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QUANTIFYING MEASUREMENT ACTIVITY IN THE UK

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Quantifying Measurement Activity in the UK

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Approved on behalf of NPLML by
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EXECUTIVE SUMMARY

CONTEXT

Measurement is a crucial operation within research, development, and the application of technologies in an economy. Accurate, traceable measurements are needed to demonstrate the quality and quantity of products to consumers and suppliers, reducing uncertainty and thus easing trade frictions. Moreover, improved measurement capabilities facilitate product and process innovation by assisting in the development of new tools and techniques which ultimately result in productivity gains. However, these measurement activities typically embody public good characteristics – the social benefit outweighs the private benefit to those who provide them meaning that they are susceptible to market failure. This begs the question of who should pay for measurement activities and how much should be invested? Without an understanding of the overall scale of measurement activity within an economy, it is difficult to formulate the most efficient policy towards this segment of science and innovation.

Pre-existing studies on the market for measurement goods and services generally estimate measurement spend by industry to range between 1% and 5% of Gross Domestic Product (GDP).[1] While these studies provide a reference for understanding the scale of measurement, their age means that these results may not reflect the current level of measurement activity; the most recent study by Williams (2002) analysed the turnover of NMIs and the expenditure on instrumentation in the EU. In the decades since, state of the art measurement technology has become increasingly more precise and more accessible, birthing brand-new sub-industries that are enabled by the creation of new standards, products and processes that were previously unfeasible. Hypothetically, the modern measurement economy has changed drastically even since Williams' assessment; using it as a barometer for the scale of measurement activity today would be misguided. Moreover, none of these studies focus on the UK. Measurement activities are highly specialised - specific knowledge required and high R&D costs are barriers to entry - meaning that expenditure on measurement is likely to vary significantly from one country to another.

This report assesses what the current scale of measurement activity is in the UK and how it varies across different sectors. Understanding the scale of measurement in the UK makes it easier to formulate more efficient policies for science and innovation that is underpinned by measurement and supplies NPL and other agents with improved knowledge on the market within which they operate.

APPROACH TO QUANTIFYING THE SCALE OF MEASUREMENT ACTIVITY

The applicability of measurement knowledge and tools across a broad range of users makes it a cumbersome task to precisely estimate the overall scale of measurement activity within the UK economy. The approach taken in this report identifies three primary sources of measurement activity within an economy: the use of measurement tools; the manufacture of measurement tools; and metrological innovation. Each of these is then broken down into their core components, resulting in a total of four key elements of measurement activity: labour input; investment; intermediate demand; and research and development.

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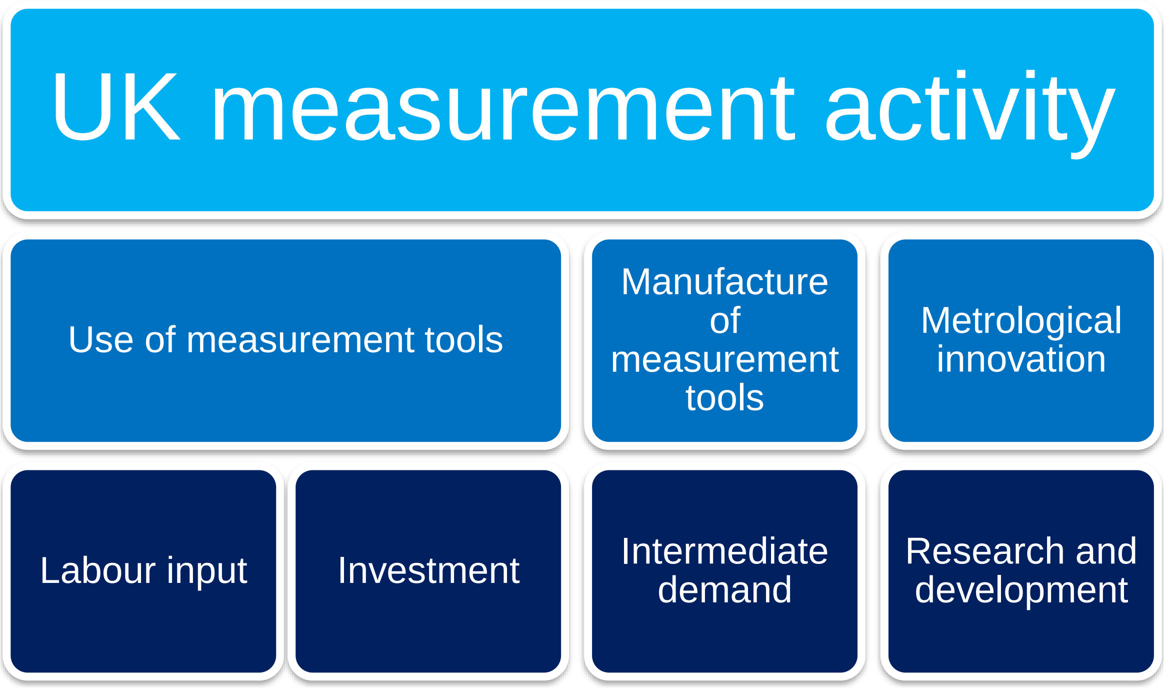
1 See (Huntoon, 1967), (Paulson, 1977), (Don Vito, 1984) and (Williams, 2002).



The four key elements of measurement activity guide the following chapters where, through a combination of widely accepted economic theory and clearly stated assumptions, paired with the relevant national statistics from credible sources, we arrive at estimates for the value of each element. This novel method transcends aggregated estimates of the scale of measurement activity, offering certain results by industry or by primary measurement purpose. The analysis spans a 17-year period between 2000 and 2017, exposing trends.

Below is a brief description of the objectives and outputs of each chapter:

- **Labour Input** – Labour is required in the generation of output. This element estimates the number of people employed in the UK whose job requires the use of instrumentation and reports the value of their labour. This is achieved through a thorough analysis of Standard Occupational Classification 2010 (SOC 10) codes, selecting those that are related to measurement, and applying those filters to national statistics which are frequently published in these SOC codes. In addition, this element includes a further sub-category that highlights the size of the UK calibration and testing sector, referred to as 'measurement services'. Individuals employed to provide measurement services are tasked with maintaining instrumentation and/or verifying that products and processes meet accredited standards.

- **Investment** – Investment refers to the purchase of instruments that are used directly to make measurements. More specifically, these are instruments intended for use in the production of other goods and services for a period of more than a year. We use data from the Observatory of Economic Complexity (OEC) which provides detailed product classifications to divide the total investment in instrumentation into three broad instrument types that represent their primary measurement purpose – these are: Health and Life Sciences; Engineering, Manufacturing, Utilities and Construction; and Transport and Communication. The resulting figures are comparable with the widely collected economic variable 'gross fixed capital formation' (GFCF) which, when used in conjunction, provide indicators of measurement intensity for further insights. In addition, estimation of this element allows for further analyses regarding the UK capital stock of instrumentation.

- **Intermediate demand** – Intermediate demand refers to the sale of instruments that are used indirectly to make measurements. More specifically, these are instruments that are used as inputs that are either transformed or used up in the production process. This is value primarily generated by the Manufacturing sector and does not require any specific measurement knowledge or expertise. Like for investment, the results in this chapter are disaggregated by instrument type, but also by origin. Data for imported instrumentation are retrieved from the OEC, whereas data for domestic instrumentation are retrieved from the UK manufacturers' sales by product (ProdCom).
- **Research & Development** – As measurement is a science, commonly referred to as metrology, a large portion of measurement activity in any economy will concern research and development (R&D). Henceforth, this section attempts to quantify the amount of funding in the UK that is allocated to projects that have a strong focus on measurement, from which we can extrapolate the foreseeable economic benefit of such research using widely accepted economic theory. This is achieved via an analysis of data on UK published patents and scientific articles retrieved from the World Intellectual Property Organisation (WIPO) and Web of Science (WoS), respectively.

The final product is a thorough market analysis, the likes of which have never before been published in the UK, that justifies the UK's measurement infrastructure as an integral part of science and innovation strategy.

RESULTS

Below are some of the headline results from each chapter of this report:

Labour Input

- In 2017, 6.3% of total employment in the UK was comprised of occupations that involve taking measurements and the total compensation offered to employees in these measurement related occupations was £58.3bn which accounts for 2.8% of UK GDP.
- Taking a closer look at the concentration of measurement related occupations within industries, 14.3% of all employees in the Research & Development industry and 7.9% of all employees in the Defence industry hold occupations that may require calibration or testing practices.
- Between 2007 and 2017, the number of employees in measurement related occupations rose by 13% – 4 percentage points more than overall employment over the same period – to a total of 2 million. This was mostly driven by an uplift in occupations that may or may not require calibration or testing practices.
- In 2017, there were 162,000 employees specifically providing calibration and testing services in the UK. These employees were awarded a total of £4bn in annual pay.

Investment

- Investment in instrumentation has increased annually and this amounted to just over 3.6bn in 2017, accounting for 4.1% of investment in productive and tangible assets and 7.2% of investment in all machinery equipment.

- In 2017, we estimate that the gross capital stock of instrumentation was valued at £36.8bn, 0.5% of the UK's total gross capital stock, 57% of which was accounted for by instruments for Health and Life Sciences.

Intermediate demand

- Intermediate demand for instrumentation has increased, in real terms, from £6.8bn to £9bn between 2008 and 2017, while the ratio of each type of instrument produced has remained relatively constant.
- From 2008 to 2017, the UK has become increasingly dependent on imports of instrumentation for intermediate input. This peaked at 60% of total intermediate demand in 2017.

Research and Development

- In 2017, the total expenditure on measurement-related R&D was just over £2bn, 87% of which were performed by private businesses.
- Over the last decade, 7.5% of all UK originated granted patents relate to a measurement technology – almost 16k in total.
- A similar analysis of journal articles reveals that measurement research accounts for 2.4% of all papers published in the last 10 years – almost 21k in total. Academic measurement R&D has been declining over the decade. In the UK, the proportion of total papers published that were on measurement related topics was 0.3 percentage points higher in 2007 than it was in 2017.

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1 INTRODUCTION

Measurement knowledge is applicable across many sectors of the economy and at almost every stage of the value chain; producers and consumers make constant use of measurement products and services. For that reason, this report analyses the role of measurement from several standpoints – the aim is to provide the reader with a holistic view of the value of measurement in the UK productive economy.

To unpick the ubiquitous nature of measurement, we have developed a conceptual framework which shows the production and use of measurement products and services based on the National Input-Output Analytical Tables (IOATs). The IOATs are published roughly every five years by the Office for National Statistics (ONS) in order to provide a picture of the flows of products and services, both domestically produced and imported, in the economy for a single year and are used to set the level of annual Gross Domestic Product (GDP).

Using the findings in this report, we have adapted the IOATs to highlight the flows of measurement related goods and services within the economy; we refer to this analysis as the Input-Output Measurement Tables (IOMTs). The IOMTs are developed in two stages:

- First, the IOATs are collapsed to focus on industries with a high dependency on measurement.
- Then, the relevant aggregated estimates generated within the report are implemented, in conjunction with some further analysis to draw the necessary detail from them, to fill the simplified tables.

The final products are the Domestic-Use IOMT (*Figure 1A*) and the Imports-Use IOMT (*Figure 1B*).

		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
		Instrumentation	Manufacturing	Other production	Wholesale, retail and transport	ICT	Technical testing and analysis	R&D	Central gov. activities	Health	Other	Total intermediate demand	Households	Gov. and NPISHs	GFCF	Exports	Total demand
1	Instrumentation	360	1,034	118	101	193	17	4	692	730	210	3,459	42	0	0	3,466	6,926
2	Manufacturing	2,287	78,204	44,940	28,002	2,123	991	917	7,926	10,077	46,891	222,359	65,900	4,227	18,916	139,319	450,762
3	Other production	147	14,396	164,436	11,232	1,141	805	148	7,979	3,626	42,030	245,940	39,632	6,617	140,685	20,661	453,535
4	Wholesale, retail and transport	1,597	60,227	18,889	76,302	2,703	919	461	7,336	9,421	51,108	228,961	174,772	2,863	11,637	81,282	499,515
5	ICT	117	3,235	4,433	9,236	13,328	984	468	3,576	2,080	34,971	72,428	16,445	0	24,327	20,725	133,925
6	Technical testing and analysis	0	2,023	5,088	536	2	8,658	0	916	1,721	4,413	23,359	0	0	7,244	10,477	41,080
7	R&D	0	0	0	0	0	0	7,462	0	0	0	7,462	0	1,044	27,219	6,294	42,019
8	Central gov. activities	8	815	1,508	2,545	44	2,996	18	248	147	4,456	12,785	4,566	130,928	1,069	2,006	151,354
9	Health	65	225	35	0	0	0	0	180	1,671	500	2,676	12,972	135,000	0	193	150,841
10	Other	797	43,633	27,786	62,497	19,239	4,219	3,565	23,208	17,172	262,863	464,979	591,489	141,480	29,959	193,140	1,421,047
11	**Total consumption**	5,377	203,431	267,233	190,451	38,772	19,589	13,043	52,061	46,644	447,444	1,284,047	905,818	422,159	261,056	477,563	3,350,644
12	Imports of goods and services	2,131	93,697	17,703	29,630	12,494	2,688	1,250	8,096	9,186	55,968	232,842	233,513	5,777	48,979	78,709	599,821
13	Taxes less subsidies on products	21	2,197	9,059	8,380	170	185	-126	6,441	6,139	26,653	59,120	113,603	-297	33,658	11,227	217,310
14	Taxes less subsidies on production	13	2,300	4,134	11,564	803	368	66	0	91	7,105	26,444					26,444
15	Compensation of employees (Calibration)	14	312	65	78	12	78	68	33	291	277	1,229					1,229
16	Compensation of employees (Testing)	13	743	425	223	41	670	253	150	482	893	3,893					3,893
17	Compensation of employees (Non-measurement)	3,267	107,312	67,817	173,137	54,386	18,470	6,269	61,440	66,999	403,506	962,602					962,602
18	Gross operating surplus	1,643	65,931	96,840	75,200	30,238	4,673	5,913	25,172	23,416	454,940	783,966					783,966
19	Gross value added	4,950	171,648	169,281	260,202	85,479	24,259	12,570	86,795	91,279	866,721	1,778,134					1,778,134
20	**Total output**	12,518	475,884	463,276	488,664	136,915	46,722	26,737	153,393	153,248	1,396,786	3,354,143	2,158,752	849,798	604,750	1,045,062	8,012,505

FIGURE 1A
Domestic-Use IOMT (at basic prices), 2016

		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
		Instrumentation	Manufacturing	Other production	Wholesale, retail and transport	ICT	Technical testing and analysis	R&D	Central gov. activities	Health	Other	Total intermediate demand	Households	Gov. and NPISHs	GFCF	Exports	Total demand
1	Instrumentation	98	1,137	148	15	96	53	3	905	1,945	112	4,513	43	0	3,087	5,544	16,207
2	Manufacturing	1,482	72,238	4,853	14,926	1,079	1,485	370	5,104	6,657	9,010	117,203	162,988	5,775	41,463	72,068	422,123
3	Other production	0	14,045	9,925	74	0	156	0	0	0	513	24,712	352	2	0	63	25,796
4	Wholesale, retail and transport	64	627	126	4,895	152	0	0	0	0	603	6,467	16,367	0	0	6	23,444
5	ICT	47	417	37	806	8,073	72	11	4	0	1,729	11,196	434	0	0	0	13,446
6	Technical testing and analysis	33	683	202	262	27	147	26	2	0	648	2,028	585	0	0	0	3,435
7	R&D	0	0	0	0	0	0	446	0	0	0	446	0	0	4,427	0	5,319
8	Central gov. activities	0	0	85	146	0	278	0	23	0	335	867	0	0	0	0	1,503
9	Health	0	0	0	0	0	0	0	0	6	0	6	1,465	0	0	0	1,477
10	Other	142	4,912	2,328	8,508	3,066	498	393	2,058	578	43,019	65,502	51,279	0	2	1,029	164,358
11	**Total**	1,867	94,058	17,703	29,630	12,494	2,688	1,250	8,096	9,186	55,968	232,941	233,513	5,777	48,979	78,709	677,108

FIGURE 1B
Imports-Use IOMT (at basic prices), 2016

The IOMTs serve two primary purposes:

- For the improved comprehension of the reader, it draws together key information from each chapter of this report, thus providing an overview, in tabular form, of where each source of measurement activity originates from.
- It expands upon the aggregated figures in the report by showing the intermediate transactions that take place within the economy, thereby revealing the interdependency between measurement and other sectors.

Each chapter of the following report investigates the role of measurement from a specific standpoint. The IOMTs serve as a structural framework that brings together the results of each chapter, thus providing the reader with a holistic view of the report. There is a two-way relationship between the chapters of the report and the IOMTs: on the one hand, each chapter pertains to a certain part of the IOMTs; on the other hand, the IOMTs makes use of the results of each chapter, plus additional information from the IOATs, to expand on the information found in the report:

- Chapter 2 analyses labour required to generate measurement outputs. The goal of this chapter is to estimate the number of people employed in the UK who use instruments as a share of total employment. The IOMTs estimate the wages earned by workers producing measurements by industry (A15:P17).
- Chapter 3 estimates investment in instrumentation. This refers to acquisitions of instruments that are used to produce other goods and services, rather than instruments that are installed as components of other machinery and equipment. These figures feature in the IOMTs under GFCF, which is the proxy used for investment (N1).
- Chapter 4 examines the demand for measurement goods that are used as inputs that are either transformed or used up in the production process. The IOMTs allows us to estimate the distribution of consumption of instrumentation across different industries (A1:J1).
- Chapter 5 examines the role of metrology (the science of measurement) in the economy. The goal of this chapter is (a) to quantify the amount of funding that is allocated to projects that focus on measurement, and (b) estimate the economic benefit of such research using widely accepted economic theory. The IOMF expands on this by computing the consumption of instrumentation by the R&D industry (G1).

Lastly, the IOMTs add additional insight by estimating the inputs of the Instrumentation industry (A:A).[2]

2 For further detail on the IOMTs see (NPL, 2021.a)

2 LABOUR INPUT

In any market, output is the result of a combination of inputs which typically consist of labour and capital. This section focuses on the former. Taking intricate measurements to a high degree of accuracy is often vital, particularly in industries where output is subject to stringent regulation (e.g. Pharmaceuticals), requiring the knowledge of highly skilled technicians and engineers. It is anticipated that these estimates will form the majority of all value that is created through measurement activity.

This section aims to estimate the number of people employed in the UK who use instrumentation in their work. This is achieved through a thorough analysis of Standard Occupational Classification (SOC) codes.

Highlights:

- In 2017, 6.3% of total UK employment was comprised of occupations that involve taking measurements. The total compensation offered to employees in these measurement occupations was £58.3bn, accounting for 2.8% of GDP.
- 35.7% of all employees in the Technical testing and analysis industry and 14.3% of all employees in the R&D industry are in occupations with strong measurement responsibilities (CAL or T&A).
- The average wage of employees within CAL and T&A occupations is £30k, 4% more than the national average wage
- Between 2007 and 2017, the number of employees in measurement related occupations rose by 13% – 4 percentage points more than overall employment over the same period – to a total of 2 million. This was mostly driven by an uplift in CAL and T&A occupations.
- Measurement specific services employed around 162,000 people in 2017
- Despite rising employment, real annual pay awarded to employees providing measurement services has declined by 20% over 10 years between 2007 and 2017.

2.1 KEY DATA SOURCES

In this section we introduce data on employment, organised by occupation, from three different ONS publications:

- **Census 2011**[3]: The UK census is a survey of the entire population, conducted once every 10 years, where the results are collated into various tables that provide detailed demographics. For this analysis, we are specifically interested in table *CT0144 – occupation by industry*. This is an irregular matrix with occupations along the columns and industries down the rows. Any number within the table represents the number of people employed for a certain occupation by employers within a certain industry. Unfortunately, the most recent census was published in 2011. Nonetheless, there is overlap with our time series here and there is no other dataset with a sample size as large that combines occupational and industry data.

3 (ONS, 2011.b)

- **Annual population survey (APS)**[4]: Due to the age of the census, we use it in conjunction with the APS. The APS has the largest coverage of any household survey, usually returning about 320,000 responses. The differences between the APS and the Census are that the non-discriminatory data collection of the Census supplies in-depth statistics on multiple variables, whereas the APS provides an aggregated count of occupation totals that omits workers under 16, communal establishments apart from NHS housing and student in halls of residence, and members of the armed forces whom are not in private accommodation. However, the benefit of the APS data is that, as the name suggests, it is collated every year including for the time period we are concerned with, 2007-2017.
- **Earnings and hours worked, occupation by four-digit SOC code (ASHE Table 14.7a)**[5]: Annual estimates of paid hours worked and earnings for UK employees by sex, and full time and part time, by occupation. Specifically, Table 14.7a is for annual, gross pay. Gross pay includes wages and all other earnings/benefits. ASHE is based on a 1% sample of employee jobs taken from HM Revenue and Customs (HMRC) Pay As You Earn (PAYE) records and all estimates of pay are accompanied by coefficients of variation (cv) that indicate the quality of the estimate.

