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# A SURVEY OF UK-BASED BUSINESSES USING LABORATORIES FUNDED THROUGH THE NATIONAL MEASUREMENT SYSTEM (2023)

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# A survey of UK-based businesses using laboratories funded through the National Measurement System (2023)

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## ABSTRACT

This report presents detailed analysis of a survey that was conducted in 2023 for the National Measurement System (NMS) programme. The data was collected through a telephone survey of customers who work with three NMS laboratories: NPL, NML at LGC, and NEL. By this means, the NMS programme aims to understand its private sector users, demonstrate the extensive reach of the NMS labs in the UK economy, and assess the impact of the support on innovation and measurement. The respondents belong to defined segments of the population and the poststratification method adjusts the sampling weights to account for underrepresented segments in the sample. The key findings from this report are that: (1) users in the private sector are concentrated in technologically important parts of the UK's economy; (2) 20% of the customers observe transformational changes in innovations and £500 million in sales revenue is attributed to innovations that wouldn't have succeeded without the NMS labs; (3) businesses working with the NMS labs spend £7.7 billion on measurements and the core labs indirectly support 75,500 organisations in the UK through fanout; (4) NMS labs achieved an overall NPS score of 47, with 55% of the respondents identified as promoters and 8% as detractors.

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Approved on behalf of NPL by
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## EXECUTIVE SUMMARY

The UK National Measurement System (NMS) is the nation's technical infrastructure which underpins trade, industry, and regulation. The NMS is supported by the Department for Science, Innovation, and Technology (DSIT) and delivered through measurement laboratories who are dedicated to world-class measurement science. These labs deliver services to underpin the certification of calibrations; and they play a vital role in supporting innovation and growth in the UK.

This is a full report of the NMS Survey findings which essentially covers all the three questionnaires:

- Question set 1 – Questions on context & feedback
- Question set 2 – Measurement related questions
- Question set 3 – Innovation related questions

Every three years, the NMS commissions a survey of customers who use one or more of the following labs: the National Physical Laboratory (NPL), the National Measurement Laboratory at LGC (NML at LGC) and the National Engineering Laboratory (NEL). This report will refer to these as the 'NMS labs', although the NMS programme also provides limited funding to a few other organisations that are not included in this study.

In 2023, Team Telemarketing interviewed a sample of the NMS labs' customers from the private sector. The survey was designed to allow the NMS labs to:

- Assess the reach and impact of the NMS laboratories on the UK private sector businesses.
- Understand the level of innovation activities and the breadth of impact from innovative products/services.
- Understand the scale and value of measurement activities based on spending and fanout.
- Benchmark satisfaction.

This survey is part of the NMS evaluation plan, designed to maintain accountability for the public investment and to enable future funding to be allocated based on evidence of what worked well.

The NMS labs have an extensive private sector customer base of approximately 3000 sites in the UK. The site-level approach allows the NMS labs to better understand the direct impact that the NMS has on businesses. Therefore, the customers were asked about their place of work (e.g., a division of their company) rather than for the whole enterprise. This report refers to 'businesses' but it should be understood that this refers to 'business sites'.

### TOP FINDINGS

1. ***By supplying calibration services and reference materials, the NMS labs reach into important parts of the UK's private sector, and their direct userbase is of an economically significant scale.***

   The businesses that work with the NMS labs make great contributions to the UK's economy. These businesses employ **~711,500 people in the UK**. The business sites that have worked with the NMS labs have **an aggregate turnover of £154 billion**. **The revenue per employee for the sites that work with the NMS labs is ~£216,450**. Around half of these businesses operate within the UK's manufacturing

sector, and these businesses account for **13% of employment in UK manufacturing.**

2. ***The NMS labs play an important role in achieving groundbreaking innovation changes.***

   **20%** of users experience a **transformational change** from their innovations and nearly **two thirds** attribute this change to the NMS labs. **60%** of users experience a **breakthrough change** from their innovation and **a third** attribute this change to the NMS labs. The more radical the scale of innovation, the more importance users attach to the support they receive from the NMS labs.

