or Masters students, and has collaborative projects underway with universities that give them access to the diverse set of skills they need. Croda also has well-established, regional, graduate schemes.

A number of Croda's chemists work in roles outside of the laboratory, with a high level of technical knowledge and expertise needed in both sales and marketing to help customers understand the chemistry and formulation requirements of the ingredients Croda makes. Most employees in sales have a chemistry background and it is not uncommon for them to have Chemistry PhDs, which help them to sell novel technologies and better understand customer needs. This variety of high quality technical skills underpins Croda's success.

*Qualitative evidence*

This emphasizes the point highlighted in Section 5.1. that the nature of innovation in modern economies is changing towards more cross-industry collaboration. Firms who want to persist as innovation leaders increase their collaborative activities, which in turn require adaptability and broader skillsets from employees. With regards to the chemical sciences, this implies that employees need to integrate their technical skills with softer skills such as translation, collaboration and communication, for the purpose of developing new products and generating innovative content (HM Government 2018b, Royal Society of Chemistry n.d.). Overall, most qualitative studies on innovation in the sciences agree that analytical, computational and programming skills, as well as subject matter expertise and high-level tertiary education remain important drivers of innovation, but that softer skills are required to render the industry "future proof".

## 5.3 Skills required for innovation

*Skills required for innovation*

The range of skills identified in the literature as contributing to innovation is wide, but empirically identifying them and their link to innovation is difficult as matching the data on both variables at the appropriate level of specificity and for the correct time period is complicated. As the OECD (2011) points out, this complexity of the relationship between skills and innovation indicators requires more work to understand the use of different skill groups in innovation activities. It finds that no specific skill per se is linked to innovation, but that the requirement seems to hinge on the industry, the type of innovation activity and the stage of the innovation process. It outlines five families of skills that often appear in conjunction with innovation, these include:

- Basic skills & digital age literacy
- Academic skills: subject matter areas covered in education institutions
- Technical skills: academic skills & knowledge of certain tools
- Generic skills: problem solving, critical thinking, creativity, ability to learn
- Soft skills: interacting and working in teams and heterogeneous groups, communication, motivation

As Hanel (2008) pointed out earlier, the type of innovation determines the skill requirement: minor improvements in a product call for different skills than world-first breakthroughs. Furthermore, depending on the industry, innovation necessitates a different skills spectrum. For example, science-based firms such as pharmaceuticals and chemistry are heavily dependent on R&D professionals and academic scientists, while specialist firms such as instrument or software suppliers have a higher need for a workforce with high level vocational and practical skills (Tether, et al. 2005). It is important to note however, that while those with PhDs often work in scientific research and analysis departments and thereby are overwhelmingly part of the innovation process, there is a significant contribution from the non-university-trained workforce, especially when it comes to incremental innovation (Toner 2010). In this way, not all innovation activities necessitate a workforce qualified to PhD level.

## Case study: skills for innovation

Afton Chemical Corporation is part of the Newmarket Corporation family of companies, and has been a leading player in the fuel and lubricant additives technology for over 90 years, supporting automotive and industrial markets. Afton uses chemistry, formulation and engineering expertise to develop fuels and lubricants that reduce emissions, improve fuel economy, extend equipment life and lower the total cost of vehicle and equipment operation. Afton invests as much as 90%-95% of their research budget on finding direct or indirect ways for reducing emissions.

Afton Chemical has global operations in Asia Pacific, EMEAI, Latin America and North America, with a similar global manufacturing footprint, Corporate Research Centre in Richmond, VA and European Technical Centre located in Bracknell. In total, Afton employs 2000 people, approximately 700 of that work specifically in R&D.

There are certain skills Afton looks for in every employee. Innovation needs people with an inquisitive nature, to be constantly asking questions to develop better understanding, and have the resilience to drill down to the core of an issue. But this in itself will not solve problems so staff must also be aware of and understand the 'whole system'. It is not enough for chemists to be just chemists. Staff of all areas will often need to move beyond their own discipline to find an innovative solution to a problem. Collaboration at Afton necessitates staff specialising in different science and engineering disciplines working together and working with regulatory, legal and marketing specialists.