In each dataset, occupation is based on the current Standard Occupation Classification 2010 (SOC 10) codes. In total there are 369 4-digit SOC codes, providing enough detail for us to select specific occupations that likely involve the use of measurement equipment. These are conveniently ordered into nine major groups which bring together occupations that are similar in terms of the qualifications, training, skills and experience commonly associated with the competent performance of work tasks.

2.2 METHODOLOGY

The method for finding the labour input required to take measurements relies on a thorough analysis of SOC codes. A fine sift through all SOC codes, assisted by an ONS occupation coding tool, leaves behind an assortment of measurement related occupations that can be organised into four groups based on how strongly the responsibilities of that occupation pertain to carrying out measurements.

The occupation coding tool matches inserted text against the SOC 10 Volume 2 coding index.[6] Some keywords entered to direct our search for relevant SOC codes include “measure”, “test”, “technician”, “analyst”. To ensure we capture all relevant occupations, we referred to our list of instruments included in the capital stock (see Table 8BC – this list is founded on a methodology explained in Chapter 4) and considered occupations that use those instruments but did not appear in the initial search. For example, a veterinarian may not relate to any of the key words, but they will often use measurement tools like cardiographs. Each SOC code comes with a detailed description of the occupation and a list of responsibilities it may involve.

Figure 2A represents the basic thought process behind the grouping of occupations that involve taking measurements. The further from the point of the pyramid a group is, the more loosely those occupations are linked to measurement. This becomes our first assumption, ***A1***:

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4 (ONS, 2018.a)

5 (ONS, 2018.c)

6 (ONS, 2019)

A1: Selected SOC codes capture all employees that use instruments to make measurements as a requirement of their job and can be divided into one of four groups that indicate the strength to which that occupation pertains to measurement.

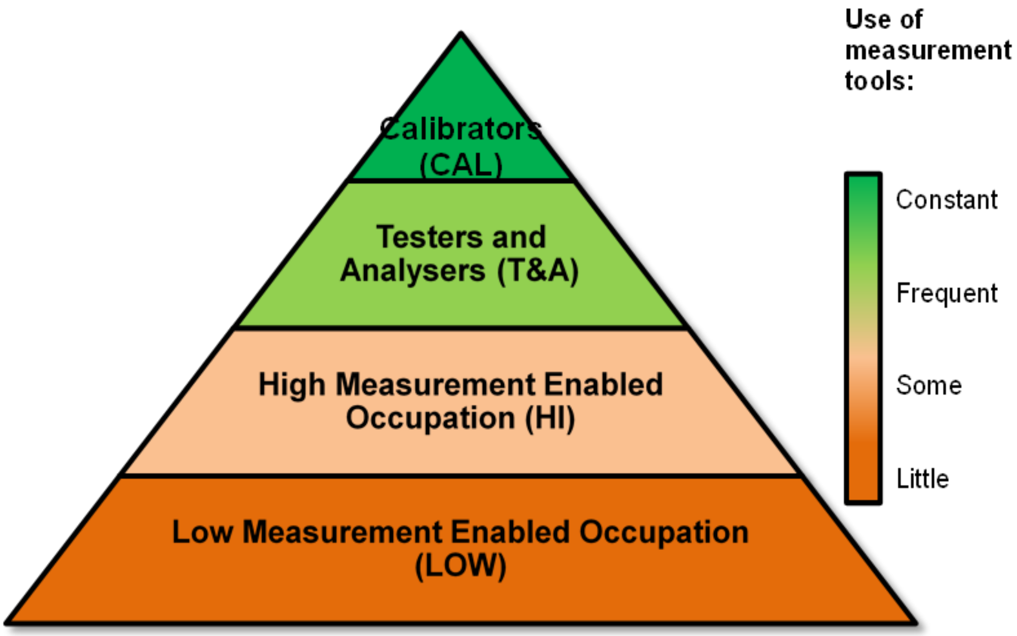

FIGURE 2A
Graphical representation of the grouping of SOC codes that contain reference to measurement

CAL: The top level of occupations includes all persons whose job may involve calibrating machinery and equipment to ensure accurate measurements. Examples of these include Laboratory technicians and Cardiographers. There are four occupations within this group. It is important to note here that, due to the limited detail provided by SOC codes, not all employees within this group will hold jobs where the primary function is to provide calibration services. However, we assume that all employees in the UK economy who practice calibration to some degree are accounted for by the selected SOC codes and that all jobs that fall under those codes are heavily reliant on measurement. Therefore, CAL represents the sum of employees for whom providing calibration services is a major part of their job, CAL(1), and employees for whom providing calibration services is a minor part of their job, CAL(2).[7]

T&A: The second level of occupations includes all persons whose job it is to conduct tests and make measurements for either quality control, research or medical purposes. Examples of these include Medical radiographers and Routine inspectors and testers. There are eight occupations within this group. Using a similar logic applied to CAL occupations, not all employees within the T&A group hold jobs where the primary function is to provide testing services. Rather, T&A captures all employees in the UK economy who practice testing and analysis to some degree and is the sum of employees for whom providing testing services is a major part of their job, T&A(1), and employees for whom providing testing services is a minor part of their job, T&A(2). Irrespective of this distinction, all T&A occupations are significantly reliant on measurement.[8]

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7 Mathematically, this is: CAL = CAL(1) + CAL (2)

8 Similar to CAL: T&A = T&A(1) + T&A(2)

HI: The third level of occupations includes all persons who carry out measurements on a frequent basis but whose job function is neither to test nor calibrate. The objectives of such occupations are aided by, and often dependant on, making sophisticated measurements. These include engineers and veterinarians. There are 15 occupations within this group.

LOW: The bottom level represents occupations where testing and measuring is a necessary part of the job but is one of many duties or tasks of similar importance. These are often simple measurements that can be read off a piece of apparatus. Examples of these include Paramedics and TV engineers. There are six occupations within this group.

Table *CT0144* of the 2011 Census disaggregates the total employment of each occupation by industry. Industries are classified by three-digit Standard Industrial Classification 2007 (SIC 07) codes of which workers are allocated to by the primary SIC code of their employer. Understanding which industries employees work within indicates which sectors of the economy are most measurement intensive and allows us to conduct a more nuanced analysis by subtracting from our results employees within industries that are unlikely to be related to measurement.[9]

Since the Census is only produced once every 10 years, we have based our results on the APS which is available every year for the entire time series, 2007 – 2017. The APS merely supplies us with the total number of workers within each SOC code, thus, we have attempted to disaggregate these by industry. We estimate these figures by multiplying the total employment of an occupation, as stated in the APS, by a vector of ratios of which each unit represents the fraction of workers of that respective occupation working within a particular industry, based on the 2011 Census. These ratios are constant over the time series. The following equation summarises this final step:

$$L_{i,o,t} = APSl_{o,t}\left(\frac{Cl_{i,o,11}}{Cl_{o,11}}\right) \qquad \textbf{E[3.1]}$$

Where L is labour input, APSl is employment as stated in the APS, Cl is employment as stated in the Census, i is industry, o is occupation and t is the time period – in this case, the year. Finally, multiplying the number of employees in each occupation by their respective average annual gross pay, we have calculated an estimate for the cost of labour input required to make measurements.

2.3 RESULTS

Figure 2B summarises the key findings. On average, an employee with a CAL/T&A occupation earns 5% more, roughly £1.5k, per year than an employee in an occupation that requires the use of instrumentation but is otherwise not related to either calibration or testing (i.e. HI + LOW occupation groups). The average annual wage for a CAL occupation was 15% below the overall average UK wage (£29k) in 2017, but 13% above for a T&A occupation.

9 For example, because we have included SOC *3218, Medical and dental technicians*, our totals will include more than 6% of all employees working within *dental practice activities*, making it one of the most measurement intensive industries. However, based on the description of the SOC code, we have made the judgment that dental technicians do not feature in any of the four tiers of workers who take measurements and thus we can eliminate them from our results by subtracting all those employees accounted for under the SIC code *86.23 - dental practice activities*.

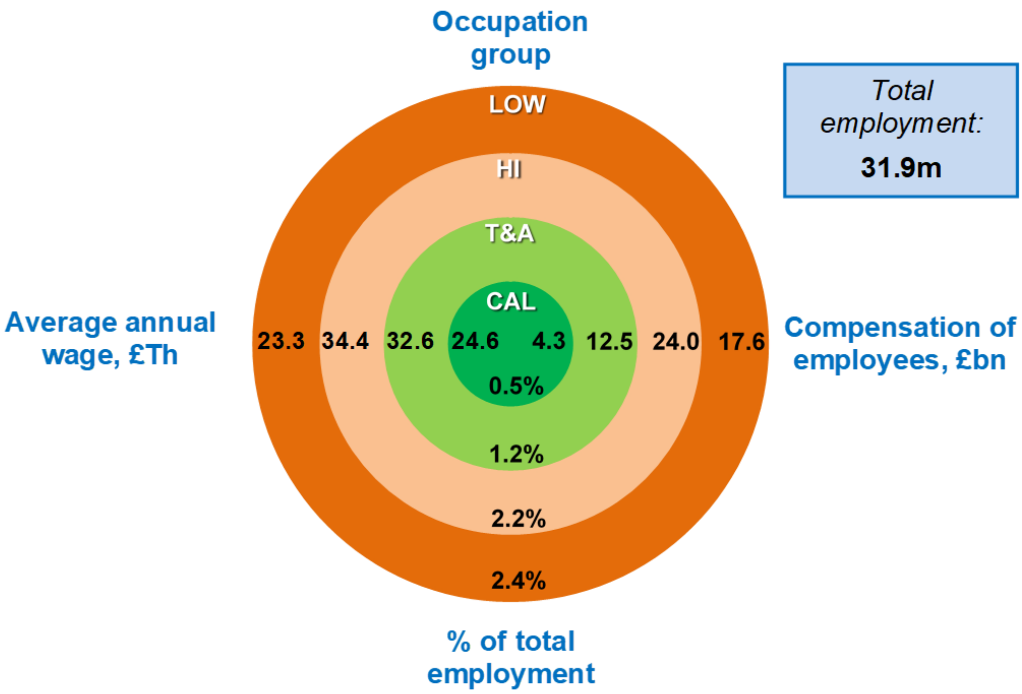

FIGURE 2B
Summary statistics for labour input required to use instrumentation in the UK economy (2017)

Figure 2C reveals the measurement *intensity* of each industry. The top 6 most measurement intensive industries are *Maintenance and repair of motor vehicles and motorcycles* (70.2%), *Technical testing and analysis* (48%), *Defence activities* (45.7%), *Energy and water* (19.6%), *Scientific research and development* (19.2%) and *Construction* (18%). These industries have a high proportion of their total employment being measurement occupations. Even at the lowest end of the scale, 1.9% of employment in both *Banking and finance* and *Agriculture and fishing* are workers whose tasks include taking measurements, demonstrating the economy wide necessity for measurement.

Although true that more than 70% of all employment within the *Maintenance and repair of motor vehicles and motorcycles* industry are workers in occupations that involve taking measurements (i.e. a measurement occupation), this can be slightly misleading as the vast majority of these workers are counted under the SOC code *5231: Vehicle technicians, mechanics and electricians*, a LOW measurement occupation, which by nature correspond strongly to SIC codes *45.2* and *45.4*. Tasks required by this job include “visually checking, test driving or using test equipment to diagnose engine and mechanical faults” and “reassembling, testing, adjusting and ruing the appropriate parts, systems or entire engine”, so, while the result is valid, it is less relevant to measurement than some other industries, as indicated by only 1.1% of employment in the same industry being CAL and T&A occupations. Furthermore, *Maintenance and repair of motor vehicles and motorcycles* is a relatively small industry compared to other industries with lower measurement intensities. For example, in 2017, the total employment of the *Construction* industry was more than six times greater than the *Maintenance and repair of motor vehicles and motorcycles* industry and employed almost 100,000 more workers in measurement occupations. See *Figure 8BA* for full employment of measurement occupations by industry estimates.

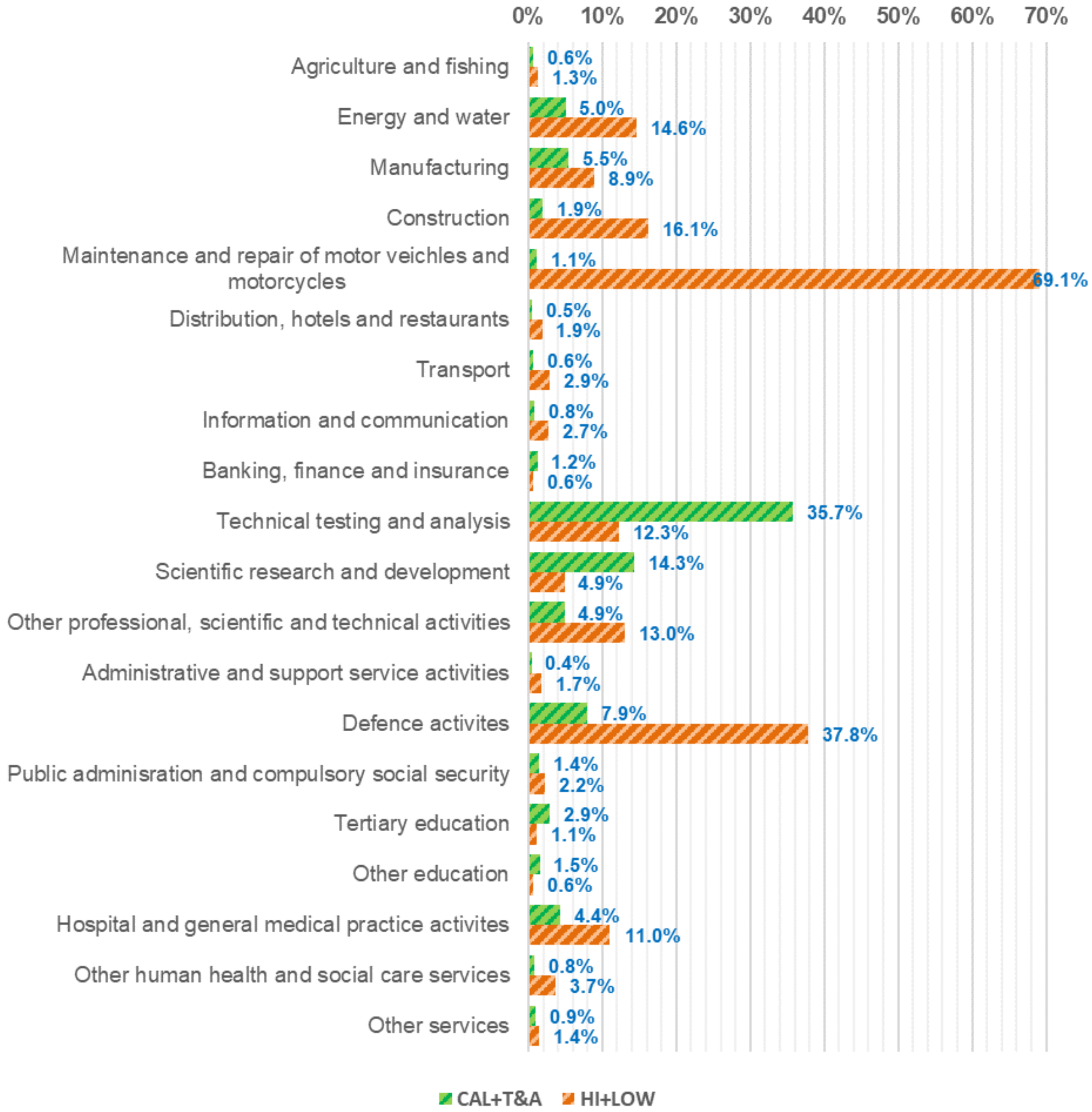

FIGURE 2C
Employment of occupations that require the use of measurement tools as a percentage of total employment, by industry (2017)

A quarter of industries listed have more CAL and T&A workers than HI and LOW (Technical testing and analysis, Scientific research and development, Tertiary education, Other education, Banking and finance), and there are eight industries where CAL and T&A workers alone make up more than 2% of all employment:

1	Technical testing and analysis	**35.7%**
2	Scientific research and development	**14.3%**
3	Defence activities	**7.9%**
4	Manufacturing	**5.5%**

5	Energy and water	**5.0%**
6	Other professional, scientific and technical activities	**4.9%**
7	Hospital and medical practice activities	**4.4%**
8	Tertiary education	**2.9%**

Figure 2D displays how the labour input involved in measurement activity has changed over time. Over ten years, the total number of workers employed in occupations that require measurements to be taken has risen by 13% from 1.8m to 2m. This has increased at a faster rate than the overall employment of the economy which was raised by 9% over the same period. Much of the uplift in measurement related jobs is driven by CAL and T&A occupations which increased by 17% between 2007 and 2017.

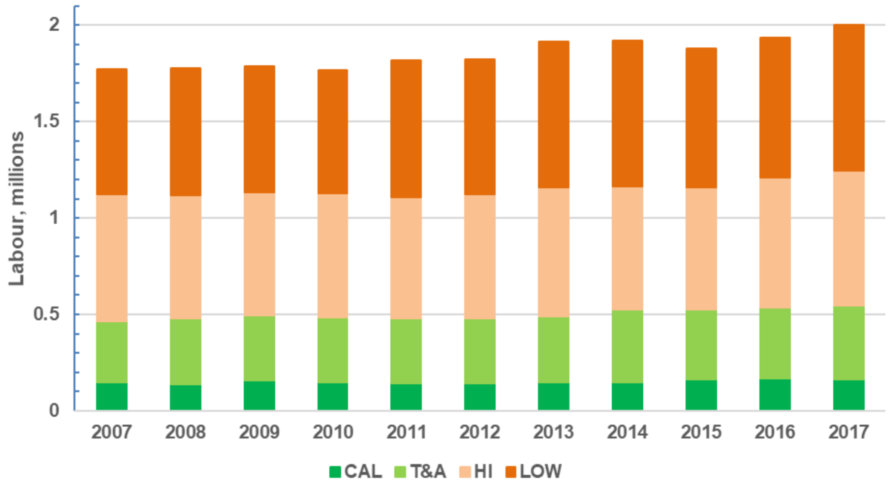

FIGURE 2D
Total employment within occupations that require the use of measurement tools (2007-2017)

2.4 MEASUREMENT SERVICES

This section attempts to draw further detail from the findings reported in section 3.3 by distinguishing CAL(1) from CAL(2) and T&A(1) from T&A(2) . While all jobs categorised under CAL and T&A involve practicing calibration or testing to some degree, only a subset of those jobs exist for the primary purpose of providing measurement services (i.e. calibrating and/or testing products and processes). This subset of employees forms the labour input for the calibration and testing sector.

Context on the calibration and testing sector

Calibration is the comparison of an instrument against a reference or standard to identify and correct for errors in the instrument readings. Instrument users wanting to make good quality measurements or ensure that industry specifications are met will need their instruments to be calibrated with an accuracy and precision that fits their intended purpose.

NPL sits atop of a chain of measurements that uphold national standards – the UK National Measurement System (NMS). The NMS is the technical and organisation infrastructure which ensures a consistent and internationally recognised basis for measurement in the UK.[10] Its central objectives are:

- to enable individuals and organisations in the UK to make measurements competently and accurately;
- to demonstrate the validity of such measurement;
- and to coordinate the UK's measurement system with the measurement systems of other countries.

Alongside NPL at the top layer of the NMS are five other core laboratories, known as the NMS labs.[11] The NMS labs have the capacity to support metrology in several fields, from mass and nuclear metrology to chemical analysis, fluid flow and biometrology. They underpin the UK's technical infrastructure by supplying services to commercial calibration laboratories, who then go on to calibrate the instruments of their own customers, diffusing measurement accuracy through a chain of linked calibrations. For example, NPL holds the national standards; this knowledge can be sold to commercial calibration labs who are then able to use techniques to calibrate the instruments of their customers or validate that their customer's products meet their desired specification, thus enabling them to signal high quality goods traceable to national standards.

This 'fan-out' of national measurement standards extends the reach of the NMS to thousands of organisations across the UK. Consequently, once an instrument user receives one calibration, they may use that knowledge as reference to calibrate any number of their own similar instruments or products – this is referred to as 'in-house' calibration. In-house calibration is not specific to any particular industry because instrumentation is useful in multiple sectors, hence why there are no available national statistics that quantify the scale of these activities.