3. ***Many new or improved products would not have existed without support from the NMS labs, and such products currently generate considerable sales revenue for customers.***

   Revenue impact is the calculated headline number that represents the sales income generated by private businesses from developing or improving new products and reaching new markets using labs' support. The overall private sector customer base, around 2870 UK-based businesses that engaged with the NMS labs, generated **£1.56 billion in revenue from sales of new and improved products**.

   So, what fraction of the aggregate revenue from sales of these new and improved products can be attributed to the labs? **A third of users from the private sector believe that their new and improved products would not exist without the support they received from the NMS labs**. Therefore, each year, around 920 of the UK-based businesses collectively attribute **£500 million** in sales revenue to innovations that wouldn't have succeeded without the NMS labs.

4. ***Innovation support provided by the NMS labs has a notable impact on employment and wages.***

   About **15%** of the users report that innovation activities lead to a **3% increase in employment**, while **basic wages rise by 7.5%**. These findings are consistent with other econometric studies that highlight the strong performance of the supported businesses across various economic indicators, including employment growth.

5. ***The NMS labs facilitate product diffusion through their support towards innovation projects.***

   Product diffusion refers to the indirect benefits or spillovers that arise from pre-defined standards and commercialisation of innovations. The model reveals that **products have a lifetime of 7 years within the firm that originally created them** and a **lifetime of 13 years within the firm's industry.** The calculations also show that there is a **55-45 split** between direct and indirect benefits respectively.

6. ***Extensive and valuable measurement activities are conducted by the NMS labs.***

   It is estimated that **businesses working with the labs spend 5% of their turnover on measurement** and this amounts to **£7.7 billion** each year. Additionally, the measurement spend could also be broken down into **£1.5 billion for calibration** and reference materials, and **£6.2 billion for testing** and analysis. The results also show that the **NMS labs are twice as important as the foreign NMIs** when providing measurement services, underscoring the national importance of the labs.

7. ***The NMS labs provide fanout and traceability of calibration services in the UK economy.***

   The labs work with 35% of all the United Kingdom Accreditation Service (UKAS) accredited calibration labs. This survey found that **the NMS labs indirectly supported 75,500 organisations in the UK through the "fanout" of calibration services** (UKAS labs provide calibrations that are traceable to measurement standards maintained by the NMS labs) provided by the customers.

8. ***Neglecting calibrations would drive up costs in the conformance testing process for firms working with the NMS.***

   The scrap rate derived from the model is 3%, which also equals the scrap rate estimated from the survey responses. Moreover, **a third of the scrap rate comes from the cost of type 1 errors**, meaning that good output is mistakenly scrapped, which is potentially avoidable with a perfect testing process. The other two-thirds (two percentage points) needs to be scrapped because they are defective, which is wholly unavoidable even with a perfect testing process.

   The **proportion of uncertainty that is removed through calibration is 20% of the total uncertainty**. As the uncertainties are added in quadrature, this results in a 2% increase in the relative standard deviation (RSD) of the measurements. On average, the users report an RSD of 21%, which implies that the **cost of mistakes made during conformance testing would increase by 0.1 percentage points**, if the firm were to forego calibrations.

9. ***The NMS labs most strongly provide support to innovations amongst businesses that share a connection to environmental protection and/or could affect human health. The labs are also starting to play a role for a small group of customers who are developing Quantum Technologies.***

   **49%** of the userbase has a line-of-business (or activity) that's connected to improving environmental protection. Moreover, **37%** of these businesses attributed innovations to support from the NMS labs.

   **47%** of the userbase has a line-of-business that feeds into the provision of healthcare services or connects to the fields of public health. Moreover, **31%** of such businesses attributed innovations to support from the NMS labs.

   **7%** of the userbase has a line-of-business connected to the development of quantum technologies. Moreover, **38%** of these businesses attributed innovations to support from the NMS labs (In this case, the sample-size is rather small but these conditional probabilities are noticeably higher than for most other technological areas).