It is this specific combination of curiosity and ability to understand and think across a wide range of perspectives that means Afton's recruitment policy does not focus solely on traditional qualification requirements. PhDs and qualifications in general, will be part of a wider framework when recruiting technical staff. At Afton, softer skills developed during PhD i.e. critical thinking, problem solving, holistic thinking are equally sought versus purely seeking in-depth technical knowledge.

Afton also look for particular attitudinal attributes in their recruits: a high level qualification by itself does not bring about good innovation. Problem solving and curiosity, but also a willingness and aptitude to learn new skills is paramount to success at Afton. Afton actively encourage learning and development in their staff, but this too is only part of the picture. Staff are encouraged to find opportunities to apply new skills, to learn from each other, sharing best practice and experience.

Looking ahead, digital skills in R&D are increasingly important to ensure efficiency of R&D spend, and produce superior innovation. Afton are putting a great deal of effort into upskilling their formulators with key digital skills required for the future.

In addition, skills requirements differ depending on the stage that an innovation process is at. While throughout the process generic skills are required, the first stages such as sourcing and selection of ideas demand creativity, filtering and market research skills as well as knowledge of intellectual property protection mechanisms. Subsequently, the development stage requires skills linked to assembling teams, managing budgets and generating spaces for experimentation as well as technical skills. Then, the testing, stabilisation and commercialisation phase calls for good risk management and strategy formulation skills. Finally, for implementation and diffusion of a new product, marketing skills and the ability to coordinate supply chains are highly valued.

Overall, the successful introduction of a new or improved product thus links back to high quality management that makes effective use of skills, knowledge and technologies at their disposal (Bloom and van Reenen 2007). Managerial and entrepreneurial skills are required to enable organisations to adapt and respond in a competitive environment and consequently to put innovative ideas into practice. For this reason, Korea established the Korea Institute of Human Resource Development in Science and Technology in 1997 and extended its training offer to give research personnel the opportunity to build complementary capabilities in the planning, execution and management of research.

Among the range of knowledge, skills and abilities that were found in Chapter 2 above to be common within each of the four identified groups of chemistry using professionals, there are a number of skills and abilities that would appear to be highly relevant to the ability to innovate. These include complex problem solving, critical thinking, coordination and troubleshooting skills; and information ordering and originality abilities.

## Case study: diversity in skills and talent

Reading Scientific Services Limited (RSSL), a subsidiary of the snack giant Mondelēz International is a contract research organisation (CRO), part of a relatively new and fast growing sector of the economy, which provides research services to companies seeking to outsource their R&D operations or those who need to adapt to regulatory or market changes. RSSL supports around 3,000 clients across 60 countries, in the areas of food, consumer goods, pharmaceutical, biopharmaceutical and healthcare

RSSL has a turnover of £20 million and continues to go from strength to strength with growth of between 10-15% year on year in both financial terms and employee numbers. RSSL currently employs 265 staff in Reading in the United Kingdom.

RSSL needs a diverse workforce with a wide spectrum of technical skills at different skill levels from school leaver apprentices, to graduates and PhDs. RSSL is dedicated to growing the next generation of scientists and is proud to be able to play their part in closing the skills gap and equipping its' scientists with good laboratory skills, which can be hard to find. The trainee scientists (apprentices) work in different laboratories and gain practical experience across different scientific disciplines, as well as benefit from both classroom and online learning, becoming well-rounded individuals in as little as 2 years on the apprentice scheme.

RSSL also provides a graduate and industry placements scheme giving approximately 20 undergraduates/recent graduates the opportunity to work in an industrial setting each year. Partnering with universities, RSSL sponsors PhD training programmes enabling them to nurture the next generation and identify specific in depth technical skills. Similarly, some technical teams and projects need specialised staff to lead them but this can be hard to find, often requiring a global search. RSSL currently employs staff from 27 countries.

Providing solutions to market issues requires creative problem solvers and those with deep knowledge, for example flavour chemists, who can provide the technical expertise necessary to respond to clients' needs.

The nature of RSSL's work also requires staff to have a broad range of soft skills including project management, team leadership, communication skills and the ability to collaborate effectively. Having business acumen and the ability to be entrepreneurial is also crucial to RSSL's success as a CRO, where technical staff will need to keep up with market developments and be watchful of new trends.