The testing sector uses measurement tools and theories to test the characteristics and performance of products. Their services assure consumers, businesses and government institutions of the safety and quality of the products they buy and sell with specific regard to British, European and International standards. Companies whose primary service is to provide testing services are conveniently grouped into one SIC 07 code, ***72.1*** *Technical Testing and Analysis*. It is a sub-category of section M in the SIC classification, *Professional, scientific and technical activities*. Businesses in the industry offer a wide range of services including acoustics and vibration testing, testing of composition and purity of minerals (etc.), testing of physical characteristics and performance of materials. However, within many sectors, testing is often a vital stage in the production process and can also occur in-house.

Methodology

This method captures the cost of labour for all calibration activity – traceable and in-house – and testing activity. It is based on a similar methodology to the labour input estimates (section 3.3).

A1 states that there are four SOC 10 codes that capture all employees in the economy whom part of their job is to calibrate instruments and there are eight SOC 10 codes that capture all employees in the economy whom part of their job is to use instruments to test.

10 (Department of Trade and Industry, 1989)

11 The six NMS labs are: National Physical Laboratory (the UK's National Measurement Institute), National Measurement Laboratory at LGC (chemical and biometrology), National Engineering Laboratory (fluid flow metrology), Office for Product Safety and Standards (legal metrology), National Gear Metrology Laboratory (gears metrology), National Institute for Biological Standards and Control (bioactivity metrology).

CAL occupations		T&A occupations	
SOC 10	**Description**	**SOC 10**	**Description**
3111	Laboratory technicians	**2111**	Chemical scientists
3115	Quality assurance technicians	**2112**	Biological scientists and biochemists
3218	Medical and dental technicians	**2217**	Medical radiographers
5224	Precision instrument makers and repairers	**2434**	Chartered surveyors
		2461	Quality control and planning engineers
		3119	Science, engineering and production technicians
		8133	Routine inspectors and testers
		8134	Weighers, graders and sorters

TABLE 2A
CAL and T&A occupations

It is acknowledged that employees within these occupations spend only a fraction of their time calibrating instruments or testing with instruments, hence why the findings from section 3.3 only make a claim on the value of all measurement related jobs rather than the value of what is strictly measurement activity. We have attempted to refine these estimates by taking a fraction of the employment from each of the 12 SOC codes listed above to represent CAL(1) and T&A(1). These fractions correspond to the number of tasks that involve calibration or testing out of all tasks required by the job listed in the ONS description of the SOC codes.

For example, the ONS lists eight tasks carried out by Precision Instrument Makers and Repairers of which two relate to calibration ("tests, adjusts and repairs precision and optical instruments" and "checks prepared parts for accuracy using measuring equipment, assembles parts and adjusts as necessary using hand and machine tools"). Hence, we assume that roughly 25% of a Precision Instrument Maker/Repairer's is spent on calibration activity and therefore our final estimate will reflect 25% of valued added by the work of Precision Instrument Makers and Repairers. A full list of these decisions can be viewed in *Table 8BA* and *Table 8BB*.

It is acknowledged that, because one's job can be broken down into any number of tasks depending on how specifically they are described, it is likely that the fractions of time spent calibrating or testing are slightly inflated and, thus, the resulting estimates of employment and contribution to value added by those employees should be considered upper bound values. Nonetheless, all occupation tasks have been scribed by the ONS to provide an all-encompassing description of employment, leading us to believe that there is some uniformity in the importance of the tasks listed. Therefore, we can reasonably assume that each task attributed to a SOC code holds equal weight.

Once we have calculated our refined estimates of CAL and T&A employment to represent CAL(>) and T&A(>) employment, we apply the same methodology to these figures, as in section 3.3, to estimate the cost of labour of the calibration and testing sectors by industry. For simplicity, and to highlight the sectors of most importance, the results are presented by the grouping of industries listed in *Table 2B*.

Sector	SIC 07
Manufacturing	10-33
Other production	05-09, 35-39
Wholesale, retail and transport	45-53
ICT	61-63
Technical testing and analysis	71.2
Research and development	72
Central government activities	84
Health	86
Other	All else

TABLE 2B
Grouping of SIC 07 industries into broad sectors

Results

In 2017, we estimate that the total number of employees in the calibration and testing sector was around 162,000. The total compensation offered to these employees sums to just under £4bn.

In terms of employment, the calibration and testing sector has grown by 14% in the 10 years between 2007 and 2017. Ranked below are the number of employees with calibration or testing jobs as a percentage of total employment in each industry in 2017.

1	Technical testing and analysis	**20.5%**
2	Research and development	**4.0%**
3	Manufacturing	**1.6%**
4	Health	**1.1%**
5	Other production	**0.7%**
6	Central government activities	**0.5%**
7	Other	**0.3%**
8	ICT	**0.2%**
9	Wholesale, retail and transport	**0.2%**

These figures hint at the interdependency between measurement and different industries; the ranking represents which industries are most or least measurement intensive.

Despite almost consistently rising employment between 2007 and 2017, over the same period, change in compensation awarded to those employees has been relatively unstable. In real terms, compensation of employees in the calibration and testing sector has declined by 7% in 10 years from £5.33bn to £4.96bn, reaching as low as £4.52bn in 2013.

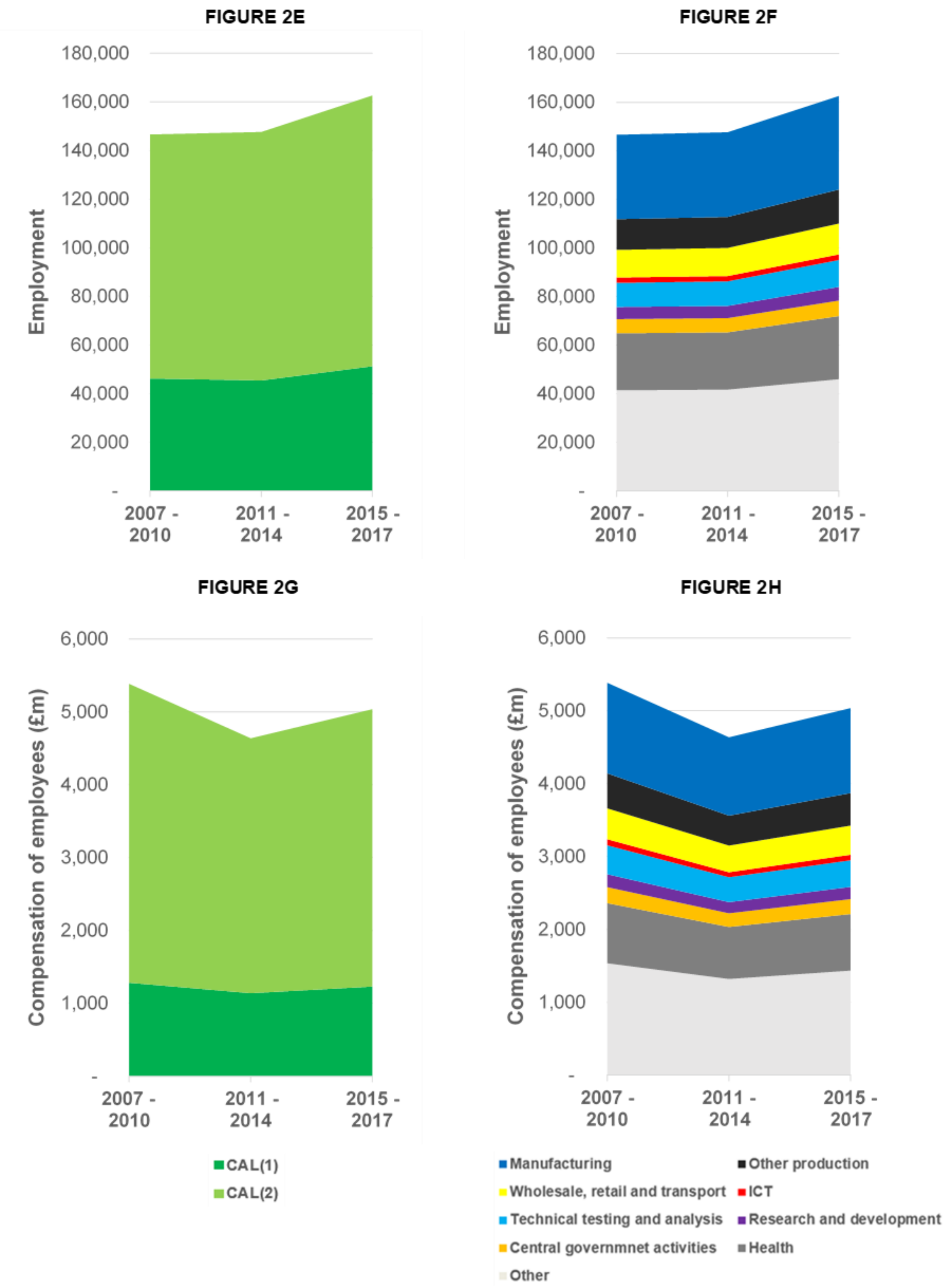

FIGURE 2E-H
Average annual employment and compensation of employees of the calibration and testing industry by occupation and sector(2007 – 2017)

These two opposing forces are largely a result of stagnating wages for calibration and testing jobs. *Figure 2I* plots the real annual pay for jobs that provide measurement services over time. Overall, real annual pay for employees who provide measurement services has declined by 20% in the 10 years between 2007 and 2017.

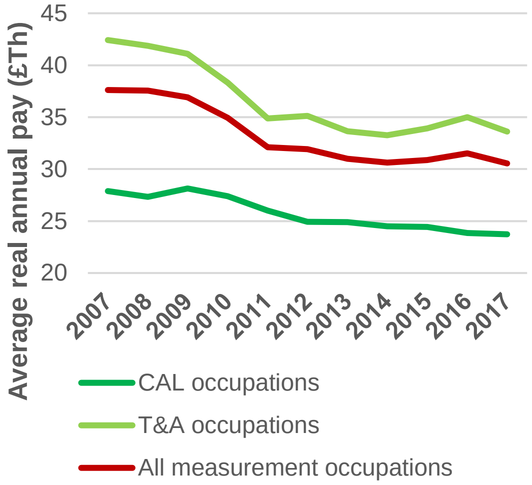

FIGURE 2I
Average real annual pay (2007 – 2017)

LinkedIn Research

To further validate the findings laid out above we pursued an alternative method for estimating the size of the calibration and testing sector which produced similar results.[12]

This method was designed to utilise the wealth of employment data collated from members of the professional social network LinkedIn (linkedin.com) whom self-report their employment history on the website. This crowd-sourced dataset has two main advantages: firstly, the data is highly granular including specific job titles rather than occupation categories; secondly, whereas for national statistics a significant amount of time passes between the initial data collection and publication of the results, employment data on LinkedIn changes instantaneously and therefore provides near real time estimates.

By manipulating LinkedIn advanced search filters, we conducted a comprehensive search for members in the UK currently employed in a calibration or testing related job. The result of this operation represents the segment of the UK calibration and testing sector workforce that are members of LinkedIn. To account for those who are not members of LinkedIn, we once again engaged the LinkedIn advanced search filters to find that, of a sample of UK companies who are likely to employ measurement staff, the median percentage of their employees on LinkedIn is 63%.[13] This step accounted for industry bias in the estimate.

Using this method, we arrived at a lower bound estimate for the employment of the calibration and testing sector of 146,000.[14]

Future iterations of this research may seek to gain further insights into the size and structure of the calibration and testing sector by utilising more LinkedIn advanced search filters such as ‘industry’, ‘years of experience’ and ‘level of education’.

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12 For full methodology and results, see: (NPL, 2021.b)

13 The World Bank Group (WBG) recently partnered with LinkedIn to generate metrics on skills, employment by industry and talent migration using LinkedIn’s rich employment data. Their methodology highlights that “*LinkedIn data are best at representing skilled labour in knowledge-intensive sectors*”: (Juni Zhu, Fritzler, & Orlowski, 2018)

14 Based on data extracted from LinkedIn on 03/08/2020.

3 INVESTMENT

Highlights:

- Investment in instrumentation has increased annually, amounting to just over £3.6bn in 2017. This figure accounts for 4.1% of all productive and tangible assets and 7.2% of all machinery and equipment.
- Instruments for Health and Life Sciences and Engineering, Manufacturing, Utilities and Construction account for 58% and 38% of the UK's total investment in instrumentation, respectively, in 2017.
- In 2017, we estimate that the gross capital stock of instrumentation was valued at £36.8bn, 0.5% of the UK's gross capital stock with instruments for Health and Life sciences accounting for 57% (£20.8bn).

In the context of this report, investment in instrumentation refers to acquisitions of those instruments that are used directly to make measurements, rather than instruments that are installed as components of other machinery and equipment. Throughout this analysis we use the widely collected economic variable 'gross fixed capital formation' (GFCF) as a proxy for investment. The ONS defines GFCF as '*the acquisition less disposals of produced fixed assets; that is, assets intended for use in the production of other goods and services for a period of more than a year*'.[15] This distinction becomes crucial in the following analysis.

3.1 ECONOMIC FRAMEWORK AND CONCEPTS

Careful inspection of the ONS published Input-Output Analytical Tables (IOATs) uncovers the second assumption of this report which unlocks the path to calculating the annual investment in instrumentation.

Packaged withing the IOATs are the Use Tables which provide a picture of the flows of products and services in the economy for a single year and are used to set the level of GDP. The values within the Use Tables represent the demand for products and services and are disaggregated by component of total demand. One of the components of total demand is GFCF.[16]

The IOATs are produced roughly every 5 years as needed for the national accounts rebasing of constant price estimates. Recent versions use the Classification of Products by Activity 2008 (CPA 08) classification for products and SIC 07 classification for industries. Unfortunately, these data alone are not useful to us because it is impossible to separate instrumentation from the other products they are grouped amongst in broader CPA/SIC codes. The last IOATs to be published based on these classifications was in 2010. Prior to that, the IOTs were based on the IO 123 classification. This was a more detailed industry grouping that divided the economy into 123 parts meaning that the groups themselves often represent more intricate, specific industries. One of these groups solely represents instrumentation – *76: Medical and Precision Instruments*.[17]

For the purposes of this analysis we scrutinised the two most recent IOATs based on the IO 123 classification; these are the 1995 and 2005 tables. Taking the row for the product *76* in

15 (ONS, 2018.b)

16 For more detail on the IOATs see: (NPL, 2021.a)

17 The ONS published a full list of IO123 codes, translating them into SIC07 codes (ONS, 2011.a)

both domestic-use and import-use tables, comparisons can be made of the overall change in the components of total demand, as well as the change in the domestic to imported ratio of each, over the time period. *Figure 3A* summarises these changes:

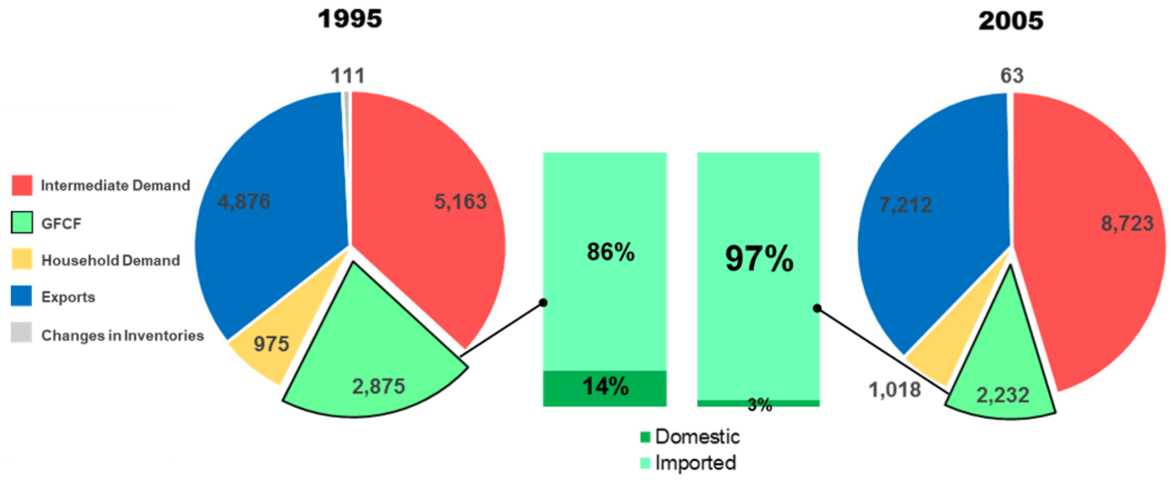

FIGURE 3A
76: Medical and Precision Instruments Total Demand, £m (basic prices)

The variable we are most interested in for the purposes of this section of the analysis is GFCF. The illustration above shows that over the decade the overall investment in instruments has shrunk significantly, in favour of intermediate demand. Simultaneously, the proportion of investment in instrumentation that is imported increased, represented by the bars in the centre of *Figure 3A*. In 1995, the vast majority of investment in instrumentation, 86%, was imported, increasing to 97% in 10 years. We postulate that this is not an unusual economic change given the highly specialised nature of instrumentation. There are many branches of instrumentation, each of which require specific plant machinery and expertise to produce. Due to high costs it is more beneficial for countries to specialise in an area of instrumentation, or none at all, and to import others from more efficient overseas producers. This is the principal of comparative advantage. Rapid technological change during the analysed period stimulated an increasingly globalised economy, possibly encouraging the UK to close domestic instrumentation plants to obtain gains from international trade in this sector. Thus, since 2005, it is likely that this domestic-imported ratio has either remained the same or converged closer to becoming 100% imports. Henceforth, we make our second assumption, ***A2***:

> **A2:** The UK imports **all** investment in instruments that are used for the production of goods and services for a period of more than one year (i.e. 100% of instrumentation GFCF is imported).

3.2 KEY DATA SOURCES

Assuming ***A2***, detailed data on the UK's imports of instrumentation is required. The Observatory of Economic Complexity (OEC) provides just that.

The OEC is a tool created by Alexander Simoes, co-founder of Datawheel, which "*allows users to quickly compose a visual narrative about countries and the products they exchange*".[18] It

18 (OEC, 2019.a)

serves to calculate a variable of complexity of a country's outputs which supposedly indicates a degree of economic development.

"The complexity of an economy is related to the multiplicity of useful knowledge embedded in it" and "*is measured by the mix of these products that countries are able to make. Some products, like medical imaging devices* [a type of instrument] *or jet engines, embed large amounts of knowledge and are the results of very large networks of people and organizations. These products cannot be made in simpler economies that are missing parts of this network's capability set. Economic complexity, therefore, is expressed in the composition of a country's productive output and reflects the structures that emerge to hold and combine knowledge."*[19]

The OEC tool employs an expansive database of trade data for 221 countries, including the UK, spanning over more than 50 years. All data is classified either by SIC codes or Harmonised System (HS) codes. Each classification has various iterations as they are updated every 5 years or so to adjust for structural changes in the economy. For the years 1995 – 2017 the OEC data is complete by the HS 92 classification. HS 92 comprises more than 5,000 commodity groups, accounting for over 98% of the merchandise in international trade, each identified by a six-digit code. All types of instrument are grouped between sections 90 – 92; 230 individual products in total.[20]

For the assumption ***A2*** to apply, the recorded imports of the product corresponding to IO 123 code *76* from the IOTs and the recorded imports of instruments from the OEC data must be identical variables. *Table 3A*, below, compares these values:

	1995	**2005**
OEC **recorded** value of instruments[21]	$**7,824** million	$**15,744** million
OEC value of instruments imports, converted to Pounds Sterling[22]	£**4,957** million	£**8,656** million
Import-use IOATs **recorded** total demand for *76*	£**5,151** million	£**8,715** million

TABLE 3A
Data comparison between the IOATs and the OEC data for the imports of instruments

While the two data sources are not exact, they are evidently measuring the same variable. Some of the error may be accredited to the imperfect method of converting the OEC imports data, given in $USD, to £GBP using historic exchange rate yearly averages. The rest is so small in terms of the scale of the variables that it is largely negligible, meaning that we can credibly assume that the value of imports of instrumentation recorded in the OEC data represents 100% of investment.

3.3 METHODOLOGY

To recap:

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19 (OEC, 2019.b)

20 See (United Nations, 2019) for more information on HS 92

21 Values taken from: (OEC, 2019.c)

22 Converted $USD to £GBP using the annual average exchange rate. Data acquired from *poundsterlinglive.com.*

- in *3.1* we find through the IOATs that the UK imports the vast majority of its investment in instrumentation. Furthermore, the proportion of imported-to-domestic investment in instrumentation increased further over the first decade of the time series and is likely converging towards 100%, thus, allowing us to make the assumption ***A2***. And,
- in *3.2* we show that we can delve further into the investment in instrumentation aided by instrumentation imports data from the OEC and by applying assumption ***A2***. These data are comparable with the product group *76: Medical and Precision Instruments* of the IO 123 classification in the IOATs.