10. ***Customers are satisfied with the NMS labs.***

    To deliver greater impact in the future, it is important to understand how the businesses in the userbase view their relationship with the NMS labs. To measure satisfaction, a Net Promoter Score (NPS) was calculated. With 55% of the respondents identified as promoters and 8% as detractors, NMS labs achieved **an overall NPS score of 47** which is considered 'good' and indicates that there are more happy customers than unhappy ones. However, this also suggests that the NMS labs need to reflect on their current ways of working and strive to deliver the best value for their users. It was also noted that the NMS users are **most satisfied with the quality and least satisfied with price**.

# 1 INTRODUCTION

## 1.1 NMS LABORATORIES

The UK National Measurement System (NMS) is the nation's technical infrastructure which exists to provide the nation with dependable measurements. The top layer of the NMS is comprised of six core laboratories, known as the NMS labs, which underpin measurement accuracy in the UK. The NMS labs are responsible for maintaining the UK's national measurement standards and associated facilities. They then make the benefits of this available to users through a wide range of services and knowledge transfer activities.

**Table 1 Details of the six core NMS labs**

| | | |
|---|---|---|
| **NPL** | National Physical Laboratory | The UK's National Measurement Institute |
| **NML at LGC** | National Measurement Laboratory at LGC | Designated for chemical and biometrology |
| **NEL** | National Engineering Laboratory | Designated for fluid flow metrology |
| **DSIT** | Office for Product Safety and Standards (part of the Department for Science, Innovation, and Technology) | Designated for legal metrology |
| **NGML** | National Gear Metrology Laboratory | Designated for gears metrology |
| **NIBSC** | National Institute for Biological Standards and Control | Designated for bioactivity metrology |

The core NMS labs have the capacity to support metrology in a range of fields, from mass and nuclear metrology to chemical analysis, fluid flow, and bio-metrology. The NMS labs underpin the UK's technical infrastructure by supplying services to the commercial calibration laboratories and to the suppliers of certified reference materials. The calibration labs then go on to calibrate the instruments of their own customers, diffusing measurement accuracy through a chain of linked calibrations. The benefits coming from this second layer of the infrastructure is not discussed in this report, as customers of the commercial calibration laboratories were not interviewed in the survey.

The NMS labs are funded by the Department for Science, Innovation, and Technology (DSIT). DSIT invests ~£100m annually into the NMS so that it can maintain the national measurement standards needed to supply traceable calibration services, as well as undertake research and development (R&D) into new measurement techniques. The NMS laboratories sell products and services to companies to generate additional revenue for the labs, which is then reinvested into the system to increase the impact of the NMS[1].

[1] NMS Customer Survey Report 2018

### 1.2 NMS SURVEY

The NMS survey is a telephone survey of customers who work with the National Physical Laboratory (NPL), the National Measurement Laboratory at LGC (NML at LGC) and the National Engineering Laboratory (NEL). The survey was commissioned by the NMS and run by an independent survey company, Team Telemarketing. Between May and September in 2023, Team Telemarketing contacted 3087 sites who use the NMS labs, and 788 of those contacted responded, achieving a response rate of ~26%.

The NMS survey is a site-based survey, specifically looking at sites for medium and large companies. This survey consists of three question sets:

- Question set 1 – Questions on context & feedback
- Question set 2 – Measurement related questions
- Question set 3 – Innovation related questions

The first question set will be answered by all the respondents, and every site was pre-tagged on a random basis to answer either measurement or innovation related questions. At the beginning of the fieldwork, the total number of sites for the survey were 3087, where 1546 sites were randomly allocated to answer the measurement question set and 1541 sites were allocated to answer the innovation question set.

However, multiple duplicate surveys (more than one survey from the same site) were identified in the final survey responses extract. To fix this complication, sites were redefined using the company account number and postcode. This process resulted in 736 unique sites. The duplicate survey responses from the same site were deleted on a random basis in Stata. For the purpose of analysis, this has resulted in a total of 736 survey responses, where the measurement question set has 393 responses, and the innovation question set has 343 responses.

A first findings report has already been published which is a preliminary analysis that pulls out the top level impact numbers that the NMS labs generate. This report combines the analysis from all the three questionnaires with an aim to: provide insight into the demographics of the NMS users; provide an overview of the innovation activities and explain the role of labs in creating impact from innovations; assess the scale and value of measurement activities along with establishing the fanout of calibration services and estimate the cost of mistakes during conformance testing if firms were to forego calibrations. Additionally, this report also delves deeper and provides an insight into the four key challenge areas.