Continued learning and development is a strong focus across all levels of the business at RSSL. Each member of the team has an individual training plan, which includes technical training as well as non-technical, such as presentation skills, influencing or business development, depending on the skills needs of the business but also the aspirations of staff members. As well as upskilling their workforce, this provides RSSL with the opportunity to identify their rising stars; staff members who may be nurtured for promotion. It is the search for and fostering of a broad range

## 5.4 The benefits of higher degrees

It is important to also recognise that academia plays a key role when it comes to generating and reaping the economic benefits from innovation. While the literature focuses mainly on the impact of basic or intermediate level qualifications on economic indicators, there is a body of literature that finds a significant premium attached to the possession of a postgraduate degree and that argues that a PhD is required for significant innovation generated within industry. It is hence unsurprising, given the high potential for innovation in the chemical sciences, that a total of 55% of RSC Pay and Reward Survey respondents in 2019 hold a doctoral qualification. However, little is known about how returns vary by subject, as, often, the data doesn't allow this kind of decomposition by discipline (Lenton 2019, Lindley and McIntosh 2015). This hinders our analysis insofar as the returns to chemistry-related PhDs cannot be identified separately from the average returns to PhDs in any discipline.

*Benefits to the individual*

Casey (2009) finds that the earnings benefits associated with gaining a PhD depend heavily on the subject studied, with the largest earnings premia found in medicine, sciences, business and finance and engineering (for men only). In common with learning at other levels, women generally experience larger earnings benefits than men.

Also, Mertens and Roebken (2013) look at rates of return for German doctorate holders and find that those who specialise in economics and law experience the highest earnings returns. Holders of doctorates in subjects such as mathematics and the sciences are lower, with the differences most likely due to industry effects: they tend to work in public scientific institutions and research programs, which provide lower salary levels than in the private sector.

A BIS study attempted to quantify the earnings returns to Masters and PhD degrees in (2011), albeit it didn't decompose results by subject area. It found that women and men holding a doctorate saw a 16-17% earnings premium over individuals holding just an undergraduate level degree. However, this value is somewhat overstated as these individuals are likely to also possess a Master's qualification in addition to their PhD. This study also finds that women in possession of a doctorate are 4.5 percentage points more likely to be employed than those holding just an undergraduate degree, compared to 2.7 percentage points for men. Overall, the authors find a mean net postgraduate lifetime wage premium for men educated to PhD level relative to those with undergraduate degrees of £76,000, with the women's lifetime wage premium standing at £42,000. An older study by O'Leary and Sloane (2005), who used LFS data from 1994-2002, found that the percentage wage returns to PhDs can rise to 31% and 60% for men and women respectively if benchmarked relative to individuals whose highest qualification are A levels.

*Benefits to firms and society*

In addition, there are so-called 'spillover' effects from workers with PhDs as suggested by Casey (2009). In other words, that the gains to society as a whole are greater than the gains for the individual, owing to the fact that PhD research adds to the stock of knowledge and that PhD holders help to improve the skills of those around them. This can spur innovation and subsequently positively affect economic growth as well as reduce inequality as detailed in the subsequent section (Bhutoria 2016).

This finding of 'spillovers' is supported by UKRI research (CFE Research, 2014) on the impact of doctoral careers, which examines the roles, value to employers, contribution to innovation and wider socioeconomic impact of doctoral graduates. In general PhD holders are highly-prized by their employers, with one in five saying that they are business critical – without them, their business could not function.

Employers value doctoral graduates' deep specialist subject knowledge, excellent research and analytical skills, their capacity for critical thinking and ability to learn new skills, as well as their ability to bring fresh perspectives to problems or the organisation. These skills enable doctoral graduates to innovate, developing new or improved goods, services, processes and ways of working. This also helps to raise value added per worker and can contribute to economic growth as previously mentioned, albeit the quantitative evidence for qualification specific benefits to employers in the UK is very limited (Bhutoria 2016).

The vast majority of doctoral graduates responding to the research said they had been involved in improving the problem-solving skills of others or helping them to think more creatively. This was corroborated by their employers, who described how doctoral graduates encourage, support and inspire those they work alongside to achieve more. This is especially visible when staff from universities or research institutions collaborate with industry as part of strategic partnerships. This enhanced two-way flow of knowledge can therefore spur innovation and maximise the economic benefit through acceleration of the introduction of new products to market and response to market needs (Royal Society of Chemistry 2019).