By a combination of these datasets, some assumptions and technical intuition we can calculate figures for the investment in instrumentation.

Extracting the UK imports of instrumentation data, classified by HS 92, for 1995 – 2017 from the OEC provides us with the import value of each specific product, within which we assume under ***A2*** is 100% of investment. As we know from the IOATs, each of these products are categorised under one or more of the following three components of total demand:

- **Intermediate demand:** Goods that are used as inputs and are either transformed or used up in the production process.
- **GFCF:** Goods that are assets intended for use in the production of other goods and services for a period of more than a year.
- **Household demand:** Goods that are complete, ready to be sold, often to households, by the tertiary sector.

Using these definitions and our best judgment we have attempted to categorise each specific product of instrumentation into one of these three components of total demand. This is our third assumption, ***A3***:

A3: Each specific instrument is a fraction of either intermediate demand, GFCF or household demand in the total demand for instruments.

In some cases, a specific product of instrumentation could have multiple purposes leading it to belong to two categories. In this scenario we split the total value of that instrument 50:50 amongst both categories because with the available data it is impossible to know for certain by what proportion the instrument is divided into components of total demand. There are no cases in which an instrument belongs to all three categories.

Table 3B gives different examples of the specific instruments, how they've been categorised and the reason for doing so.[23] Applying the same logic to all instrumentation HS 92 codes gives estimates for the imports of instrumentation by component of total demand. Because the HS 92 classification remains consistent over the time period we can apply the same categorisation of instruments in every year we have data for. These estimates are summarised in *Figure 3B*.

23 Full categorisation of instruments into their components of total demand can be found in *Table 8BC*.

HS92	Description	Examples	Component of total demand	Reasoning
900110	Optical fibres, except for telecommunications	Light guides Imaging optics	Intermediate demand	Specifies not for telecommunication use. Often consumed by manufacturers in the production of other goods that use optical fibre technology.
900130	Contact lenses	Contact lenses	Household demand	Contact lenses are complete goods intended for household consumption.
901820	Ultraviolet or infrared ray apparatus	Lamps Transilluminators	Gross fixed capital formation (GFCF)	These are instruments that are complete pieces of machinery to be used in a laboratory. In this classification, “apparatus” is often a buzzword for an item of capital.
901831	Syringes, with or without needles	Syringes	Inter-mediate demand	Syringes are one-use goods. They will not enter the capital stock of instruments in the following year and are therefore not classified under GFCF. Typically used in healthcare, thus, cannot be household demand.
902580	Hydrometer, pyrometer, hygrometer, alone or combined	Hydrometer Pyrometer	Intermediate demand / GFCF	It is not possible to differentiate any further between these types of products, so we assume that half of the total investment in this class of instruments belong to each category. This product has the highest import value of all instruments, and so carries a lot of weight in our final estimates.
920210	String musical instruments, played with a bow	Violins Cellos	Household demand	Musical instruments are also included in the data. Most musical instruments have been categorised as household demand as they are most commonly considered consumer goods. Despite the highly specific product group, musical instruments account for an almost negligible amount of instrumentation imports (roughly 2%).

TABLE 3B
Examples and explanation of the categorisation of instruments into components of total demand

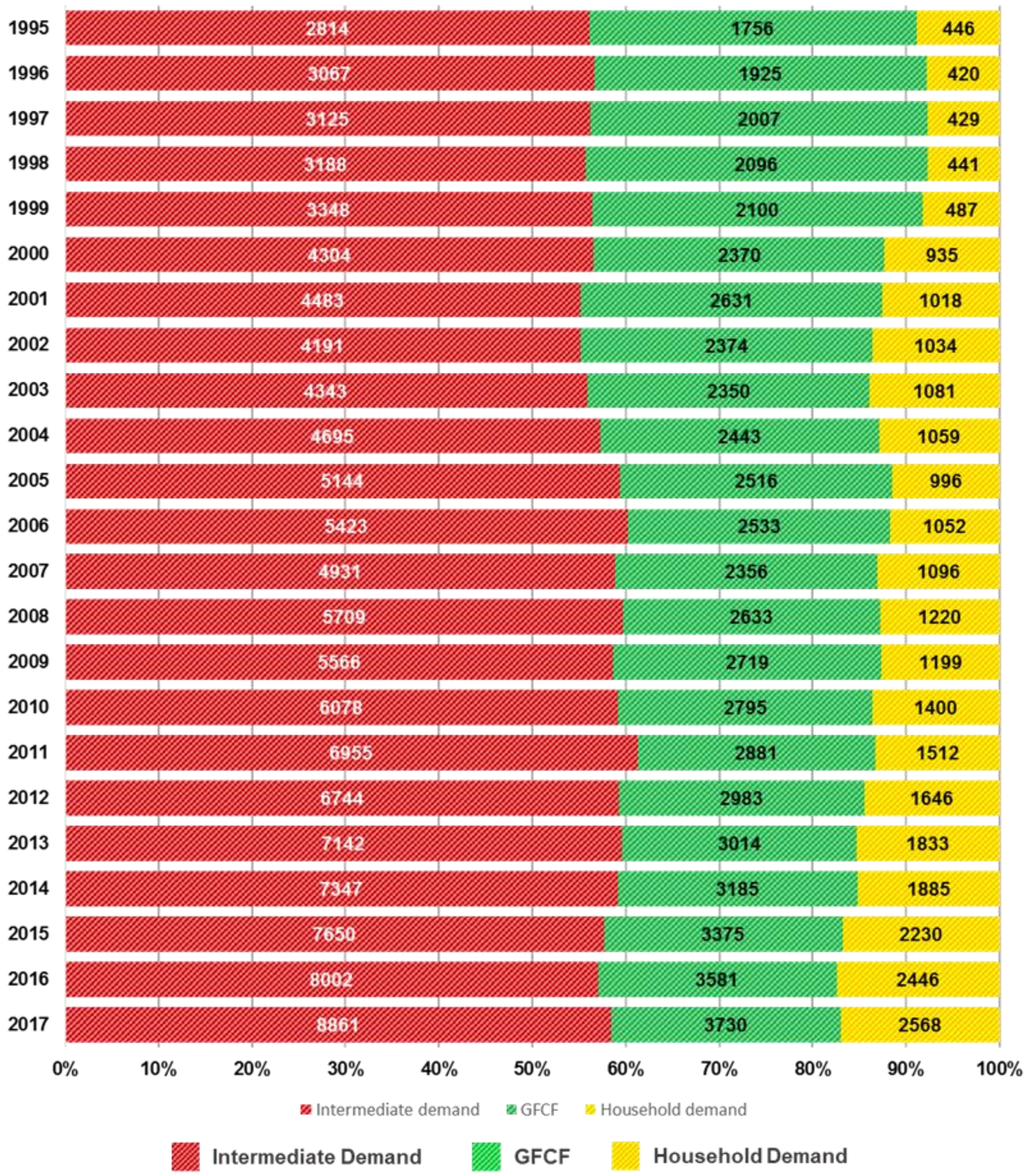

FIGURE 3B
Estimated composition of total demand for imports of instrumentation (1995 – 2017). Values are in £millions at current prices).

According to these first estimates, the proportion of imported total demand for instrumentation that is investment gradually reduces by 10% over the 22-year period. We can gauge their accuracy by comparing them with the real figures for these variables which we know for the years 1995 and 2005, courtesy of the IOTs. The estimates for 2005 appear to be statistically strong. Investment is overestimated by 4% which is mostly compensated for by an underestimation in intermediate demand of 5%, leaving household demand overestimated by 1%. In contrast, the estimates and actual figures for components of total demand for imported instruments do not align so closely in 1995. Investment is underestimated by 13%, intermediate demand is overestimated by 18% and household demand is underestimated by 4%. *Figure 3C* portrays this skewness between the estimated and actual figures in 1995 next to the relative accuracy of that in 2005.

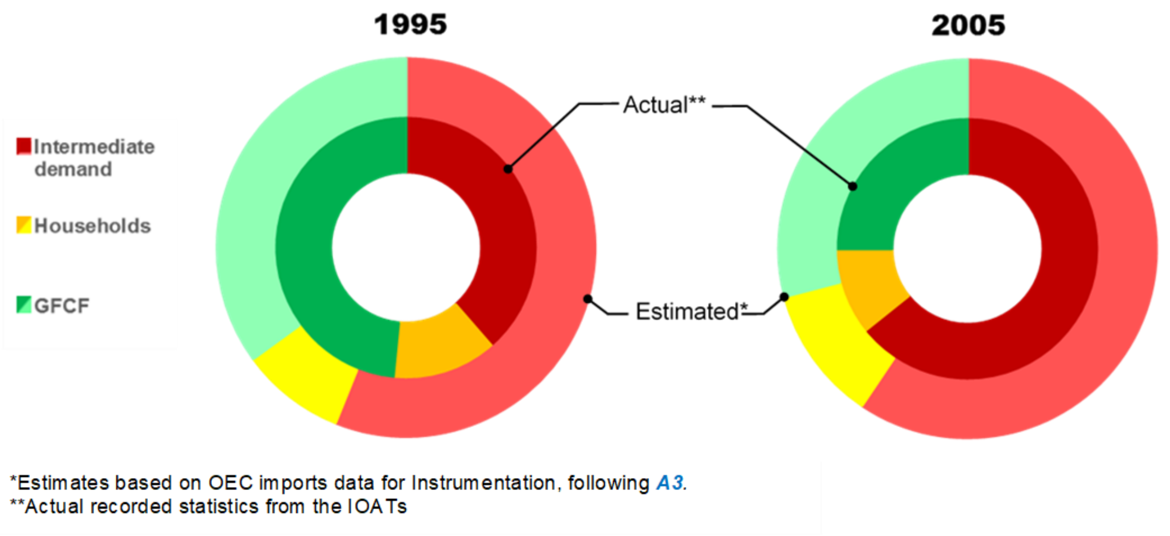

FIGURE 3C
The estimated composition of total demand for imports of instrumentation against the actual composition of that.

The apparently stark differences between our estimated and actual figures in 1995 are not alarming, but to be expected. Over the first 10 years of our time series, bookended by periods for which we have data on instrumentation from the IOATs, the rate of technological change begins to accelerate. It tells us that, within those product groups that contain a combination of goods that are GFCF and one other, before the beginning of the 21st century the UK imported more instruments that enter the capital stock than it did instruments that are incorporated as components of other pieces of machinery. A logical explanation for this is that as time progressed, so did technological change bringing with it waves of new innovations that depend on measurement, thus expanding the uses for instrumentation that is of the intermediate demand type. Additionally, the absolute value of investment in instrumentation decreased over the period.[24]

Disaggregating by Instrument Type

The high granularity of HS 92 product groups allows us to draw even more insightful conclusions than just the overall investment in instrumentation. With the aid of expert opinion, it is possible to bundle the instrument products into categories of which their primary use is.

Firstly, it is important to strip out instruments that are not relevant to measurement in our calculations (e.g. musical instruments, photocopiers).[25] We are then left with only instruments that are used to make measurements which we assign to one of the following three instrument types which reflect their primary use:

- **Health and Life Sciences**: Consists of instruments that are used to make measurements for medical or other scientific purposes. These are predominantly used by the Healthcare and Research and Development sectors and includes instruments such as electro-cardiographs and stereoscopic microscopes.
- **Engineering, Manufacturing, Utilities and Construction**: Consists of instruments that are used to make measurements of gases, fluids and electrical currents, within

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24 To combat these structural changes to the economy, our analysis includes upper and lower bound estimates for the investment in instrumentation. The process for calculating these can be found in Chapter 8.1.

25 Table 8BC lists all HS 92 codes that are considered instruments for the purpose of measurement.

extraction or production processes, or on construction sites. These are often crucial in the operation, maintenance and inspection of goods and services and can have multiple applications across a range of sectors. Instruments in this category include chromatographs, spectrometers, and rangefinders.

- **Transport and Communication**: Consists of instruments that are used to take measurements related to time and location. These are distinguished from Engineering, Manufacturing, Utilities and Construction instruments as they have a narrower set of applications. The precise measurement of time and location is required for some services provided by the Energy, Telecoms, and Finance sectors, but Transport and Communication instruments are particularly important in Aerospace and Defence and Manufacture of Transportation sectors. Instruments in this category include navigational instruments and appliances and time of day recording apparatus.

All instruments considered to be used for measurement purposes have been placed into one of these four types of instrument. This is our fourth assumption, ***A4***:[26]

A4: HS 92 instrumentation products can be categorised by one of the following three types which reflect the primary use for those instruments: Health and Life Sciences, Engineering, Manufacturing, Utilities and Construction, and Transport and Communication.

From this, we get an idea of the UK's most instrument intensive sectors.

3.4 RESULTS

Figure 3D displays the overall annual investment in instrumentation in constant prices (2017=100).[27]

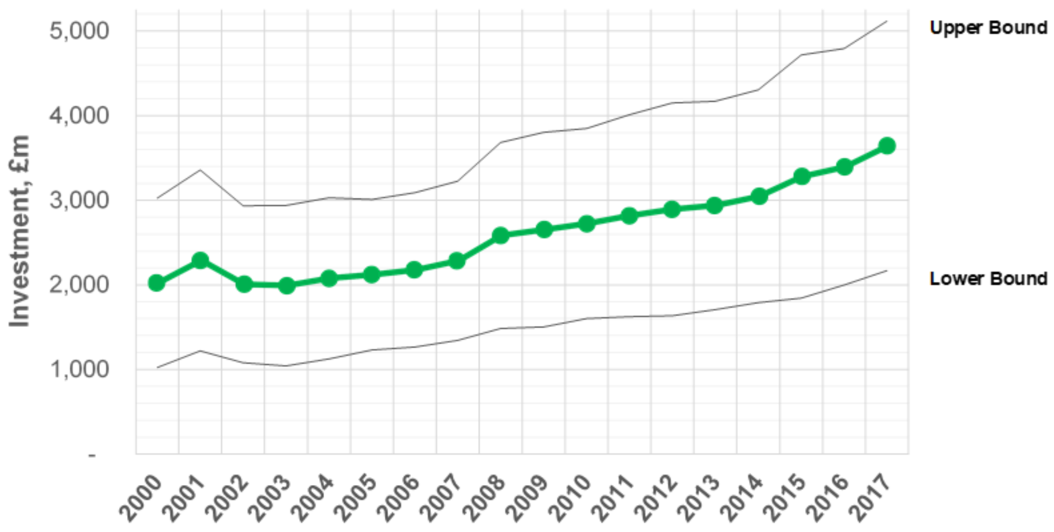

FIGURE 3D
Annual investment in instruments, constant prices (2000 - 2017)

Since 2003, in real terms, investment in instrumentation has increased annually, peaking at just over £3.6bn in 2017. This accounts for 1% of all investment in the UK economy that year.[28]

26 Table 8BC indicates the categorisation of instruments by ***A4***.

27 All estimates in this document given in constant prices have been calculated with 2017 as the base year.

28 Normalised by UK annual GDP figures (ONS, 2018.d)

There is a near continuous upward trend which could suggest that the industry for manufacture of instrumentation is resilient to typical economic cycles. This becomes more apparent when comparing the annual investment in instrumentation against that of other assets.

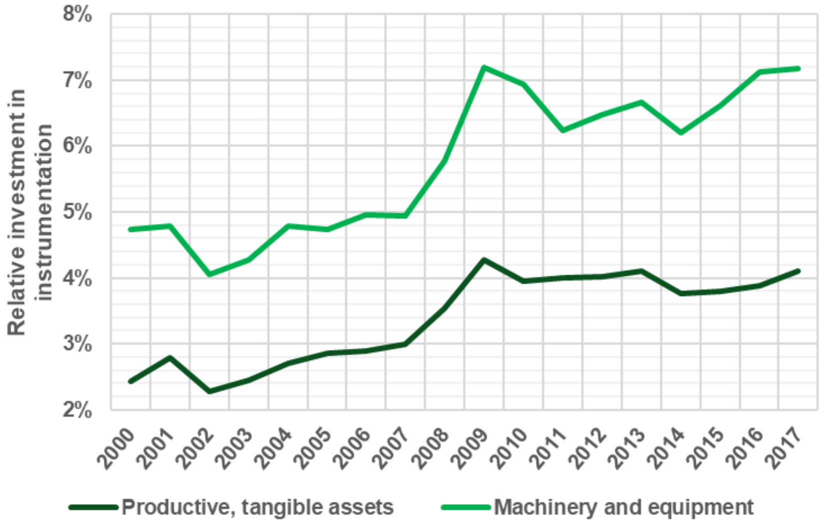

FIGURE 3E
Annual investment in instrumentation as a percentage of investment in other assets (1997-2017)

By eliminating unproductive assets (dwellings and buildings) and intangible assets (intellectual property products) from total GFCF figures, we find that instrumentation accounted for 4.1% of investment in productive, tangible assets in 2017 – rising by 1.7 percentage points in nearly 20 years.[29] Even more specifically, in the same year, investment in instrumentation accounted for 7.2% of investment in all machinery and equipment – an increase of two percentage points in nearly 20 years.[30]

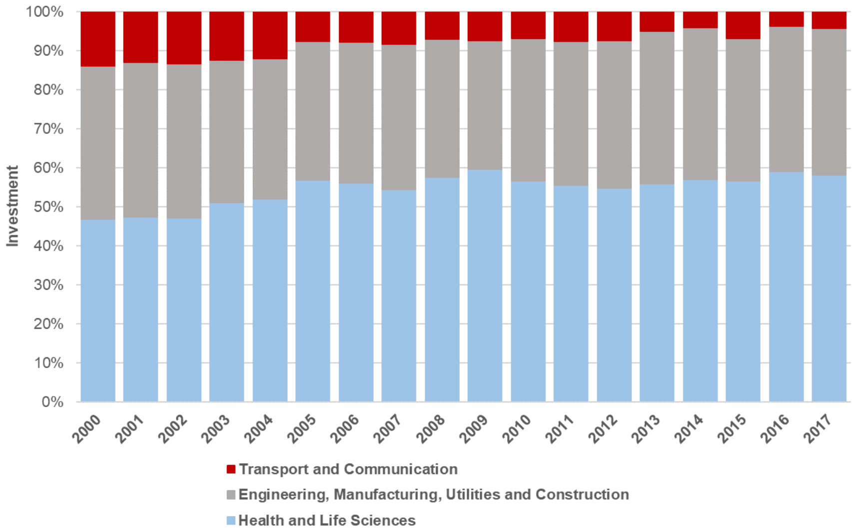

FIGURE 3F
Composition of annual investment in instruments used to make measurements by sector (2000-2017)

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29 Normalised by aggregate UK GFCF figures (ONS, 2020.a)

30 Machinery and Equipment is an asset category of which Instrumentation must be a subset of. The ONS recognises five top level asset categories: Machinery and equipment; Cultivated assets; Dwellings; Other buildings and structures; Intellectual property products (IPP). (ONS, 2017)

In 2000, instrumentation for Health and Life Sciences and Engineering, Manufacturing, Utilities and Construction made up 86% of total investment in instrumentation. In the 17 years since then, the dominant area of investment in instrumentation has shifted away from Engineering, Manufacturing, Utilities and Construction and towards Health and Life Sciences, each claiming 38% and 58% of total instrumentation investment, respectively, in 2017. During this period, annual investment in instruments for Health and Life Sciences increased by 120% – 1.75 times more growth than investment in instruments for Engineering, Manufacturing, Utilities and Construction.

Simultaneously, investment in instrumentation for Transport and Communication has seen its share of total instrumentation investment decline by 10% over the same period. In real terms, annual investment in these instruments was 47% less in 2017 than it was in 2000.

3.5 CAPITAL STOCK

This section of the analysis attempts to extrapolate an annual capital stock of instruments from our investment estimates, using a combination of economic theory and assumptions based on existing studies.

The capital stock of instruments is the value of all instruments that are classed as 'fixed assets' still in use in a given period. Knowing this parameter grants the opportunity to compare the scale of instrument usage in the perspective of the whole economy, for which capital stock data is collected comprehensively.

Economic Framework and Concepts

There are two types of capital stock – net and gross. The OECD definitions of these two terms are:

- **Net capital stock** – the sum of the written-down values of all the fixed assets still in use when a balance sheet is drawn up. That is, the value of the capital stocks after depreciation.[31]
- **Gross capital stock** – the value of all fixed assets still in use when a balance sheet is drawn up; it is valued at the actual or estimated current purchasers' prices for new assets of the same type irrespective of the age of the assets.[32]

To clarify: the net capital stock is the current value of all fixed assets which depreciates at a constant rate over its estimated lifetime. For example, an instrument with an estimated lifetime of 10 years acquired in year 0 will contribute half its original value to the capital stock in year 5. The gross capital stock is the same calculation, but without the depreciation factor. In other words, the original value of an asset is calculated in the capital stock in every year until it reaches the end of its estimated lifetime, after which it exits the capital stock entirely.