### 1.2.1 Segmentation and weights

The NMS users that were supported in between the years 2018 to 2022 were segmented based on the size of their firm and the level of support received.

The size of the firms is defined by the number of people employed in the organisation:

- Micro (M) refers to the firms that have 1 to 9 employees.
- Small and medium (SME) refers to the firms that have 10 to 249 employees.
- Large (L) refers to the firms that have 250 or more employees.

The level of support to a firm by the NMS laboratories is defined by three categories:

- Engaged (E) refers to low-intensity support such as classroom trainings, e-learnings, events, and free downloads i.e., anything that is not an invoice or a collaboration.
- Supported (S) refers to the support provided for 1 to 4 years in a 6 year moving window.
- Regulars (R) refers to the support provided for at least 5 years in a 6 year moving window.

The NMS users are segmented in such a way that they represent both the size of their firm and the level of support received. For example, ‘M-E’ in the table below refers to users that are micro and engaged. The weights have been calculated for each segment using the poststratification method. Poststratification is a method to adjust the sampling weights to account for underrepresented segments in the population to decrease bias. This involves adjusting the sampling weights so that they sum to the population sizes within each stratum.

It should be noted that the analyses conducted throughout the report are representative of the entire population of the survey, correcting for the differences in response rates within various segments of the population (unless specified in the report).

**Table 2 Poststratification weights for the whole sample**

| Segment | Sample | Population | Weight |
|---|---|---|---|
| M-E | 63 | 241 | 3.83 |
| SME-E | 130 | 475 | 3.65 |
| L-E | 52 | 341 | 6.56 |
| M-S | 52 | 131 | 2.52 |
| SME-S | 174 | 482 | 2.77 |
| L-S | 86 | 440 | 5.12 |
| SME-R* | 97 | 246 | 2.54 |
| L-R | 82 | 514 | 6.27 |
| **Total** | **736** | **2870** | |

**This segment includes micro sites as well because there are very few micro regulars.*

**Table 3 Poststratification weights for the sample that answered the Innovation Questionnaire**

| Segment | Sample | Population | Weight |
|---|---|---|---|
| M-E | 30 | 241 | 8.03 |
| SME-E | 62 | 475 | 7.66 |
| L-E | 18 | 341 | 18.94 |
| M-S | 25 | 131 | 5.24 |
| SME-S | 82 | 482 | 5.88 |
| L-S | 35 | 440 | 12.57 |
| SME-R* | 47 | 246 | 5.23 |
| L-R | 44 | 514 | 11.68 |
| **Total** | **343** | **2870** | |

**Table 4 Poststratification weights for the sample that answered the Measurement Questionnaire**

| Segment | Sample | Population | Weight |
|---|---|---|---|
| M-E | 33 | 241 | 7.30 |
| SME-E | 68 | 475 | 6.99 |
| L-E | 34 | 341 | 10.03 |
| M-S | 27 | 131 | 4.85 |
| SME-S | 92 | 482 | 5.24 |
| L-S | 51 | 440 | 8.63 |
| SME-R* | 50 | 246 | 4.92 |
| L-R | 38 | 514 | 13.53 |
| **Total** | **393** | **2870** | |

# 2 DEMOGRAPHICS OF USERS OF THE NMS LABS

This section establishes the reach of the NMS laboratories in the UK private sector and identify how economically important their private sector customers are. The NMS is interested in the scale of economic activity amongst the private organisations the labs work with to enable an understanding of the size and importance of its userbase among the wider population of businesses.

## 2.1 PROFILE OF THE NMS USERS

The private sector is very important to the NMS labs and it represents the largest proportion (80%) of their userbase, excluding commercial calibration laboratories. Calibration labs have been self-identified by the survey respondents and form the remaining 20% of the userbase. 42% of the private businesses are small and medium-sized enterprises (SMEs).