In general, the review of the literature suggests that there are three types of returns generated by a workforce holding PhDs. Benefits accrue to the individual in the form of earnings premia, to the firm as productivity gains and spillovers to other workers, as well as society as a whole, which benefits from the increased knowledge stock and the innovation and economic growth that this underpins. In addition, the literature hints at the potential for sectoral effects, i.e. that those working in the public sector or publicly-funded research institutes may suffer a pay penalty compared to their peers in the private sector. But the same limitations that have been previously outlined hold, as earnings are a very narrow measure of overall benefits associated with higher degree qualifications.

For chemistry using professionals and sectors, a combination of CPD, lifelong learning and a workforce educated to PhD level is essential for the industry to remain innovative. However, future research could usefully identify specific upskilling actions that the industry should undertake, in order to raise productivity, become more innovative, increase economic output and contribute towards the ambition of raising total R&D investment to 2.4 percent of GDP by 2027, as set out in the Government's Industrial Strategy.

## 5.5 The impact of continuing professional development on economic indicators

As detailed above, a range of skills are needed to drive innovation and economic growth. As 76% of the workforce today are expected to still be in the workforce in 2030[17], lifelong learning/professional development activity is important for firms to remain innovative and competitive. The previous section discussed the benefits that a highly educated workforce brings to the individual, employers and the overall economy. The evidence base is less comprehensive regarding non-formal and informal education, but there is some evidence to suggest that potentially large economic benefits can be realised from increasing occupational, practical and basic competencies including reading, numeracy skills or financial literacy (Bhutoria 2016). Chemistry using professionals are most likely to need to continuously update their computational, mathematical and statistical skills to make the most

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[17] Labour Force Survey, October-December 2019.

efficient use of modern digital tools and to draw meaningful conclusions (Royal Society of Chemistry 2019).

However, there are several methodological and data challenges associated with estimating the impact of lifelong learning on earnings and employment outcomes. One is around identifying causal effects, since many datasets do not capture the full range of factors that influence a person's propensity to undertake learning and earn higher wages (such as innate ability, motivation, attitude to learning, etc.). This so called 'omitted variable bias' can lead to the returns to training being overstated, as some of the apparent benefit to lifelong learning may really be down to the fact that only very able or motivated individuals undertake lifelong learning in the first place. Lifelong learning may also be used by some to certify their existing skills, which may in part explain why some qualifications appear to exhibit low wage returns. Also, identifying an appropriate comparison group against which to measure effects can also be challenging in some circumstances.

*Formal and non-formal training – effect on wages*

Despite these challenges, many studies find a positive impact of lifelong learning on labour market outcomes to some degree. Jenkins et al (2002) use longitudinal data and find that those who were out of the labour market were more likely to be in employment almost 10 years later if they had undertaken some lifelong learning in the intervening period. They also find positive earnings returns for some groups who have undertaken lifelong learning, such as those with no qualifications, women who undertake a degree level qualification and men who undertake a higher degree as a mature student. They also find, as do Vignoles and de Coulon (2008) that undertaking one episode of lifelong learning increases the probability of an individual undertaking further learning.

More recently, a study by BIS (2011) also finds positive earnings returns for many qualifications, though this can depend on age of acquisition: earnings benefits tend to be higher if qualifications are gained before the age of 30.

There is some evidence to suggest that earnings benefits from lifelong learning are higher for women than for men. For example, Blanden et al. (2008) found that the attainment of certifiable qualifications in adulthood is associated with a 10% increase in women's earnings, while there was no significant beneficial effect in aggregate for men. Vignoles and deCoulon (2008) also find that attaining NVQ2 qualifications in mid-career is associated with a 23% increase in earnings for women, whilst the estimates for men were not statistically significant. These findings have been confirmed for the Canadian labour market by Ci et al. (2015) whose wage premia estimates for women are similar to Blanden et al. (2008).

Studies looking at work-related training instead of formal, certifiable education also find a positive impact on wages, with also the effect for men outweighing that for women (Blanden, et al. 2008, Blundell, et al. 1999). For example, Feinstein et al (2004) identify an earnings advantage of 4-5 percent higher wage growth for men undertaking work-related training at mid-career age (33-42 years old) relative to those who did not upskill. However, it is important to bear in mind that there may be an element of self-selection driving the results here: that it is the most productive firms that can afford to pay for training and the higher salaries that result, which potentially make the results less applicable more generally.