For the purposes of this analysis we will be calculating a gross capital stock of instrumentation. There are two main reasons for this:

1. It opens a window for an additional estimate of the labour input required to use instrumentation. When considering the relationship between capital and labour is not necessary to account for the devaluation of capital because although an instrument made in period t will have a lesser value in period t+1, it requires the same quantity of labour to operate it in both years.

31 *OECD definition of net capital stock* (OECD, 2001)

32 *OECD definition of gross capital stock* (OECD, 2003)

2. The gross capital stock is the simpler calculation, therefore there is less chance of error in our estimates.

The formula used in our estimation for gross capital stocks is as follows:

$$K_t^a = \sum_{i=0}^{x-1} GFCF_{t-i}^a \quad \textbf{E[3.1]}$$

Where a is the type of asset, t is the time period, and x is the estimated lifetime of the asset.[33]

Determining Lifetime of Instruments

To determine the x variable in our capital stock calculations, we have drawn from a handful of existing studies based in various economies that attempt to estimate the lifetimes of particular assets and asset types.[34]

The relevant findings of these studies are summarised in *Table 3C* below:

Source	Year	Asset type	Economy	Lifetime
Statistics Netherlands	1993-2001	Machinery and equipment of the industry: *Research and development*	Netherlands	11 years
US Bureau of Economic Analysis (BEA)	2003	Instruments	United States	12 years
Statistics South Korea	2011	Medical instruments	South Korea	14 years
Statistics South Korea	2011	Measuring and testing instruments	South Korea	13 years
Statistics South Korea	2011	Optical instruments	South Korea	11 years

Table 3C
Estimates of the average lifetime of an instrument from previous studies

Three studies, all based in different economies, quote lifetimes for instruments, ranging from 11 to 14 years. In each study the instrument variable is measured differently, as indicated by the ‘asset type’ description. Of these variables, the Statistics Netherlands study has the weakest link to instrumentation, aggregating the average asset life of all machinery and equipment that exists on the books of Dutch research and development organisations. This has a strong link to instrumentation but neither solely nor entirely captures it – this study also happens to be the oldest of the three. A study by the BEA in the US estimates that ‘instruments’ have an average lifetime of 12 years, and a more recent study by Statistics Korea is even more specific, giving various estimates, based on the general type of instrument, that range from 12 to 14 years.

33 The ONS estimates gross capital stock using the following equation: [GFCF this period – Last year’s gross stock – Assets at end of life – Loss from scrappage]. (ONS, 2018.b). ***E[3.1]*** accounts for the first three variables, but not the latter. Loss from scrappage usually occurs when a firm goes into liquidation and discards all its capital, exiting the capital stock. There is currently no means to estimate this variable using available data, especially not in a form consistent with our instrumentation investment estimates, and therefore we have excluded it from our calculation. Although it is likely that this is only a trivial fraction of the capital stock it means it is possible that we have slightly overestimated the labour input required to use instruments.

34 All data sources are referenced in: (Rincon-Aznar, Riley, & Young, 2017)

All estimates are within a sensible range, but we have decided not to take the midpoint of these because asset lifetime estimates are typically integers. Instead, we have given more weight to the estimates at the upper end of the range because these are given by the most recent Statistics Korea study in 2011. Measuring and testing instruments and medical instruments, of which our GFCF of instrumentation data primarily consists of, have estimated asset lives of 13 and 14 years, respectively. However, the same study estimates that optical instruments have an average lifetime of 11 years - this, and the BEA study, informs us to assume that instruments have an average lifetime of 13 years. Even though this is greater than the BEA study by 1 year, we believe it is a sensible assumption because machinery and equipment lifetimes appear to trend upwards over time.

A5: The average life time of an instrument is **13 years**.

Key Data Sources

All auxiliary data within this section is sourced from the ONS to ensure consistency. The benefit of this is that data exists for a multitude of variables across the whole time series and are often reported by industry codes consistently based on the SIC 2007 classification. We pull in national statistics obtained from the following ONS publications:

- **Gross and net capital stocks for total UK economy, by industry and asset[35] –** This dataset lists the capital stock of industries by two-digit SIC codes. Capital stock is divided by asset type. In our calculations we have excluded dwellings, other buildings and structures, and intellectual property products to give a capital stock of ‘productive, tangible assets. This is then used to provide an estimate of measurement intensity within each industry.

Methodology

Using the gross capital stock equation ***E[3.1]*** in conjunction with ***A5***, we can calculate the gross capital stock of each type of instrument for the years 2007 to 2017 (where *a* is the type of instrument). Because we assume that instruments die after 13 years, 2007 is the first year for which we have all the investment data that contributes to that year’s capital stock. Prior to 2007, instruments that were invested in in the years 1994 and previous, for which we do not have data, should be calculated in the capital stock, hence we would underestimate these figures.

Results

In 2017, we estimate that the gross capital stock of instrumentation was valued at £36.8bn, 0.5% of the UK’s total gross capital stock – a proportion which has remained roughly constant over the 10-year period.

In nominal terms, the gross capital stock tends to increase year on year because new investment in capital tends to be greater than the value of the old capital that ceases to exist. However, *Figure 3G* shows that the total gross capital stock of instrumentation consistently increases, in real terms, suggesting that measurement technology and metrology are deemed to be important for growth in the modern economy.

The overall capital stock of instrumentation increased at a slower rate between the years 2010 and 2012, likely due to below average investment in all sectors of the economy in the fallout of the 2008 economic crash two years prior, before accelerating again. Most growth occurs in

35 (ONS, 2020.a)

the latter half of the time series; in 10 years, the gross capital stock of instrumentation as a percentage of all productive, tangible assets raised from 2.2% to 2.4%.

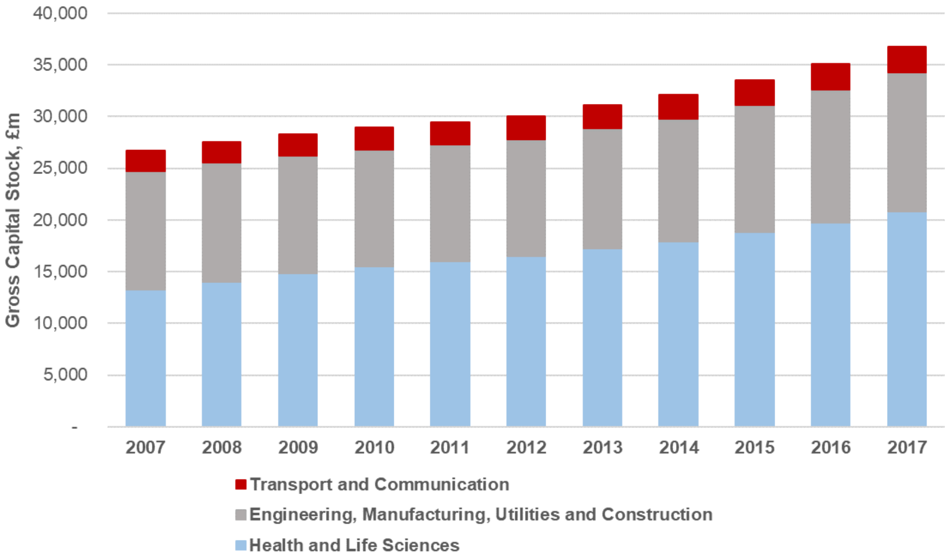


FIGURE 3G
Gross capital stock of instrumentation by sector* (2007-2017)

Like with investment, the increase in the gross capital stock is predominantly driven by instruments for Health and Life Sciences which account for £20.8bn (57%) of the total alone – up from 50% in 2007. This has largely come at the cost of below average investment in instrumentation for Engineering, Manufacturing, Utilities and Construction over the same time, reducing its proportion of the total gross capital stock of instrumentation from 43% to 37%.

Our results can be represented in terms of the growth in the gross capital stock of each instrument type *relative to the overall growth in all productive, tangible assets* in the UK economy. The following graph, *Figure 3H*, was constructed by plotting the gross capital stock of instruments by type along with total productive, tangible assets, indexing at 2007 and normalising by total productive, tangible assets in each respective year.

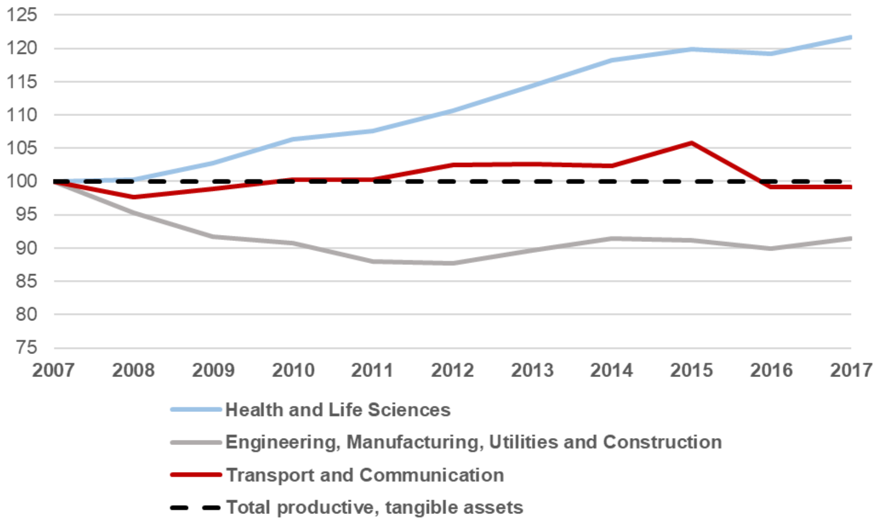


FIGURE 3H
Growth in gross capital stock of instrumentation, by sector, relative to change in total productive tangible assets (2007-2017, 2007=base year)

The output shows that, over the 10 years between 2007 and 2017, the capital stock of Construction and Transport and Communication instruments has grown roughly on par with the capital stock of all productive, tangible assets. In the same time, Health and Life Science instruments have grown roughly 20% more and Engineering, Manufacturing, Utilities and Construction instruments have grown roughly 10% less.

4 INTERMEDIATE DEMAND

So far, we have only considered the value of instrumentation that has retained its identity as a piece of measurement apparatus or equipment. Outstanding is the portion of instrumentation spend for goods classified as intermediate demand, defined in Chapter 4 as:

Intermediate demand: *"Goods that are used as inputs that are either transformed or used up in the production process."*

This chapter attempts to calculate intermediate demand for instruments, both domestic and imported.

Highlights:

- Intermediate demand for instrumentation has increased, in real terms, from £6.8bn to £9bn between 2008 and 2017 while the proportion of these instruments demanded by each sector has remained relatively constant.
- Throughout the period, the UK has become increasingly dependent on imports of instrumentation for intermediate input. This peaked at 60% in 2017.

4.1 KEY DATA SOURCES

Calculating domestic manufacture of intermediate instruments separate from imported intermediate instruments requires one data source for each part:

ProdCom[36]: The UK manufacturers' sales by product (ProdCom) presents annual statistics on the value and volume of products manufactured in the UK. While ProdCom data is collected by Eurostat for all EU countries, the data used in this analysis has been published by the ONS. The ProdCom statistics concern all manufactured products included in the EU ProdCom list, covering businesses active in the mining, quarrying and manufacturing sectors (CPA 08 Sections B and C: 8-33). Data are collected via questionnaire from a sample of approximately 21,500 businesses and 3,800 products. A non-linear estimation method is used to estimate for non-sampled businesses. Products are classified by 8-digit codes which have been derived from the Statistical Classification of Economic Activites in the European Community (NACE) Rev. 2 and the Classification of Products by Activity (CPA). An 8-digit ProdCom code has three layers. The first 4 digits are taken from NACE (of which SIC codes are derived from) and digits 5 and 6 from the CPA. The remaining digits specify the product in more detail. For example:

- ***26.51*** *Manufacture of instruments and appliances for measuring, testing and navigation*
    - ***26.51.11*** *Direction-finding compasses; other navigational instruments and appliances*
        - ***26.41.11.20*** *Direction finding compasses (including magnetic, gyroscopic, binnacle and position finding)*
        - ***26.41.11.50*** *Instruments and appliances for aeronautical or space navigation (excluding compasses)*

36 (ONS, 2020.c)

- ***26.41.11.80*** *Instruments and appliances for navigation (including for marine or river navigation) (excluding for aeronautical or space navigation, compasses)*

The granularity of this classification makes the analysis possible. ProdCom codes have remained largely the same throughout the period 2008 – 2017, however, there are instances where codes have been merged or deleted to improve the quality of data collection. Each product has also been matched to one or more corresponding Combined Nomenclature (CN) codes. CN is an EU classification that takes reference from HS to be comparable with external trade statistics. Data is published annually and exists in this format from 2008.

OEC: Provides the value of imports of instrumentation to the UK by product (refer to Chapter 3.2).

4.2 METHODOLOGY

Estimates for the value of domestic production of instruments for intermediate demand are achieved by gathering all 8-digit ProdCom codes that correspond to a CN product between 900110 and 920999. The majority of instruments are within Division 26, highly concentrated within code 26.51 in particular, but there are a handful of instruments within Divisions 27, 28 and [32]. CN codes of corresponding products also have up to 8 digits but to be comparable with our imports data we only take the first 6.

Because ProdCom codes are linked to CN codes which are linked to HS codes we can eliminate the ProdCom codes that do not relate to instruments that take measurements and implement ***A3*** to divide the remaining codes into the four main types of instrumentation.[37] This is possible for all but one code which groups ‘parts and accessories’ together. This portion has been labelled as ‘unidentifiable’ instrumentation.

Estimating the value of imports of intermediate instruments follows the same method we used for calculating the GFCF of instrumentation, detailed in Chapter 3, but for intermediate demand.

4.3 RESULTS

Figure 4A displays both domestic and imported annual expenditure on instrumentation indented for use as an intermediate good by type of instrument, in real terms. In total, annual expenditure on intermediate demand for instrumentation has been trending upwards over the last decade, but the UK has become increasingly dependent on imports of these goods in the last three years of the analysed period. In 2017, more than £9bn was spent on instrumentation that we have classified as intermediate demand. Of that value, 60% accounts for imported instruments – the largest annual proportion throughout the period analysed (2008-2017).

Engineering, Manufacturing, Utilities and Construction equipment makes up the largest fraction of intermediate demand for instruments (64% in 2017) primarily because, by definition, intermediate demand for instrumentation largely consists of goods that are internalised into another piece of machinery – work that is most frequently carried out by the manufacturing sector. In the manufacture of instruments for this purpose, the UK boasts a successful domestic market, peaking at almost £2.8bn worth of sales in 2014 alone. Our estimates show that, usually, this is supplemented by imports of similar goods of an equal magnitude although, post 2014, domestic production of in instrumentation for Engineering, Manufacturing, Utilities and Construction has consistently declined resulting in these becoming an import dominated goods.

37 Eurostat has provided a graphic that shows visually the system of classifications that link HS to PRODCOM (Eurostat, 2020)

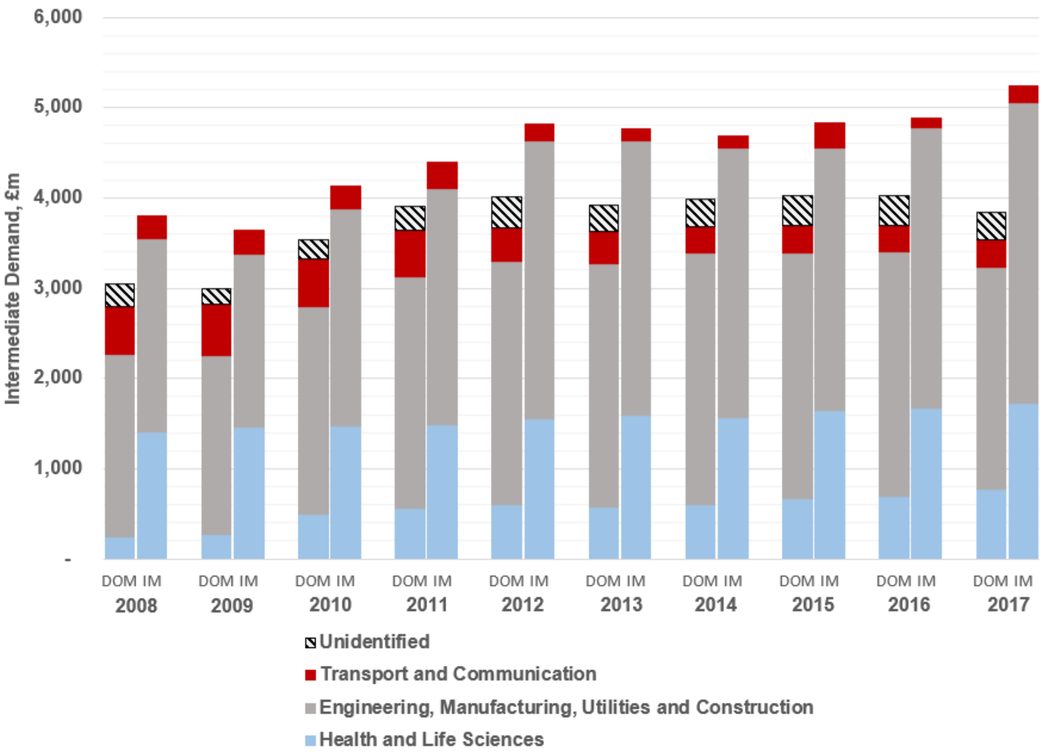


FIGURE 4A
Annual expenditure on domestic and imported instrumentation for intermediate use, constant prices (2008-2017)

The UK has been consistently growing its domestic market for instruments for Health and Life Sciences over the past decade. Since 2008, domestic production of these instruments has more than trebled, generating a value of £775m by 2017.

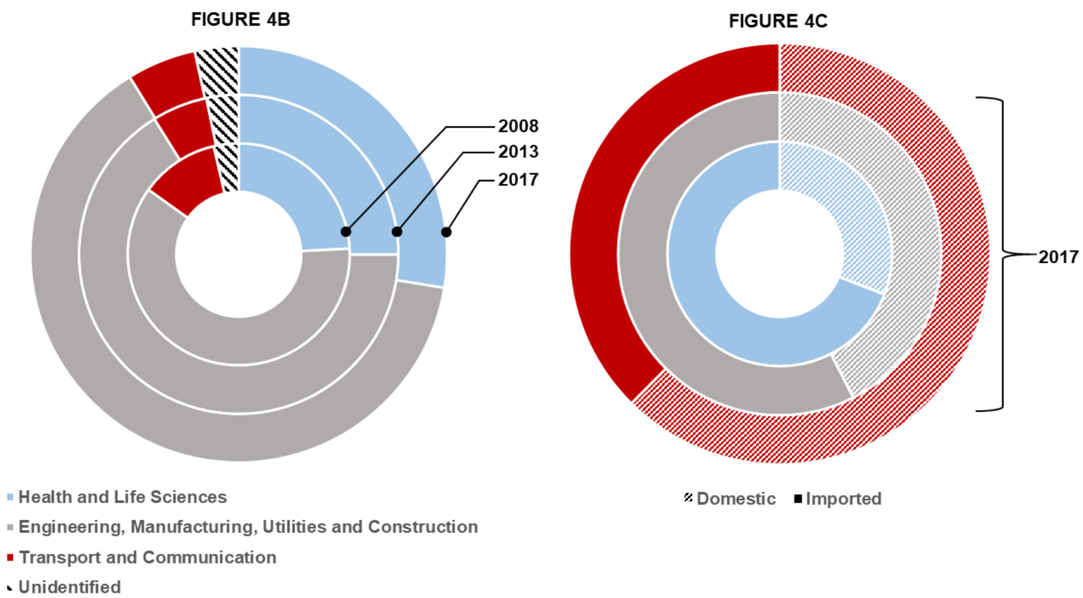


FIGURE 4B-C
Intermediate demand for instrumentation by type of instrument and origin (2008-2017)

Moreover, domestic production of instruments for Health and Life Sciences has consistently grown at a faster rate than growth of imports of the same type, more than doubling the proportion of domestic to imported from 15% to 31%.

There is a non-trivial amount of intermediate demand for Transport and Communication instruments of which the UK manufactures more than it imports. Of the almost £500m total sales in 2017, 62% were domestically manufactured goods.