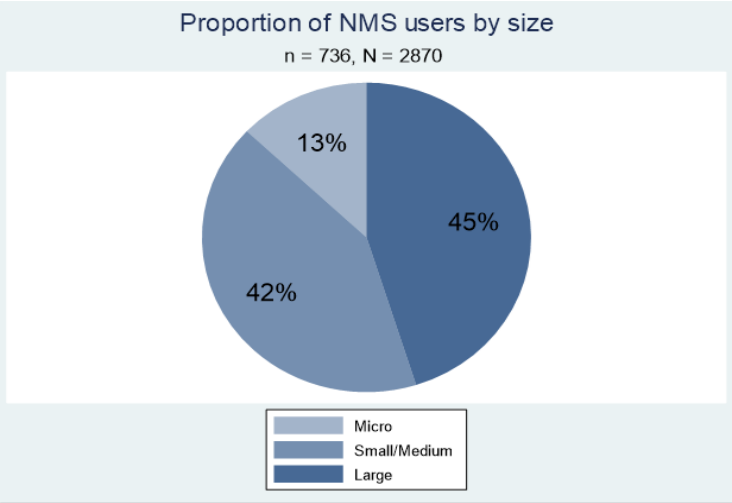



**Figure 1 Proportion of NMS users by size of organisations**

The largest proportion of NMS users is represented by the manufacturing sector, accounting for almost half (48%) of the customer base. This is followed by firms associated with professional, scientific, and technical activities, which accounts for 39% of the NMS users[2].

**Table 5 Count and proportion of users broken down by industries**

| Standard Industrial Classifications | Sample | Population | Proportion |
|---|---|---|---|
| Manufacturing sector | 347 | 1364 | 48% |
| Professional, scientific, and technical activities | 303 | 1128 | 39% |
| Utilities | 22 | 98 | 3% |
| Distribution and transportation | 11 | 52 | 2% |
| Construction | 5 | 27 | 1% |
| Primary sector | 2 | 9 | 0% |
| Other | 46 | 192 | 7% |
| **Total** | **736** | **2870** | **100%** |

The highest proportion of large firms operate in the manufacturing sector (50%) and the industry of professional, scientific, and technical activities (33%).

[2] It should be noted that all the proportions in the tables throughout the report have been rounded to the nearest whole number and therefore might not add up to a 100%.

**Table 6 Count of large firms broken down by industries**

| Standard Industrial Classifications | Sample | Population | Proportion |
|---|---|---|---|
| Manufacturing sector | 111 | 653 | 50% |
| Professional, scientific, and technical activities | 72 | 421 | 33% |
| Utilities | 11 | 63 | 5% |
| Distribution and transportation | 6 | 36 | 3% |
| Construction | 3 | 20 | 2% |
| Primary sector | 1 | 7 | 1% |
| Other | 16 | 95 | 7% |
| **Total** | **220** | **1295** | **100%** |

## 2.2 CATEGORIES OF JOB ROLES

The respondents were asked about the broad category of their job role. Since more than three quarters of them fit into either technical or production roles, this reassures that this survey has reached the right audience who carry the expertise to answer measurement and innovation related questions.