Further solidifying the finding that training tied closely to employer needs realises the biggest wage gains, Lodovici et al (2013) and Conlon and Patrignani (2011) independently found that earnings premia to apprenticeships outweigh those to other Level 1 and 2 vocational qualifications.

Generally, evidence points to a higher wage impact of training that leads towards certifiable qualifications than on-the-job training for both genders. However, a BIS (2013) study warns that the earnings premium associated with acquiring a university degree later in life is lower when compared to those who gained their degree earlier in life. For men, later qualifiers tend to have earnings 9% lower than early qualifiers, while women with a first degree who go on to gain a postgraduate qualification later in life, earn on average 4% less than women who obtained their postgraduate qualification at an earlier age.

*Effect on productivity*

With regards to productivity, Turcotte and Rennison (2004) established that, for non-graduate employees, on-the-job and classroom-based learning heightened productivity, while only the former affected degree holders’ productivity outcomes. Dostie (2013) can confirm that any type of training raised value added per worker in Canada, albeit he does not differentiate between degree and non-degree holders. He found the magnitude to vary between 3.6 and 11%, depending on the nature of the training (on the job versus classroom). His estimate lies significantly above that of Dearden et al. (2006), who found that a one percentage point increase in work-related training raised productivity by 0.6% in the UK between 1983 and 1996. This heterogeneity of training’s impact on productivity is suggested by Dostie (2013) to stem from the fact that on-the-job training was more geared toward subjects that were less productivity-enhancing such as “orientation courses”, with classroom training mainly focusing on “professional skills”.

*Non-pecuniary benefits*

In addition to the impact on economic outcomes, several studies have found that adult upskilling has wider, non-pecuniary implications. These include, amongst others, health and wellbeing, civic/political/cultural engagement, social cohesion, social mobility, and crime (Ministry of Justice 2015, Schuller 2017, Ruhose, Thomsen and Weilage 2019, Blanden, et al. 2008).

This is a well-established corner of the economics literature, with many studies undertaken by respected academics. Their results suggest that earnings are likely to be a very narrow measure of the overall benefits associated with undertaking lifelong learning. However, the challenges and limitations that apply to those studies that focus solely on earnings as benefits can also apply here: the characteristics that influence an individual’s decision to undertake lifelong learning may also make them more likely to lead a healthier lifestyle, be more active in society, vote, etc. and these characteristics are often difficult to identify in mainstream datasets. That is not to dismiss the results completely: the weight of the evidence suggests that positive, wider benefits of learning are likely to exist, even if a true, causal impact is difficult to measure.

Overall, as Feinstein et al. (2004) and Schuller (2017) point out, the impact of lifelong learning on economic outcomes is largely positive, albeit it depends not only on the quantity of experience gained and qualifications achieved, but also on the quality and appropriateness of the training for the respective individual. Further, while workers benefit from the skills accumulation over the course of their lifetime, benefits to individuals are larger if skills are acquired at an early age. There is however not much robust evidence on the precise age that maximises the returns to learning acquisition (Bhutoria 2016).

# 6 Conclusions

It is clear from the analysis carried out for this study that chemistry using professionals make a significant contribution to the UK economy. The study has looked at the impact of chemistry using professionals in terms of skills, employment, output, contribution to the exchequer, innovation and productivity.

The study has investigated the types of knowledge, skills and abilities that chemistry using professionals make use of in their everyday work, and combined the different occupations into four groups, based on similar levels of use of these attributes. Chemistry knowledge is important to each group, but to varying degrees: for example it is very important for professional chemists and less important (although still significant) for chemistry using professionals in sales or marketing roles.

Chemistry using professionals tend to be highly qualified, with most occupations classified to professional and associate professional and technical occupations, which generally (but not necessarily) require a first degree or higher.

Official data has been used to make an estimate of the number of chemistry using professionals in the UK economy. There are estimated to have been 275,000 chemistry using jobs in the UK in 2019, spread around the UK but with significant proportions in London, the South East and North West.

Further to that, the impact (direct, indirect and induced) of chemistry using professionals on output in the UK economy is estimated to have been around £87bn in 2019. They are also estimated to have contributed £3.2bn to the Exchequer in that year, through income tax and National Insurance Contributions.

The study has also reviewed the available evidence on skills, innovation and productivity, which suggests there is a strong causal link between these and, therefore, also with economic growth. This suggests that chemistry using professionals are likely to make a significant contribution to innovation and economic growth, both through the nature of the occupations they undertake and because they tend to be highly qualified.