5 RESEARCH AND DEVELOPMENT

As measurement is a science, commonly known as metrology, a large portion of measurement activity in any economy will concern research and development (R&D). Henceforth, this section attempts to quantify the amount of funding in the UK that is allocated to projects that have a strong focus on measurement, from which we can extrapolate the foreseeable economic benefit of such research using widely accepted economic theory.

Our findings separate R&D performed by business enterprise from R&D performed by 'Other' bodies (i.e. government, higher education, research councils and private non-profit). Using the same methods, we have compared these against the performance of some of the UK's global competitors in R&D.

Highlights:

- In 2017, the total expenditure on measurement related R&D was just over £2bn, 87% of which was performed by private businesses.
- Over the last decade, 211,000 patents were granted to companies of a UK origin. On average, 7.5% of all UK originated granted patents relate to a measurement technology – almost 16,000 in total.
- A similar analysis of journal articles reveals that measurement research accounts for 2.4% of all papers published in the last 10 years – almost 21,000 in total. Academic measurement R&D has been declining over the decade. In the UK, the proportion of total papers published that were on measurement related topics was 0.3 percentage points higher in 2007 than it was in 2017.
- The UK has revealed comparative advantage in measurement R&D which is demonstrated by having 1.04 times our fair share of granted measurement related patents, almost on par with Japan who have 1.06 times their fair share.

5.1 METHODOLOGY

To calculate expenditure on measurement related R&D we have used the ratio of UK measurement related patents granted to total patents granted as a proxy for expenditure by business enterprise and UK measurement related articles published to total articles published as a proxy for expenditure by other non-business bodies. These ratios are calculated annually before finding the 10-year average between 2007 and 2017. This final step accounts for the significant time lag between the initial investment and the patent being granted.

Key Data Sources

- **WIPO (Business R&D)[38]**: The World Intellectual Property Organisation (WIPO) collects international patent data for every country in the world that submits patents. For the purposes of this analysis, we have extracted figures for patents that have been *granted,* by specific technology categories that strongly pertain to metrology. Those technologies are: 'Measurement', 'Control', 'Thermal processes and apparatus'.

38 (WIPO, n.d.)

- **Web of Science (Other R&D)**[39]: The Web of Science (WoS) is a scientific citation indexing service that provides a comprehensive citation search. We have used this database to extract figures for the number of articles published on subjects related to measurement. Subjects are divided by 'WoS categories' of which we have selected three that strongly relate to metrology. They are: 'Instruments and instrumentation', 'automation and control systems' and 'chemistry, analytical'.
- **Gross Expenditure on Research and Development (GERD)**[40]: For data on overall UK expenditure on R&D we have drawn from the aggregated figures of each sector of performance from GERD. Sectors of performance include business enterprise and government, higher education, research councils and provate non-profit, which we have grouped into a second sector that represents all non-business. GERD is published annually.

All data are available on an annual basis for the entire time series.

5.2 RESULTS

Over the last decade, on average, 7.5% of all UK originated granted patents relate to a measurement technology – almost 16k in total.

A similar analysis of journal articles reveals that measurement research accounts for 2.4% of all papers published in the last 10 years – almost 21k in total.

Multiplying the total annual expenditure performed by business and by other non-business bodies by the 10-year average percentage of measurement related patents and articles, respectively, we find the following results:

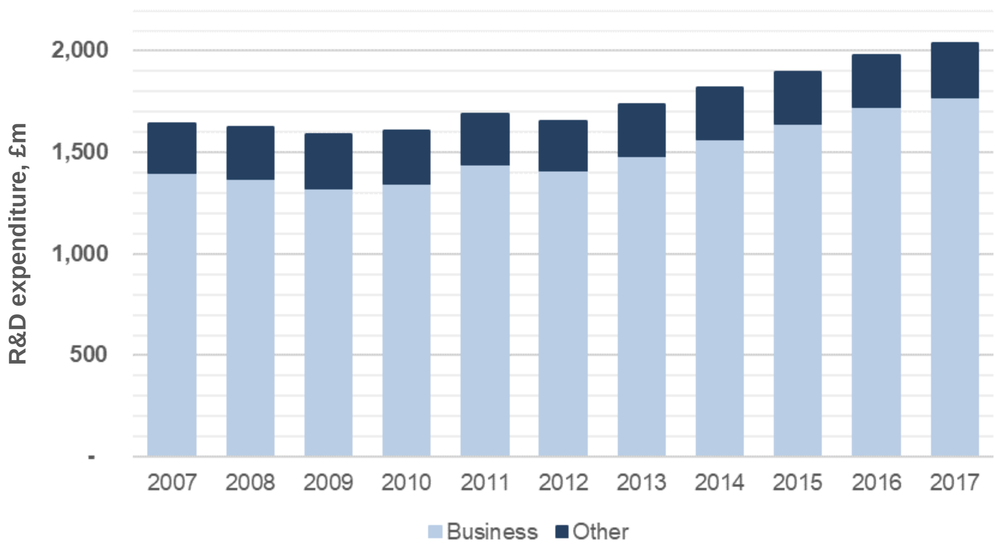


FIGURE 5A
Measurement related R&D, by performance, constant prices (2007-2017)

In 2017, the total expenditure on measurement related R&D was just over £2bn, 87% of which was performed by private businesses. In real terms, since 2009, expenditure on measurement

39 (Clarivate, n.d.)

40 (ONS, 2020.b)

related R&D in the UK has been trending upwards in both business and non-business sectors. However, the rate at which businesses are increasing investment in measurement is greater than that of the other non-business bodies as shown by their shrinking contribution to total measurement related R&D expenditure.

Econometric studies that explore the relationship between changes in output and changes in the level of R&D spending estimate that the (short term) private rate of return from R&D investments ranges from 20% to 30%. Thus, over the period analysed, R&D in measurement related topics has contributed between £3.2bn and £4.9bn to GDP.

Of the 20,770 papers published by UK organisations in the last decade, NPL has contributed to 3% of that total, placing them just outside the top 10 organisations in the country conducting measurement research. In addition, NPL works in close partnership with the University of Strathclyde which when combined rank 2nd in the list of top organisations conducting measurement research, accounting for more than 6% share of the total.

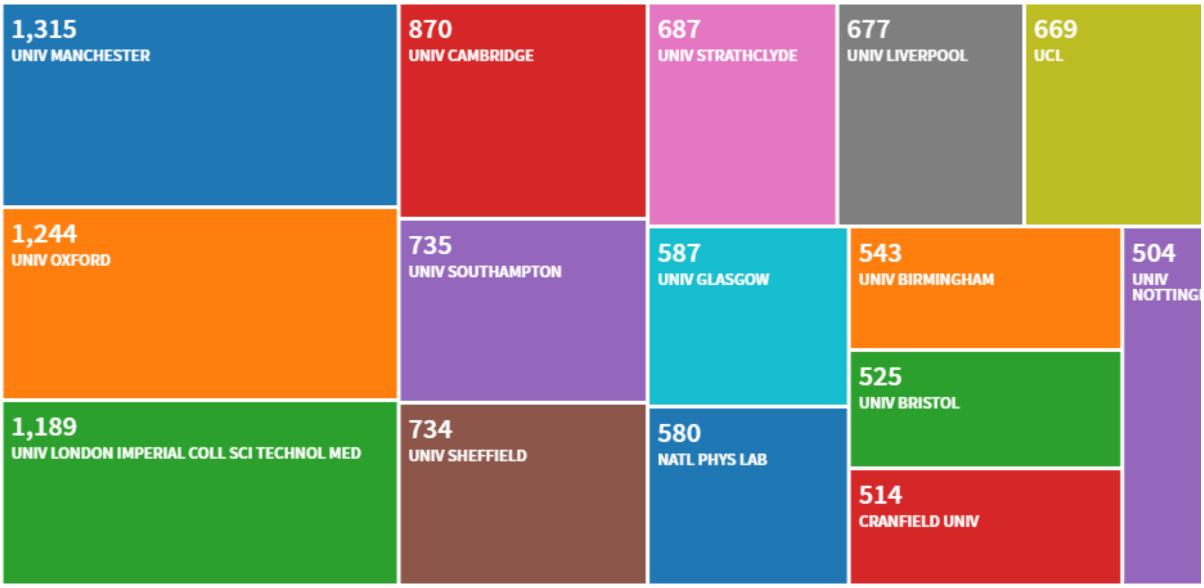


FIGURE 5B
Top 15 UK measurement research organisations by number of publications (2007-2017)

Extracting data from the Gateway to Research (GtR) reveals the total annual funding for research projects by UK research councils.[41] Our analysis shows that just 1.6% of research council funding, of which more than 90% is performed by higher education institutions, is allocated to measurement related projects. This is almost 50% less than the average academic research intensity of measurement related subjects, indicated by the 2.4% of papers published, suggesting that measurement research is under-funded in by the public sector.

5.3 INTERNATIONAL COMPARISON

Keeping all other variables constant, we have extracted data on the number of patents and articles from the WIPO and WoS for four of the UK's global competitors in R&D: France (FR), Germany (DE), Japan (JP) and the United States (US).

Patents

In absolute terms, the UK is granted the least amount of measurement related patents out of the five economies. However, relative to each countries' total output of patents of any kind the

41 (UKRI, n.d.)

UK performs about average in respect to its counterparts, roughly 0.8 percentage points below Germany, who consistently display the highest measurement R&D intensity over the time series, and 0.8 points above the US, who display the lowest measurement R&D intensity. In 2014, there is a spike in number of measurement patents granted relative to total patents granted in the UK, France and Japan, whereas Germany experiences a dip in their ratio.

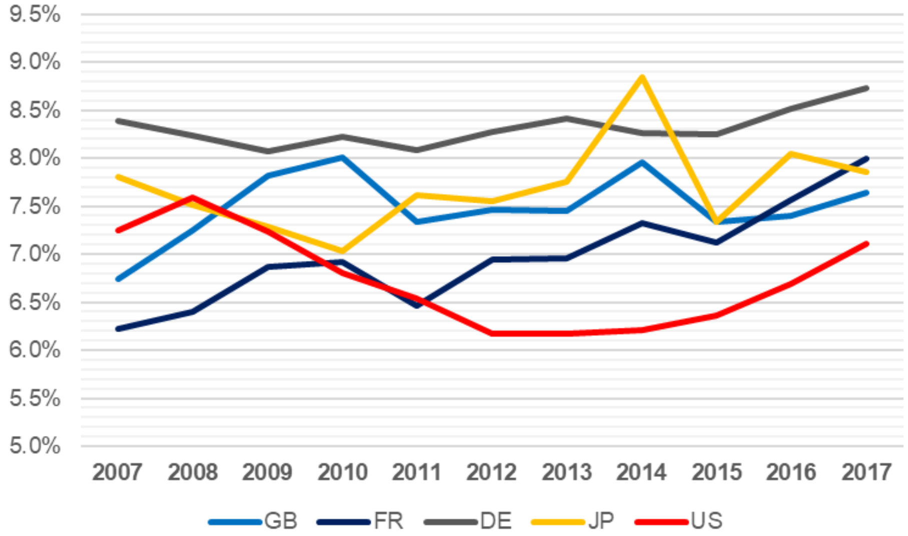


FIGURE 5C
Measurement related patents granted as a percentage of total patents granted, by country (2007-2017)

Germany demonstrates the highest measurement R&D intensity, at an average of 8.3% over the decade, better than the total world measurement R&D intensity of 7.2%. The difference between these two figures represents a revealed comparative advantage (RCA) in measurement related R&D. In other words, Germany conducts 1.15x it's global 'fair share' of measurement R&D. Thus, although having the fewest number of patents granted, the UK also have revealed comparative advantage in measurement R&D, with 1.04 times as many measurement related patents granted than its fair share. In contrast, the US, who dominate the global R&D activity with an average of 19.9% of the world's patents granted, do not have RCA in measurement R&D with only 6.7% of their total patents over the last decade being metrology related. The table below summarises these findings:

Country	Measure-ment Patents	Total Patents	% of Measure-ment Patents	'Fair Share' Factor	RCA
UK	15,860	211,370	7.5%	1.04	Yes
FR	29,812	422,678	7.1%	0.97	No
DE	72,419	869,081	8.3%	1.15	Yes
JP	242,660	3,149,958	7.7%	1.06	Yes
US	160,102	2,398,749	6.7%	0.92	No
World	**870,056**	**12,019,023**	**7.2%**		

TABLE 5A
Revealed comparative advantage in measurement related business R&D, by country (2007-2017)

Research papers

On average, the UK's measurement intensity into research outside of the business sector is lower than that of France, Germany and Japan, and only marginally better than the US.

Relatively speaking, all five economies have a similar level of performance in research into measurement, with the widest range between any two countries in one year being 0.8 percentage points. However, since 2007, measurement research intensity has been trending downward in the UK, the US and Japan, with Japan experiencing the largest decrease of more than 0.4 points over the 10 years.

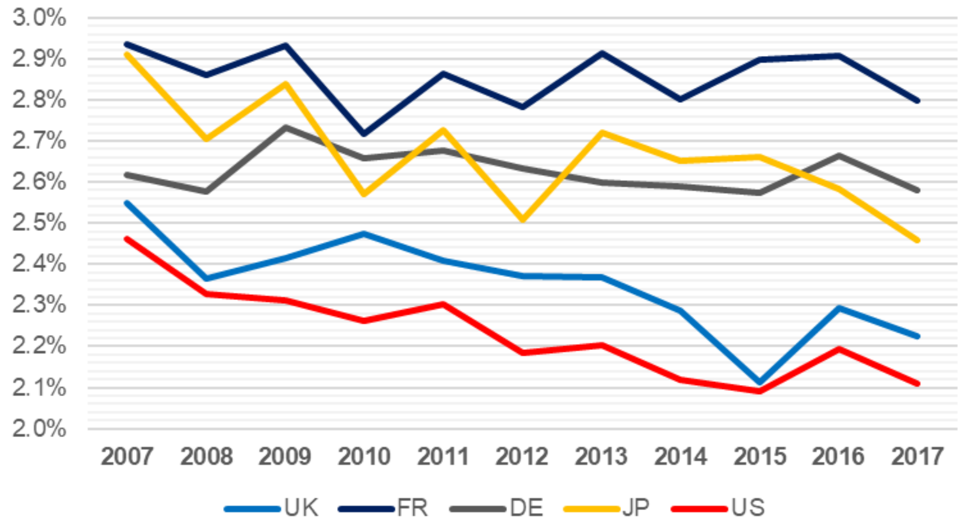


FIGURE 5D
Measurement related papers published as a percentage of total papers published, by country (2007-2017)

Similar to the method used for the business sector, by swapping patents with papers we can calculate whether or not each country has revealed comparative advantage in academic R&D in measurement related topics.

Country	Measure-ment Papers	Total Papers	% of Measure-ment Papers	'Fair Share' Factor	RCA
UK	20,770	887,436	2.3%	0.74	No
FR	19,395	679,353	2.9%	0.91	No
DE	24,890	948,091	2.6%	0.83	No
JP	21,689	813,719	2.7%	0.85	No
US	74,134	3,331,979	2.2%	0.71	No
World	**409,875**	**12,996,447**	**3.2%**		

TABLE 5B
Revealed comparative advantage in measurement related non-business R&D, by country

In all five countries, there is no revealed comparative advantage in academic measurement related R&D. Of these countries the UK are the second least efficient in this field.

Table 5B reaffirms the earlier evaluation that universities devote a less than proportionate amount of their resources towards measurement related R&D.

6 CONCLUSION

This report estimates four key elements that contribute to measurement activity in the UK: labour input, investment, intermediate demand and research and development. This section is intended to:

- Summarise the main findings of each section;
- Depict the main assumptions made in each section and how the analysis should be caveated in light of those assumptions;
- And suggest further work that could be conducted in order to strengthen and extend the conclusions of this report.

In summary, this report is the first of its kind, possessing quantitative insights on elements of measurement activity in the UK that cannot be found elsewhere. Using only open data, the analyses found in this report are easily repeatable and can be updated upon the publication of new data. Offering both a wide-angle shot of the UK measurement infrastructure and more nuanced sectorial analyses over a period spanning more than a decade, this report can be used to evidence the impact of measurement and provides the foundation for future work that may seek to model or forecast the behaviour of aspects of measurement activity in relation to changes in external forces.

Outstanding from this report is a section devoted to the international trade of instrumentation and the UK's position in the global market of measurement goods. With the aid of rich product trade data from the OEC, such analysis could be cut many different ways. Rather than giving limited space in this report to the subject, it has been decided that trade of instrumentation should be explored in greater detail in a future publication of its own.

Below are some further reflections on each chapter.

Labour input

The analysis of measurement related employment reveals that:

- In 2017, 6.3% of total UK employment was comprised of occupations that involve taking measurements. The total compensation offered to employees in these measurement occupations was £58.3bn, accounting for 2.8% of GDP.
- Taking a closer look at the concentration of measurement related jobs within industries, 14.3% of all employees in the R&D industry and 7.9% of all employees in the Defence industry are Calibrators, Testers and Analysers.
- Between 2007 and 2017, the number of employees in measurement related occupations rose by 13% – 4 percentage points more than overall employment over the same period – to a total of 2 million. This was mostly driven by an uplift in CAL and T&A occupations.
- In 2017, there were 162,000 employees providing measurement services in the UK. These employees were awarded a total of £4bn in annual pay.

These findings depend on the method devised to organise measurement related occupations based on how strongly the responsibilities of each occupation pertain to carrying out measurements. Furthermore, the fourth finding in the preceding list depends on a further assumption regarding the fraction of the time of employees from specific occupations are thought to spend strictly performing measurements (as explained in the report this approximation was made using the number of tasks that involve calibration out of all tasks required by the job listed in the ONS description of the SOC codes).

Undoubtedly, there is great variability and complexity in the tasks that workers undertake across all industries and so the method used in this report attempts to capture the main features of these activities and isolate those that are linked to measurement. As can be expected, the resulting estimates depend on the process of simplification and organisation of occupations. Nevertheless, the fact that the alternative analysis using LinkedIn data provides highly similar results supports the idea that the method utilised in the labour input section is in fact accurate.

Future iterations of research may seek to gain further measurement related employment insights by exploiting the rich data provided by professional social networks. The aim would be to extend the findings within this section, analysing the size and structure of the calibration and testing sector by devising a method that utilises advanced search criteria such as 'industry', 'years of experience' and 'level of education'.

Investment

The section dissects spending on instruments that are used directly to make measurements, rather than instruments that are installed as components of other machinery and equipment. The main findings of the analysis of investment are:

- Investment in instrumentation has increased annually, amounting to just over £3.6bn in 2017. This figure accounts for 4.1% of all productive and tangible assets and 7.2% of all machinery and equipment.
- Instruments for Health and life sciences and Engineering, Manufacturing, Utilities and Construction accounted for 58% and 38% of the UK's total investment in instrumentation, respectively, in 2017.
- Also, in 2017, we estimate that the gross capital stock of instrumentation was valued at £36.8bn, 0.5% of the UK's gross capital stock with instruments for Health and life sciences accounting for 57% (£20.8bn).

These findings are founded on the assumption that the UK imports all investment in instruments that are used for the production of goods and services for a period of more than one year (i.e. 100% of instrumentation GFCF is imported). This is based on the fact that the proportion of investment in instrumentation that is imported increased substantially between 1995 and 2005, almost reaching 100% (unfortunately, more recent versions of the IOATs are not granular enough to separate out spending on instrumentation). However, although we believe that the highly specialised nature of instrumentation combined with rapid technological change would have encouraged UK producers to obtain gains from international trade, hence reinforcing this trend from 2005 onwards, we do not have evidence of this. To test the validity of this key assumption it may be possible to generate more recent estimates of the ratio of domestic to imported GFCF by mapping products from IO 123 codes to CPA 08 codes. Unfortunately, this information is currently pending publication by the ONS.

Combined with the findings from the Labour Input chapter, estimates for the capital stock of instrumentation offers scope for further work where a production function for measurement activity could be modelled. Such a tool could be used to estimate the value added by measurement in the UK and forecast the effects of changes to the National Measurement Strategy.

Lastly, the estimates of the gross capital stock of instrumentation are based on the assumption that the average lifetime of an instrument is 13 years. Although this parameter is validated against relevant literature, future work may produce a UK instrument-specific analyses to estimate the lifecycle of instruments, including unique scrap rate parameters, which would allow for increasingly accurate estimates of the capital stock of instrumentation.

Intermediate Demand

The section explores the portion of instrumentation used as inputs that are either transformed or used up in the production process. Hence, it attempts to calculate intermediate demand for instruments, both domestic and imported. The main findings are:

- Intermediate demand for instrumentation has increased, in real terms, from £6.8bn to £9bn between 2008 and 2017 while the proportion of these instruments demanded by each sector has remained relatively constant.
- Throughout the period, the UK has become increasingly dependent on imports of instrumentation for intermediate input. This peaked at 60% in 2017.