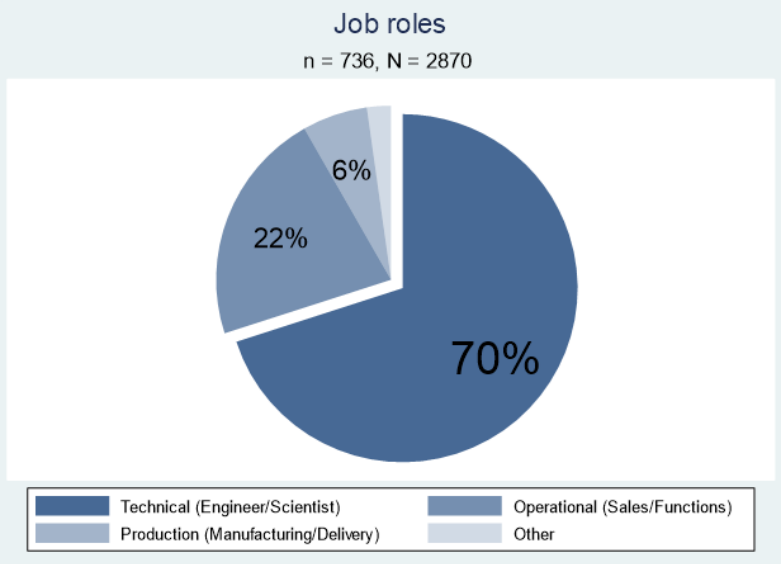



**Figure 2 Proportion of respondents within broad job categories**

## 2.3 MEASUREMENT ACTIVITY IN SCIENTIFIC AREAS

The respondents were asked to choose a scientific area in which they conduct most of their measurement activity. It can be observed that mass and dimensional, material properties, and thermal and radiometric metrology account for more than half (56%) of the measurement activity that occurs within all the scientific areas.

As the broad scientific area 'Materials & Mechanical Metrology' has a large proportion of the NMS users, it has been split into three sub-sections: Mass & Dimensional, Material Properties, and Other Engineering Metrology.

**Table 7 Count and proportion of users for scientific areas in measurement**

| Scientific areas for measurement activities | Sample | Population | Proportion |
|---|---|---|---|
| Mass & Dimensional | 180 | 725 | 25% |
| Material Properties | 149 | 566 | 20% |
| Thermal & Radiometric Metrology | 92 | 326 | 11% |
| Electromagnetic & Electrochemical Technologies | 63 | 228 | 8% |
| Other Engineering Metrology | 42 | 170 | 6% |
| Chemical & Biological Sciences | 39 | 158 | 6% |
| Medical, Marine & Nuclear | 40 | 155 | 5% |
| Atmospheric Environmental Science | 36 | 148 | 5% |
| Time & Frequency | 11 | 41 | 1% |
| Quantum Metrology | .[3] | 8 | <1% |
| Other | 82 | 345 | 12% |
| **Total** | **736** | **2870** | **100%** |

## 2.4 PRODUCTS AND SERVICES UTILISED BY NMS USERS

The respondents were asked to choose the services they utilised between 2018-2021. The figure shows that the majority of the users use calibration services, publications and collaborate with the scientists of the NMS labs.

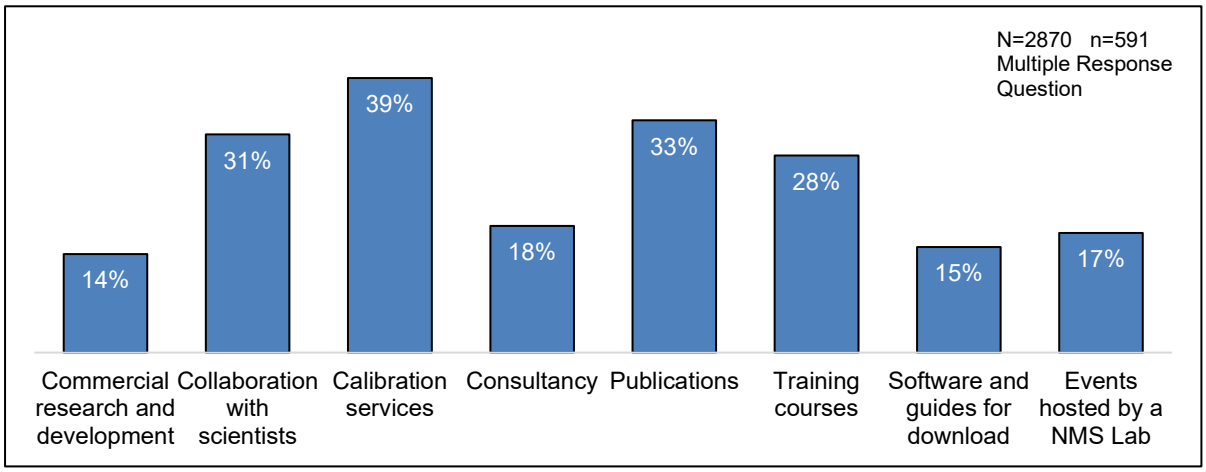



**Figure 3 Products and services that users of the NMS labs utilise**

[3] The count in this category is below 5 and therefore is not statistically significant. It is therefore represented using the period.