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# Appendices

# Appendix A

**Table 17: Share of chemistry using professionals in regional employment**

| Region | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|
| South East | 0.8% | 0.8% | 1.0% | 1.0% | 0.8% | 1.1% | 1.0% |
| London | 0.6% | 0.5% | 0.3% | 0.6% | 0.6% | 0.5% | 0.5% |
| North West | 1.2% | 1.3% | 1.0% | 1.0% | 0.9% | 0.8% | 0.8% |
| East of England | 0.8% | 1.0% | 1.3% | 1.1% | 0.7% | 0.9% | 0.9% |
| Scotland | 0.9% | 0.9% | 0.9% | 0.7% | 0.9% | 1.0% | 1.0% |
| South West | 0.7% | 0.7% | 0.9% | 0.6% | 0.8% | 0.8% | 0.8% |
| Yorkshire & the Humber | 0.9% | 0.7% | 0.8% | 0.8% | 0.6% | 0.8% | 0.8% |
| East Midlands | 0.7% | 0.8% | 0.7% | 0.4% | 1.1% | 0.8% | 0.8% |
| West Midlands | 0.8% | 0.6% | 0.6% | 0.7% | 0.6% | 0.5% | 0.5% |
| North East | 1.4% | 1.3% | 1.1% | 1.3% | 0.9% | 1.0% | 1.0% |
| Wales | 1.1% | 0.9% | 1.2% | 0.5% | 0.5% | 0.7% | 0.7% |
| Northern Ireland | 0.5% | 0.6% | 0.7% | 0.7% | 0.4% | 0.6% | 0.5% |

Source: Cambridge Econometrics analysis based on LFS and WFJ data.
Note: Shares may fluctuate from year to year due to small sample sizes in the LFS datasets.

**Table 18: Chemistry using professionals per region and sector as share of total number of chemistry using professionals in the UK**

| Sector | NE | NW | Y&H | EM | WM | EoE | Lon | SE | SW | Wales | Scot | NI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10: Manufacture of food products | 0% | 0% | 0% | 100% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| 19: Manufacture of coke and refined petroleum products | 7% | 26% | 20% | 0% | 0% | 0% | 0% | 37% | 0% | 0% | 8% | 2% |
| 20: Manufacture of chemicals and chemical products | 10% | 10% | 12% | 3% | 12% | 18% | 7% | 10% | 9% | 10% | 0% | 0% |
| 21: Manufacture of basic pharmaceutical products and pharmaceutical preparations | 7% | 13% | 5% | 9% | 2% | 16% | 11% | 12% | 2% | 7% | 14% | 3% |
| 22: Manufacture of rubber and plastic products | 12% | 10% | 28% | 10% | 0% | 8% | 0% | 9% | 15% | 9% | 0% | 0% |
| 23: Manufacture of other non-metallic mineral products | 22% | 0% | 41% | 21% | 16% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24: Manufacture of basic metals | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 17% | 24% | 58% | 0% | 0% |
| 25: Manufacture of fabricated metal products, except machinery and equipment | 0% | 0% | 0% | 0% | 100% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| 26: Manufacture of computer, electronic and optical products | 0% | 34% | 0% | 0% | 9% | 0% | 0% | 43% | 0% | 14% | 0% | 0% |
| 28: Manufacture of machinery and equipment n.e.c | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 57% | 43% | 0% | 0% | 0% |
| 32: Other manufacturing | 7% | 21% | 16% | 7% | 7% | 5% | 7% | 6% | 0% | 7% | 18% | 0% |
| 35: Electricity, gas, steam and air conditioning supply | 0% | 30% | 6% | 10% | 0% | 5% | 9% | 7% | 19% | 0% | 14% | 0% |
| 36: Water collection, treatment and supply | 0% | 0% | 6% | 11% | 0% | 12% | 18% | 23% | 7% | 0% | 22% | 0% |
| 38: Waste collection, treatment and disposal activities; materials recovery | 100% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| 39: Remediation activities and other waste management services | 10% | 59% | 0% | 0% | 0% | 12% | 0% | 0% | 0% | 0% | 19% | 0% |
| 46: Wholesale trade, except of motor vehicles and motorcycles | 9% | 10% | 25% | 8% | 0% | 8% | 0% | 6% | 0% | 0% | 25% | 10% |
| 70: Activities of head offices; management consultancy activities | 0% | 21% | 7% | 8% | 0% | 8% | 31% | 11% | 6% | 0% | 5% | 3% |
| 71: Architectural and engineering activities; technical testing and analysis | 4% | 8% | 9% | 9% | 9% | 8% | 9% | 13% | 9% | 4% | 17% | 1% |
| 72: Scientific research and development | 3% | 2% | 8% | 6% | 2% | 21% | 10% | 23% | 6% | 0% | 15% | 2% |
| 74: Other professional, scientific and technical activities | 0% | 8% | 0% | 8% | 0% | 5% | 16% | 17% | 36% | 10% | 0% | 0% |
| 84: Public administration and defence; compulsory social security | 10% | 10% | 0% | 9% | 7% | 0% | 0% | 32% | 32% | 0% | 0% | 0% |
| 85: Education | 1% | 8% | 4% | 5% | 7% | 10% | 18% | 29% | 9% | 1% | 6% | 3% |