These findings critically depend on judgements made regarding the categorisation of instruments, by HS 92 classification, into one or more of the components of total demand. HS 92 divides products of instrumentation into 6-digit groups, each pair of digits representing a further sub-grouping, but despite the high level of granularity offered by this classification there are some instances where it is still difficult to decipher the primary component of total demand the product belongs to. Hence, the value of some products has been split 50:50 into two categories as no further inference can be made from the data. While there is no data to test the validity of this assumption, the method allows for the calculation of upper and lower bounds and the findings are compared with historical data to verify their accuracy.

Future iterations of this work may seek to explore whether there is benefit in adopting the even more granular CPA 08 classification for this method, which divides products in up to 8-digit groups. As well as potentially allowing for more accurate categorisation of intermediate demand, GFCF and household demand these data could add an additional level of complexity with regards to grouping of instrument types. However, doing so could pose challenges in collating time series data since significant changes were made to the CPA classification after 2007, plus, it is not uncommon for data at this level of detail to be incomplete either due to be non-disclosure laws or inaccurate estimation, thereby losing some of the benefit of pursing this approach.

Research and Development

This section examines the role of metrology (the science of measurement) in the economy. The goal of this chapter is (a) to quantify the amount of funding that is allocated to projects that focus on measurement, and (b) estimate the economic benefit of such research using widely accepted economic theory. The main findings are:

- In 2017, the total expenditure on measurement related R&D was just over £2bn, 87% of which was performed by private businesses.
- Considering the rate of return on R&D investment, it is estimated that measurement R&D projects in 2017 generated a total of at least £3.2bn in value.

- The UK has revealed comparative advantage in measurement R&D which is demonstrated by having 1.04 times our fair share of granted measurement related patents.

The method used quantifies measurement R&D expenditure by multiplying annual total R&D expenditure figures by businesses and non-business institutions, as published in the National Accounts, by the ratio of measurement patents and articles published in the same year, respectively. The ratio of measurement patents and articles acts as a parameter that indicates the intensity to which the UK R&D sector is geared towards metrological research. Mathematically, multiplying these ratios by the UK annual expenditure in R&D to estimate measurement related R&D expenditure is simplifying the problem, assuming that the cost of R&D projects in all fields is relatively similar.

Future iterations of this work may also provide estimates of the intensity of R&D in other fields to contextualise the findings and give the reader an improved perspective on the importance of metrology.

7 REFERENCES

Clarivate. (n.d.). *Web of Science Service for UK Education*. From Web of Science: https://wok.mimas.ac.uk/

Department of Trade and Industry. (1989). *Measuring up to the Competition.* London: The Stationary Office Books.

Don Vito, P. (1984). *Estimates of the Cost of Measurement in the U.S. Economy.* NBS.

Eurostat. (2020, February 14). *NACE background*. From Eurostat Statistics Explained : https://ec.europa.eu/eurostat/statistics-explained/index.php/NACE_background#Scope_and_characteristics

Huntoon, R. (1967). Concept of a National Measurement System. *Science, Vol. 158*, 67-71.

Juni Zhu, T., Fritzler, A., & Orlowski, J. (2018). *Data Insights: Jobs, skills and migration trends methodology & results.* San Fransico : World Bank Group.

NPL. (2021.a). *Input Output Measurement Tables: Methodology and Results.* London: NPL.

NPL. (2021.b). *Using LinkedIn to Estimate the Employment of the UK Calibration and Testing Sector.* London: NPL.

OEC. (2019.a). *About the Observatory*. From The Observatory of Economic Complexity: https://oec.world/en/resources/about/

OEC. (2019.b). *Methods*. From The Observatory of Economic Complexity: https://oec.world/en/resources/methods

OEC. (2019.c). *What does the United Kingdom Import? (2017)*. From The Observatory of Economic Complexity: https://oec.world/en/visualize/tree_map/hs92/import/gbr/all/show/2017/

OECD. (2001). *Glossary of statistical terms. Net capital stock*. From OECD: https://stats.oecd.org/glossary/detail.asp?ID=1752

OECD. (2003). *Glossary of statistical terms. Gross capital stock*. From OECD: https://stats.oecd.org/glossary/detail.asp?ID=1160

ONS. (2011.a). *Blue Book 2011: Reclassification of the UK Supply and Use Tables.* Office for National Statistics.

ONS. (2011.b). *CT0144 - Occupation (full) by industry (full) (national).* From Nomis: Official Labour Market Statistics: https://www.nomisweb.co.uk/query/construct/summary.asp?mode=construct&version=0&dataset=974

ONS. (2016). *UK SIC 2007.* From Office for National Statistics: https://www.ons.gov.uk/methodology/classificationsandstandards/ukstandardindustrialclassificationofeconomicactivities/uksic2007

ONS. (2017). *A short guide to gross fixed capital formation and business investment.* From The Office for National Statistics: https://www.ons.gov.uk/economy/grossdomesticproductgdp/articles/ashortguidetogrossfixedcapitalformationandbusinessinvestment/2017-05-25#asset-and-sector-hierarchies

ONS. (2018.a). *Annual population survey - regional - employment by occupation.* From Nomis: Official Labour Market Statistics: https://www.nomisweb.co.uk/query/construct/summary.asp?mode=construct&version=0&dataset=168

ONS. (2018.b). *Capital stocks and fixed capital consumption QMI.* From Office for National Statistics: https://www.ons.gov.uk/economy/nationalaccounts/uksectoraccounts/methodologies/capitalstocksandcapitalconsumptionqmi

ONS. (2018.c). *Earnings and hours worked, occupation by four-digit SOC: ASHE Table 14.* From Office for National Statistics: https://www.ons.gov.uk/employmentandlabourmarket/peopleinwork/earningsandworkinghours/datasets/occupation3Digitsoc2010ashetable14

ONS. (2018.d). *GDP deflators at market prices, and money GDP September 2018 (Quarterly National Accounts).* From Gov.uk: https://www.gov.uk/government/statistics/gdp-deflators-at-market-prices-and-money-gdp-september-2018-quarterly-national-accounts

ONS. (2019). *ONS Occupation Coding Tool.* From ONS Digital: https://onsdigital.github.io/dp-classification-tools/standard-occupational-classification/ONS_SOC_occupation_coding_tool.html

ONS. (2020.a). *Annual gross fixed capital formation by industry and asset.* From The Office for National Statistics: https://www.ons.gov.uk/economy/grossdomesticproductgdp/datasets/annualgrossfixedcapitalformationbyindustryandasset

ONS. (2020.b). *Gross domestic expenditure on research and development time series.* From Office for National Statistics: https://www.ons.gov.uk/economy/governmentpublicsectorandtaxes/researchanddevelopmentexpenditure/datasets/governmentexpenditureonresearchanddevelopment

ONS. (2020.c). *UK manufacturers' sales by product.* From Office for National Statistics: https://www.ons.gov.uk/businessindustryandtrade/manufacturingandproductionindustry/datasets/ukmanufacturerssalesbyproductprodcom

Paulson, B. (1977). *Economic Analysis of the National Measurement System, The 1972-75 Study of the National Measurement System.* NBS Institute for Basic Standards.

Rincon-Aznar, A., Riley, R., & Young, G. (2017). *Academic review of asset lives in the UK.* London: National Institute of Economic and Social Research.

UKRI. (n.d.). *Projects*. From Gateway to Research: https://gtr.ukri.org/search/project?term=*

United Nations. (2019). *Harmonized Commodity Description and Coding Systems (HS)*. From UN International Trade Statistics Knowledgebase: https://unstats.un.org/unsd/tradekb/Knowledgebase/50018/Harmonized-Commodity-Description-and-Coding-Systems-HS

Williams, G. (2002). *The assessment of the economic role of measurements and testing in modern society.* Brussels: The European Commission.

WIPO. (2021, n.d.). *WIPO IP Statistics Data Center*. From WIPO: https://www3.wipo.int/ipstats/index.htm?tab=patent

8 ANNEX

8.1 ANNEX A: FURTHER METHODOLOGICAL DETAIL AND FINDINDS FOR INVESTMENT

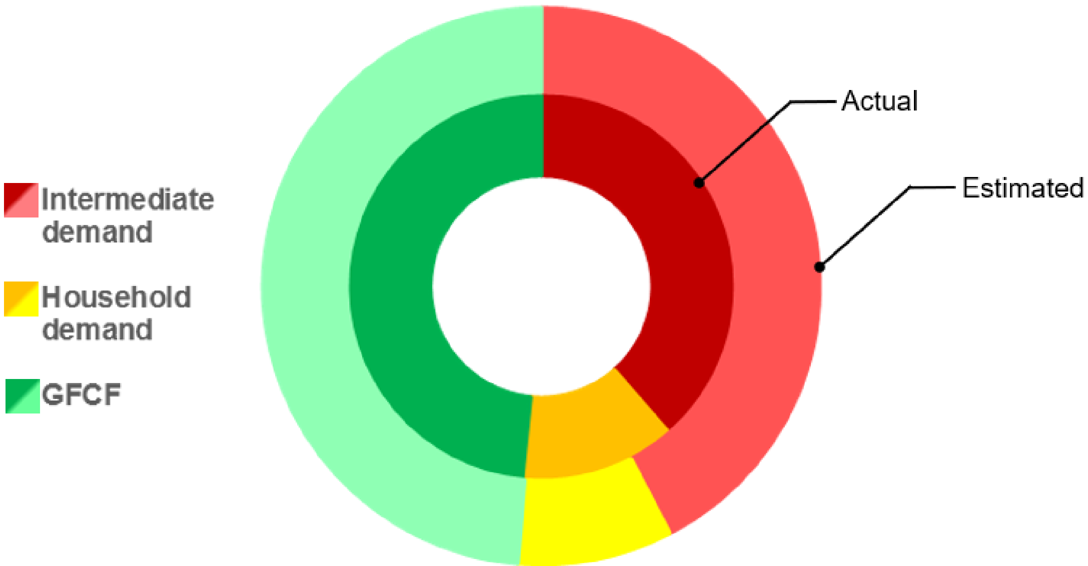
The information included in this annex relates to chapter 4, Investment. Provided are detailed descriptions of methodology and findings that are not integral to the main findings of the chapter but highlight further robustness measures and interesting insights that were calculated.

Calculating upper and lower bounds for investment

To calculate the upper and lower bounds for estimates of investment in instrumentation we take the value of those 50/50 product groups where we are uncertain of whether the instruments are GFCF or otherwise and allocate it entirely to one category or the other. For example, if a product group contains instruments which are either GFCF or intermediate demand, for the upper bound we assume that all those instruments belong to GFCF, and for the lower bound we assume that all those instruments belong to intermediate demand.

In the rare case where a product group contains instruments that belong to either intermediate demand or household demand, no changes are made.

Figure 8AA illustrates the comparison between the estimates for each component of total demand using our upper bound estimate against the actual figures for that from the IOTs. They are strikingly similar:



*Estimates based on OEC imports data for Instrumentation, following *A3*.
**Actual recorded statistics from the IOATs.

FIGURE 8AA
Upper bound estimate for the composition of total demand for imported instrumentation in 1995, against the actual composition of that.

These calculations support our hypothesis that intermediate demand for instrumentation gradually begins to take a larger portion of total demand as the time period progresses.

Capital Stock of Instrumentation by Industry

Having calculated the capital stock of instrumentation in Chapter 4.5, it is possible to gain further insight into the demand for instrumentation in the economy by assessing the fraction of each relevant industry's gross capital stock that is instrumentation as an indicator of measurement intensity. This is dependent on how it is judged which industries are users of which instrumentation. Classifying industries by two-digit SIC 07 codes, where possible, each industry has been mapped to one or more of the three types of instrumentation as the result of the assumption, ***A6***:

A6: Two-digit SIC 07 industries can be mapped to one, more than one or none of the three core categories of instrumentation based on whether the activities of those industries are likely to depend on that type of instrumentation.

The outcome of ***A6*** is summarised by the visualisation, *Figure 8AB*:

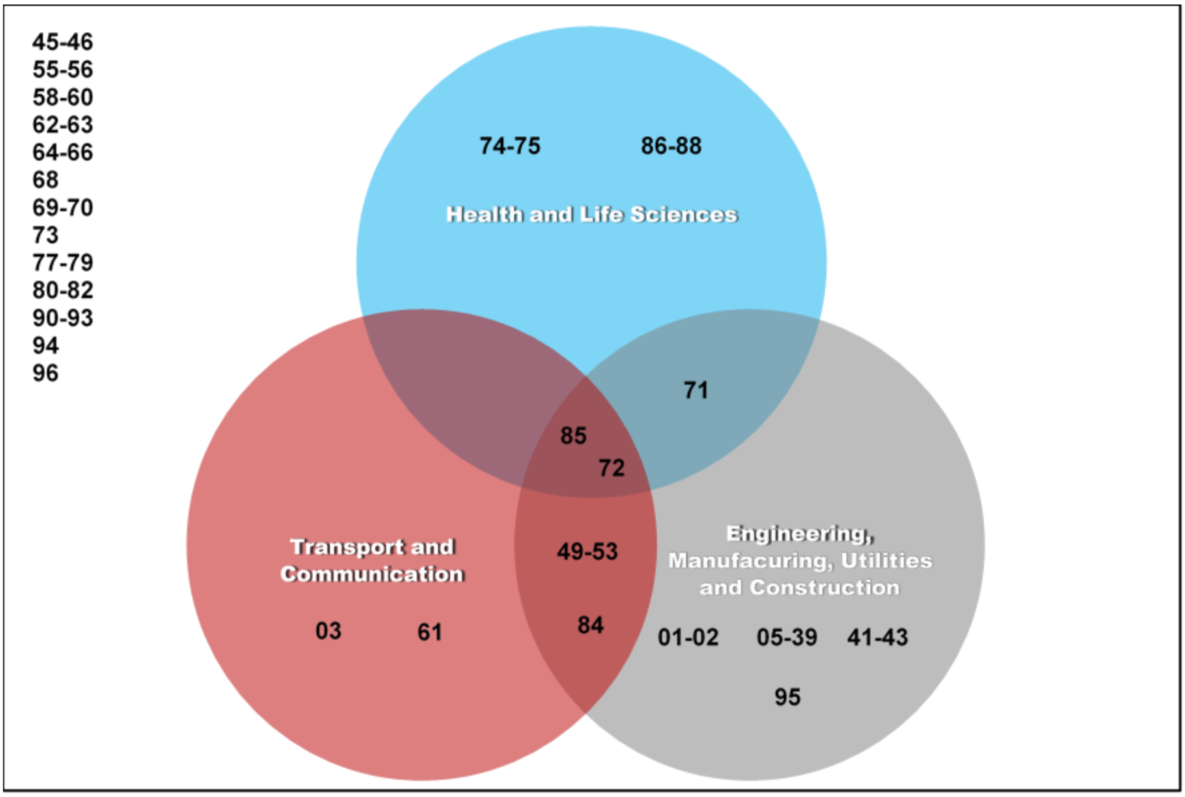


FIGURE 8AB
Venn diagram linking industries, by two-digit SIC 07 code, to the instrument types they use

Each of the circles represent one of the three main types of instrumentation. The numbers represent industries by their two-digit SIC codes.[42] Industries in sections where the circles overlap have been judged to be users of more than one type of instrumentation. Activities of industries outside the circles have been judged to have little to no relevance to any instrumentation. For example, it has been judged that *85: Education* will contain instruments from all three sectors in its gross capital stock, largely due to universities conducting research is a plethora of subjects. Conversely, *94: Activities of membership organisations* are unlikely to have any assets of the same like.

When comparing the capital stock of instruments against industries' capital stock only productive, tangible assets have been considered. This means that we have eliminated assets that are buildings, dwellings and intellectual property products from the capital stock.

Implementing ***A6***, we can roughly estimate the cumulative gross capital stock of all productive, tangible assets for the industries that consume each type of instrument. Taking the gross

42 Full details on SIC 2007 (ONS, 2016)

capital stock of instruments of a sector as a percentage of productive, tangible assets of its respective industries represents the fraction of said industries' assets used for production that are instruments. The outcome is an indicator of how dependant each sector is on instrumentation. Our results are presented in *Table 8AA* below.

	Sector		
	Health and Life Sciences	**Engineering, Manufacturing, Utilities and Construction**	**Transport and Communication**
2007	29.83%	1.32%	0.46%
2008	29.51%	1.27%	0.46%
2009	29.82%	1.22%	0.48%
2010	30.26%	1.22%	0.48%
2011	30.25%	1.19%	0.48%
2012	30.39%	1.19%	0.49%
2013	31.45%	1.22%	0.50%
2014	29.80%	1.26%	0.50%
2015	29.18%	1.26%	0.52%
2016	27.59%	1.25%	0.51%
2017	27.47%	1.28%	0.51%

TABLE 8AA
Percentage of sectors' gross capital stock that is instrumentation, 2007-2017

As well as accounting for the majority of existing instrumentation in the economy, instruments for Health and Life Sciences dwarf other types of instruments in terms of how important they are to the industries that use them. In 2013, this reached a high of 31.5% of all productive, tangible assets within the Professional, Scientific and Technical, Education and Human Health and Social Work industries, but has declined relatively quickly since (1% annually).

The next most important type of instrument to its relative sectors is instrumentation for Engineering, Manufacturing, Utilities and Construction. As a proportion of productive, tangible assets in relative sectors, the gross capital stock of instrumentation for Engineering, Manufacturing, Utilities and Construction declined during the first 5 years between 2007 and 2017 but saw a resurgence in the latter 5 years, returning to around 1.3% by the end of the period, as it was at the beginning. Despite this seemingly small percentage, it represents a very large absolute value as the industries mapped to this type of instrument held a combined gross capital stock of productive, tangible assets worth £1 trillion in 2017.

Instruments for transport and communication purposes have steadily become more prominent in their relative sectors, claiming roughly 0.05% more of productive, tangible assets in the 10 years between 2007 and 2017. However, this is still a small segment of a very broad sector.

8.2 ANNEX B: AUXILLARY FIGURES AND TABLES

Annex B contains tables and figures which provide unabridged detail for certain elements that are referenced in the main text.

Included in this annex are the following:

- **FIGURE 8BA, Employment of occupations that require the use of measurement tools, by industry (2017)**: Total employment estimates, by industry, for CAL and T&A and HI and LOW occupations (these are defined in chapter 3). Contextualises the estimates of measurement intensity, by industry, presented in *Figure 2C*.
- **TABLE 8BA, CAL SOC 10 codes**: List of CAL occupation SOC 10 codes. Includes job description, full list of related jobs and tasks, and the correspondence of tasks to calibration activity. Refer to chapter 3 for further details.
- **TABLE 8BB, T&A SOC 10 codes**: List of T&A occupation SOC 10 codes. Includes job description, full list of related jobs and tasks, and the correspondence of tasks to testing activity. Refer to chapter 3 for further details.
- **TABLE 8BC, Instruments by HS 92 classification**: List of individual products that make measurements by 6-digit HS 92 codes. Includes the component of total demand and the type of instrument each product belongs to. Refer to chapter 4 for further details.