Source: Cambridge Econometrics analysis of LFS data for 2019.

**Table 19: Employment impact of chemistry using professionals ('000s)**

| | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|
| Direct | 201 | 208 | 211 | 210 | 200 | 187 | 194 |
| Indirect | 159 | 160 | 164 | 154 | 147 | 156 | 152 |
| Induced | 135 | 136 | 139 | 134 | 129 | 128 | 126 |
| Total | 495 | 504 | 513 | 498 | 475 | 471 | 472 |

Source: Cambridge Econometrics.

**Table 20: GVA impact of chemistry using professionals (£bn)**

| | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|
| Direct | 19 | 18 | 19 | 18 | 18 | 20 | 19 |
| Indirect | 11 | 11 | 11 | 10 | 10 | 12 | 11 |
| Induced | 10 | 10 | 10 | 9 | 9 | 10 | 10 |
| Total | 40 | 39 | 40 | 38 | 37 | 41 | 41 |

Source: Cambridge Econometrics.

**Table 21: Gross output impact of chemistry using professionals (£bn)**

| | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|
| Direct | 43 | 42 | 42 | 38 | 38 | 45 | 43 |
| Indirect | 26 | 25 | 25 | 21 | 22 | 26 | 25 |
| Induced | 17 | 17 | 17 | 16 | 16 | 18 | 18 |
| Total | 87 | 84 | 85 | 76 | 76 | 89 | 87 |

Source: Cambridge Econometrics.

**Table 22: Employment impact of chemistry using professionals as percent of total UK employment 2013-2019**

| | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|
| Direct | 0.8 | 0.8 | 0.8 | 0.8 | 0.7 | 0.7 | 0.7 |
| Indirect | 0.6 | 0.6 | 0.6 | 0.6 | 0.5 | 0.6 | 0.5 |
| Induced | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Total | 2.0 | 1.9 | 1.9 | 1.8 | 1.7 | 1.7 | 1.7 |

Source: Cambridge Econometrics.

**Table 23: GVA impact of chemistry using professionals as percent of total UK GVA 2013-2019**

| | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|
| Direct | 0.59 | 0.57 | 0.56 | 0.54 | 0.52 | 0.56 | 0.54 |
| Indirect | 0.36 | 0.34 | 0.34 | 0.30 | 0.29 | 0.33 | 0.32 |
| Induced | 0.31 | 0.30 | 0.29 | 0.28 | 0.26 | 0.29 | 0.28 |
| Total | 1.26 | 1.21 | 1.19 | 1.12 | 1.06 | 1.18 | 1.13 |

Source: Cambridge Econometrics.

**Table 24: Output impact of chemistry using professionals as percent of total UK output 2013-2019**

| | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|
| Direct | 1.36 | 1.29 | 1.28 | 1.13 | 1.08 | 1.26 | 1.21 |
| Indirect | 0.81 | 0.77 | 0.76 | 0.64 | 0.63 | 0.74 | 0.71 |
| Induced | 0.55 | 0.53 | 0.52 | 0.49 | 0.47 | 0.51 | 0.50 |
| Total | 2.72 | 2.59 | 2.57 | 2.26 | 2.18 | 2.52 | 2.42 |

Source: Cambridge Econometrics.