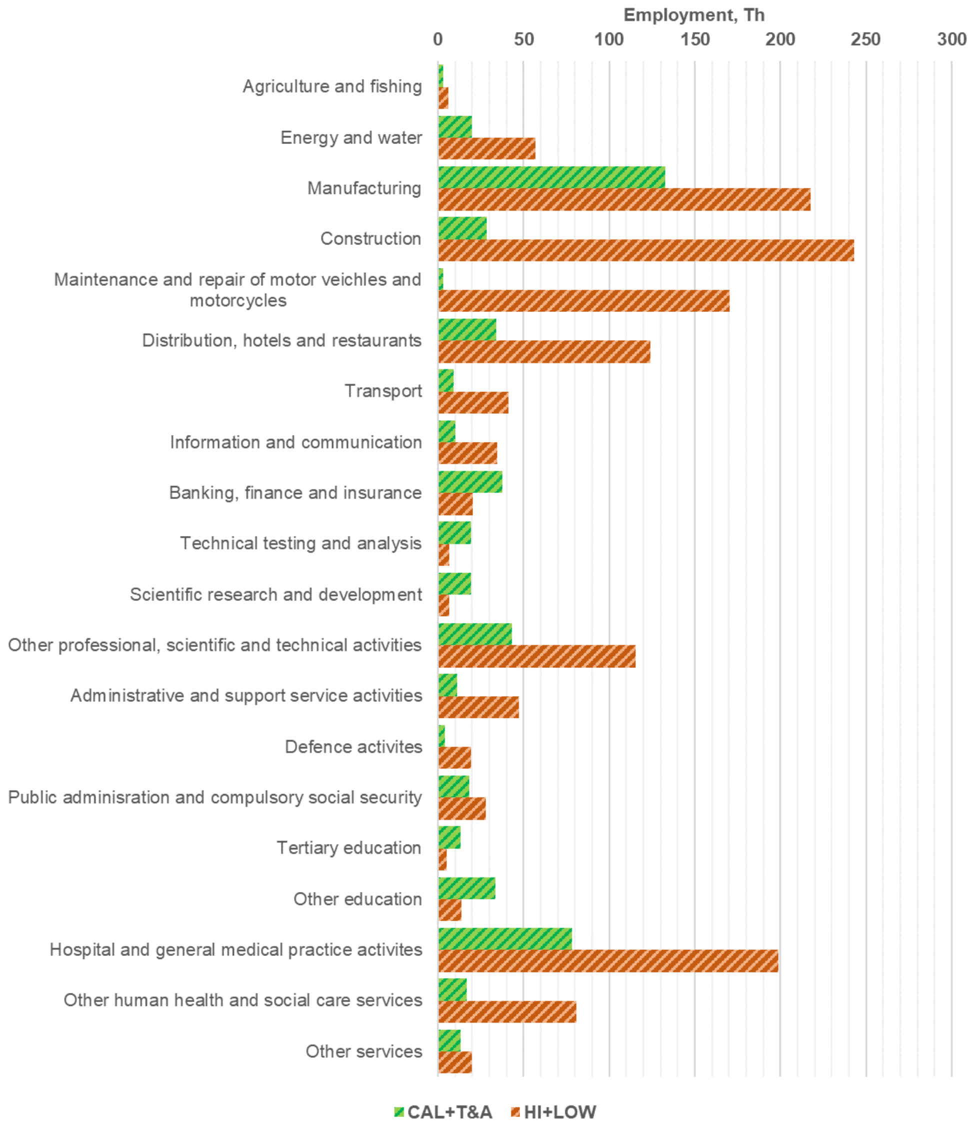


FIGURE 8BA, Employment of occupations that require the use of measurement tools, by industry (2017)

SOC	Job Description	Related Jobs	Tasks	Measure-ment Task
3111 Laboratory Technicians	Laboratory technicians carry out routine laboratory tests and checks, and perform a variety of technical support functions requiring the application of established or prescribed procedures and techniques to assist scientists with their research, development, analysis and testing, and to verify the physical, chemical and other characteristics of materials and products.	Laboratory Analyst	Sets up and assists with the construction and the development of scientific apparatus for experimental, demonstration or other purposes	Yes
		Laboratory Technician	Prepares and analyses body fluids, secretions and/or tissue to detect infections or to examine the effects of different drugs	No
		Medical Laboratory Assistant	Grows cultures of bacteria and viruses, prepares tissue sections and other organic and inorganic material for examination and stains and fixes slides for microscope work	No
		Scientific Technician	Operates and services specialised scientific equipment, undertakes prescribed measurements and analyses and ensures that sterile conditions necessary for some equipment are maintained	Yes
		Water Tester	Records and collates data obtained from experimental work and documents all work carried out	No
3115 Quality Assurance Technicians	Quality assurance technicians perform a variety of technical inspections and testing and monitoring tasks to detect processing, manufacturing and other defects.	Quality Assurance Technician	Sets up scientific, electronic, or other technical equipment to perform functional and inspection tests	Yes
		Quality Control Technician	Analyses and interprets the results of tests undertaken and writes up reports upon completion	No
		Quality Officer	Supervises the work of routine inspection staff and notes any defects reported	No
		Quality Technician	Assists quality control engineers in undertaking production audits	No
		Test Technician	Liaises with production engineers and staff to maintain the quality of output and to develop quality management systems	No
3218 Medical and dental technicians	Medical and dental technicians operate, calibrate and maintain cardiographic and encephalographic testing equipment, assist in the conduct of post mortems, give simple dental treatments, fit artificial limbs and hearing aids, and undertake a wide range of related medical and dental tasks.	Cardiographer	Operates equipment to diagnose and record or treat hearing, heart, brain, lung and kidney ailments	Yes
		Dental Hygenist	Undertakes scaling and polishing of teeth, applies medicaments, carries out post-operative hygiene work and advises on preventative dentistry	No
		Dental Technician	Makes dentures, crowns, bridges, orthodontic and other dental appliances according to individual patient requirements	No
		Medical Technical Officer	Measures patients for, and fits them with, surgical appliances, hearing aids and artificial limbs	No
		Orthopaedic Technician	Performs related medical tasks including treating hair and scalp disorders and conducting tests on glaucoma patients	No
			Takes samples for clinical examination	No
5224 Precision Instrument Makers and Repairers	Precision instrument makers and repairers make, calibrate, test and repair precision and optical instruments such as barometers, compasses, cameras, calibrators, watches, clocks and chronometers.	Calibration Engineer	Examines drawings or specifications to determine appropriate methods, materials and sequence of operation	No
		Horologist	Marks out and machines aluminium, brass, steel and plastics using machine tools such as grinders, lathes and shapers	No
		Instrument Maker	Tests watches and clocks for repair to diagnose faults and removes, repairs or replaces damaged and worn parts	No
		Instrument Mechanic	Tests completed timepiece for accuracy using electronic or other test equipment	No
		Instrument Technician	Carries out service tasks such as cleaning, oiling and regulating	No
		Optical Technician	Checks prepared parts for accuracy using measuring equipment, assembles parts and adjusts as necessary using hand and machine tools	Yes
		Precision Engineer	Positions, aligns and secures optical lenses in mounts	No
		Watchmaker	Tests, adjusts and repairs precision and optical instruments	Yes

TABLE 8BA, CAL SOC 10 codes

SOC	Job Description	Related Jobs	Tasks	Measure-ment Task
2111 Chemical Scientists	Chemical scientists analyse and research physical aspects of chemical structure and change within substances and develop chemical techniques used in the manufacture or modification of natural substances and processed products.	Analytical Chemist	Develops experimental procedures, instruments and recording and testing systems	Yes
		Chemist	Conducts experiments to identify chemical composition, energy and chemical changes in natural substances and processed materials	Yes
		Development Chemist	Analyses results and experimental data	No
		Industrial Chemist	Tests techniques and processes for reliability under a variety of conditions	Yes
		Research Chemist	Develops procedures for quality control of manufactured products	Yes
2112 Biological Scientists and Biochemists	Biological scientists and biochemists examine and investigate the morphology, structure, chemistry and physical characteristics of living organisms, including their inter-relationships, environments and diseases.	Biomedical Scientist	Studies the physical and chemical form, structure, composition and function of living organisms	No
		Forensic Scientist	Identifies and studies the chemical substances, including microbial infections, involved in physiological processes and progress of disease	No
		Horticulturist	Performs tests to study physiological and pathological characteristics within cells and other organisms	Yes
		Microbiologist	Researches the effects of internal and external environmental factors on the life processes and other functions of living organisms	No
		Pathologist	Observes the structure of communities of organisms in the laboratory and in their natural environment	No
			Advises farmers, medical staff and others, on the nature of field crops, livestock and produce and on the treatment and prevention of disease	No
			Monitors the distribution, presence and behaviour of plants, animals and aquatic life, and performs other scientific tasks related to conservation not performed by jobholders in MINOR GROUP 214: Conservation and Environment Professionals	No
2217 Medical Radiographers	Medical (diagnostic) radiographers operate x-ray machines, ultrasound, magnetic resonance imaging and other imaging devices for diagnostic and therapeutic purposes, assist in the diagnosis of injuries and diseases and are involved in intervention procedures such as the removal of kidney stones. They operate under the supervision of senior staff. Therapeutic radiographers specialise in the planning and administration of radiotherapy treatment for patients with cancer.	Medical Radiographer	Uses a range of imaging devices for diagnostic and therapeutic purposes	Yes
		Radiographer	Assesses patients and interprets clinical requirements to determine appropriate radiographic treatments	No
		Sonographer	Verifies identity of patient and ensures that necessary preparations have been made for the examination/treatment	No
		Therapeutic Radiographer	Decides length and intensity of exposure or strength of dosage of isotope	No
		Vascular Technologist	Positions patient and operates x-ray, scanning or fluroscopic equipment	Yes
			Maintains records of all radiographic/therapeutic work undertaken	No
			Plans course of treatment with clinical oncologists and physicists	No
			Calculates radiation dosage and maps volume to be treated	Yes
			Explains treatment to patient and management of any side effects	No
			Carries out post-treatment reviews and follow ups	No
2434 Chartered Surveyors	Chartered surveyors conduct surveys related to the measurement, management, valuation and development of land, natural resources, buildings, other types of property, and infrastructure such as harbours, roads and railway lines.	Building Surveyor	Surveys, measures and decribes land surfaces to establish property boundaries and to aid with construction or cartographic work	Yes
		Chartered Surveyor	Surveys mines, prepares drawings of surfaces, hazards and other features to control the extent and direction of mining	No
		Hydrographic Surveyor	Surveys buildings to determine necessary alterations and repairs	No
		Land Surveyor	Measures shore lines, elevations and underwater contours, establishes high and low water marks, plots shore features and defines navigable channels	Yes
2461 Quality Control and Planning Engineers	Quality control and planning engineers plan production schedules, work sequences, and manufacturing and processing procedures to ensure accuracy, quality and reliability.	Planning Engineer	Devises inspection, testing and evaluation methods for bought-in materials, components, semi-finished and finished products	No
		Quality Assurance Engineer	Ensures accuracy of machines, jigs, fixtures, gauges and other manufacturing and testing equipment	Yes
		Quality Control Officer (profe	Analyses plans, drawings, specifications and safety, quality, accuracy, reliability and contractual requirements	No
		Quality Engineer	Prepares plan of sequence of operations and completion dates for each phase of production or processing	No
			Prepares work flow charts for individual departments and compiles detailed instructions on processes, work methods and quality and safety standards for workers	No
			Oversees effective implementation of adopted processes schedules and procedures	No
3119 Science, engineering and production technicians n.e.c.	Job holders in this unit group perform a variety of technical support functions not elsewhere classified in MINOR GROUP 311: Science, Engineering and Production Technicians.	School Technician	Sets up apparatus for experimental, demonstration or other purposes	No
		Technical Assitant	Undertakes tests and takes measurements and readings	Yes
		Technician	Performs calculations and records and interprets data	No
		Textile Consultant	Orherwise assists technologists as directed	No
		Workshop Technician		
8133 Routine Inspectors and Testers	Jobholders in this unit group inspect and/or test metal stock, parts and products, electrical plant, machinery and electronic components, systems and sub-assemblies, textiles, wood, paper, food, plastics and rubber goods, parts and materials to detect processing, manufacturing and other defects.	Quality Assurance Inspector	Checks sequence of assembly operations and checks assemblies and sub-assemblies against parts lists to detect missing items	No
		Quality Auditor	Examines articles for surface flaws such as cracks, dents, defective sealing or broken wires by visual inspection or using aids such as microscopes	No
		Quality Controller	Reports any recurrent or major defects and recommends improvements to production methods	No
		Quality Inspector	Sets up test equipment and operates controls to check performance and operation of electrical plant and machinery and electronics systems	Yes
		Test Engineer	Examines yarn packages, textile fabrics and garments, wood or wood products, paper and paperboard, plastics and rubber materials, food products, food storage contrainers, etc., checks specifications, marks any repairable defects and rejects faulty items	No
8134 Weighers, Graders and Sorters	Jobholders in this unit group weigh, grade and sort materials, goods and products.	Grader (food products mfr)	Examines hide, skins, leather, fabric, wool, rags, scrap metal, tobacco pipe bowls, fish, fibres, ceramics, produce and other goods	No
		Metal sorter	Assesses product quality visually and by touch, and grades according to weight, thickness, colour and other quality criteria	No
		Selector (Ceramics mfr)	Ascertains material(s) required from order card, recipe, or specification and weighs and measures prescribed quantities accordingly	Yes
		Weighbridge clerk	Uses balances, springs, weighing platforms, automatics scales and weighbridges to check the wieght of goods, products and loaded vehicles	Yes
		Wieghbridge operator	Records and calculates gross and net weight, checks delivery notes and prepares documents and labels for identification purposes	No
			Operates machnies to measure lengths of rolls of material and irregularly shaped materials such as leather or sheepskin	No

TABLE 8BB, T&A SOC 10 codes

HS 92	Description	Intermediate demand	GFCF	Household demand	Health and Life Sciences	Engineering, Manufacturing, Utilities and Construction	Transport and Communications
900110	Optical fibres, except for telecommunications	X			X		
900190	Prisms, mirrors and optical elements nes, unmounted	X			X		
900211	Objective lenses for cameras, projectors, etc	X			X		
900219	Objective lenses, nes	X			X		
900220	Optical filters	X			X		
900290	Mounted lenses, prisms, mirrors, optical elements nes		X		X		
900630	Cameras for special use, underwater,aerial, etc		X				X
900659	Photographic, other than cinematographic cameras nes	X		X		X	
900691	Parts and accessories for photographic cameras	X		X		X	
901110	Stereoscopic microscopes		X		X		
901120	Microscopes, for photomicrography		X		X		
901180	Microscopes, optical, nes		X		X		
901190	Parts and accessories for optical microscopes	X			X		
901210	Microscopes except optical, diffraction apparatus	X			X		
901290	Parts and accessories for non-optical microscopes, et	X			X		
901380	Optical devices, appliances and instruments, nes	X	X		X		
901410	Direction finding compasses	X	X				X
901420	Instruments nes for aeronautical/space navigation	X	X				X
901480	Navigational instruments and appliances nes		X				X
901490	Parts and accessories for navigational instruments	X					X
901510	Rangefinders		X			X	
901520	Theodolites and tacheometers		X			X	
901530	Surveying levels		X			X	
901540	Photogrammetrical surveying instruments, appliances		X			X	
901580	Surveying, etc instruments nes		X			X	
901590	Parts and accessories for surveying etc instruments	X				X	
901600	Balances of a sensitivity of 50 milligram or better		X		X		
901710	Drafting tables and machines		X			X	
901720	Drawing, marking-out, instruments nes, slide rules		X			X	
901730	Micrometers, callipers and gauges	X	X			X	
901780	Instruments for measuring length, hand use, nes		X			X	
901811	Electro-cardiographs		X		X		
901819	Electro-diagnostic apparatus, nes		X		X		
901820	Ultra-violet or infra-red ray apparatus		X		X		
901850	Ophthalmic instruments and appliances	X	X		X		
901890	Instruments, appliances for medical, etc science, nes	X	X		X		
901910	Massage and psychological aptitude-test apparatus		X		X		
902211	Medical X-ray apparatus		X		X		
902219	Non-medical X-ray equipment	X	X			X	
902221	Medical apparatus using alpha, beta or gamma radiation		X		X		
902229	Non-medical apparatus using alpha/beta/gamma radiation	X	X			X	
902290	Parts and accessories for radiation apparatus	X				X	
902300	Instruments, apparatus and models, for demonstration		X			X	
902410	Machines for testing mechanical properties of metals		X			X	
902480	Machines for testing mechanical properties nes		X			X	

902490	Parts and accessories of material testing equipment
902511	Thermometers, liquid-filled
902519	Thermometers, except liquid filled
902580	Hydrometer, pyrometer, hygrometer, alone or combined
902590	Parts and accessories for thermometers, etc
902610	Equipment to measure or check liquid flow or level
902620	Equipment to measure or check pressure
902680	Equipment to measure, check gas/liquid properties nes
902690	Parts of equipment to measure or check fluid variable
902710	Gas/smoke analysis apparatus
902720	Chromatographs, electrophoresis instruments
902730	Spectrometers, spectrophotometers, etc using light
902740	Exposure meters
902750	Instruments nes using optical radiations
902780	Equipment for physical or chemical analysis, nes
902790	Microtomes, parts of scientific analysis equipment
902810	Gas supply/production/calibration meters
902820	Liquid supply, production and calibrating meters
902830	Electricity supply, production and calibrating meters
902890	Parts, accessories for gas, liquid, electricity meter
902910	Revolution counters/taximeters/mileometers/pedometers
902920	Speed indicators, tachometers, stroboscopes
903010	Instruments to measure or detect ionising radiations
903020	Cathode-ray oscilloscopes, oscillographs
903031	Electrical multimeters
903039	Ammeters, voltmeters, ohm meters, etc, non-recording
903040	Gain, /distortion and crosstalk meters, etc
903081	Electrical measurement recording instruments
903089	Electrical measurement instruments nes
903090	Parts & accessories, electrical measuring instruments
903110	Machines for balancing mechanical parts, nes
903120	Test benches for measuring or checking equipment
903130	Profile projectors, nes
903140	Optical instruments and appliances, nes
903180	Measuring or checking equipment, nes
903190	Parts and access for measuring, checking equipment ne
903210	Thermostats
903220	Manostats
903281	Hydraulic and pneumatic automatic controls
903289	Automatic regulating/controlling equipment nes
903290	Parts and accessories for automatic controls
903300	Parts/accessories nes for optical/electric instrument
910400	Instrument panel clocks etc for vehicles/aircraft etc
910591	Clocks, nes, battery or mains powered
910599	Clocks, nes, non-electric
910610	Time-registers, time-recorders
910690	Time of day recording apparatus, nes
910700	Time switches
902520	Barometers

TABLE 8BC, Instruments by HS 92 classification

9 GLOSSARY

Basic prices	The price that the producer receives in return for goods and services less any tax payable on products, plus any subsidy receivable.
Calibration	The comparison of an instrument against a reference or standard to identify and correct for errors in the instrument readings.
Comparative advantage	An ability to produce goods or services at a lower opportunity cost than other competitors. The principle of comparative advantage states that countries can benefit from international trade if they specialise in producing goods or services for which they have the lowest opportunity cost, thereby increasing the total global production of goods.
Compensation of employees/Gross pay	Total pre-tax wages plus benefits payable by an employer to an employee in return for work done.
Constant/real prices	The price of goods and services adjusted for inflation, as opposed to the current prices which indicate the price of goods and services at a given moment in time.
Gross capital stock	The cumulative value of all fixed assets in an economy, valued at the current price for new assets of the same type irrespective of the age of the assets.
Gross fixed capital formation	Acquisition, less disposals, of produced assets that are intended for use in the production of other goods and services for a period of more than a year. Excludes the purchase of land and natural resources as these do not come into existence as a result of a production process. Commonly referred to as "investment".
Household demand	Consumption of goods and services by households.
Industry	A specific grouping of companies who conduct similar activities. Companies within an industry may supply a particular type of good or service. In national statistics, larger companies who supply multiple types goods and/or services are allocated to the industry that most closely represents their primary activity.
Input-output analytical tables	A package of tables including supply and use tables (product by industry matrices) which demonstrate how the domestic production and import of goods and services are used for intermediate consumption and final use and derived analytical tables (product by product or industry by industry matrices) which are used for economic impact analysis and modelling.
Intermediate demand	Goods and services consumed as inputs by a process of production. They may be either transformed or used up by the production process.
Measurement goods/products	A device or a piece of machinery/equipment that is used to measure something or makes discrete measurements that enable the operation of other products.
Measurement services	The use of highly sophisticated measurement tools and techniques to either calibrate or test goods to a specified degree of accuracy.

	Measurement services are carried out by specially trained employees.
Metrology	The scientific study of measurement.
National Measurement System (NMS)	The UK's technical organisation infrastructure, headed by six laboratories, designed to enable individuals in the UK to make measurements competently and accurately, demonstrate the validity of such measurement and coordinate with the measurement systems of other countries.
Non-profit institutions serving households (NPISHs)	Organisations which are not mainly financed and controlled by government and which provide goods and services to households for free or at prices that are not economically significant. For example: religious societies; sports clubs; trade unions; political parties.
Processes	The methods employed for producing outputs.
Productive, tangible assets	Physical assets that are actively used in the creation of outputs. This excludes intellectual property and dwellings and buildings.
Public good	A product or service that is non-excludable and non-rival in consumption. Individuals cannot deny each other the opportunity to consume a public good and their consumption does not affect another's opportunity to consume the same good.
Purchasers' prices	The price that the producer receives in return for goods and services plus any tax payable on products (except deductible VAT), less any subsidy receivable.
Sector	A broader grouping of companies which categorise a large segment of the economy. Sectors are made up of industries with similar characteristics, thus, companies within a sector may specialise in supplying different types of goods and services.
Standards	Agreed specifications, recommendations, guidelines or principles on products and services. Standards are intended to boost productivity, kick-start innovation and support trade.
Testing	The use of measurement tools and techniques to test the characteristics and performance of products in order to assure consumers, businesses and institutions of their safety and/or demonstrate their quality.
Total demand	The total amount of demand for all finished goods and services in an economy, otherwise known as aggregate demand.