## 2.5 GEOGRAPHICAL SPREAD

A site-based survey is a better measure to analyse the geographical spread because the headquarters of an organisation is mostly located in a major city, for e.g., London, but the technical work would ideally be conducted at sites which are situated away from the headquarters. This explains why the numbers for London could be lower when compared to areas such as the Midlands.

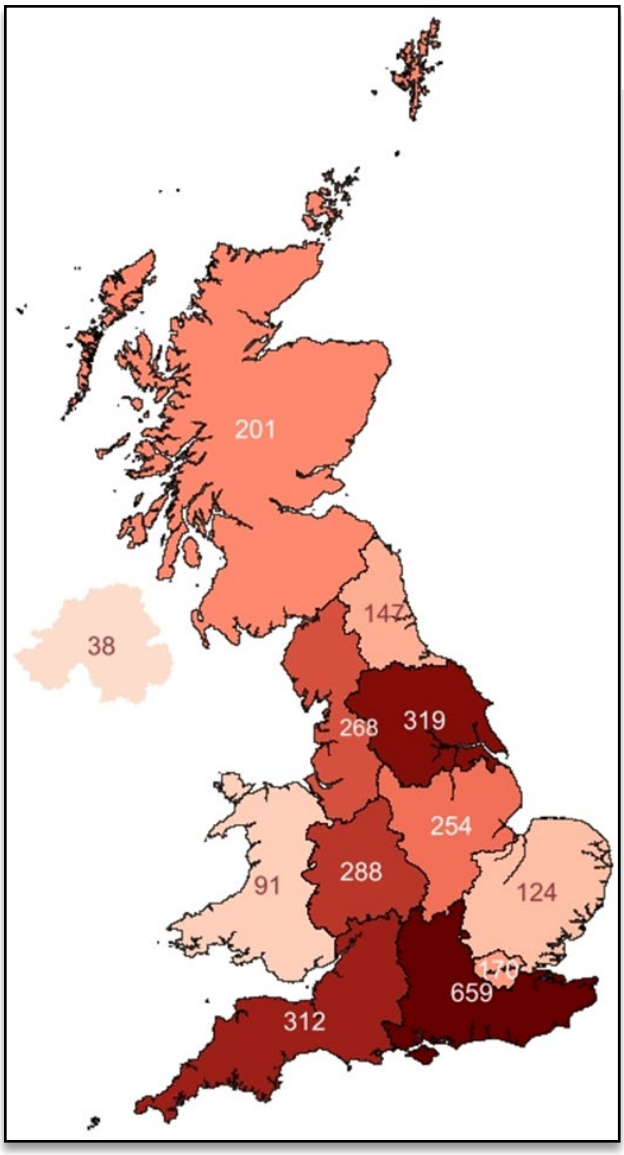



**Figure 4 Count of NMS users in NUTS regions**

**Table 8 Count of NMS users in NUTS regions**

| NUTS Region | Sample | Population |
|---|---|---|
| North East | 35 | 147 |
| North West | 72 | 268 |
| Yorkshire and the Humber | 77 | 319 |
| East Midlands | 64 | 254 |
| West Midlands | 71 | 288 |
| East of England | 32 | 124 |
| London | 43 | 170 |
| South East | 172 | 659 |
| South West | 87 | 312 |
| Wales | 24 | 91 |
| Scotland | 50 | 201 |
| Northern Ireland | 9 | 38 |
| **Total** | **736** | **2870** |

South East England, South West England, and Yorkshire and the Humber are three most populated areas with NMS customers in the United Kingdom (UK). **The Greater South East (GSE) region, comprising the South East England; London; and East of England, amounts to 33% of the NMS users**.

### 2.5.1 NMS regularly supported firms in comparison with GDP proportions

The map below shows the proportion of NMS regularly supported firms in each NUTS region. The GSE region amounts to 33% for the NMS regularly supported firms in the UK. Similarly, when the regional product in the UK is computed, the GSE region amounts to 46%.

Comparatively, this shows that the NMS regularly supported firms operate in regions outside of the GSE area, accounting for widespread business activity. It is important for the NMS labs to have beneficiaries scattered all over the UK rather than focusing on and around the "Golden Triangle".

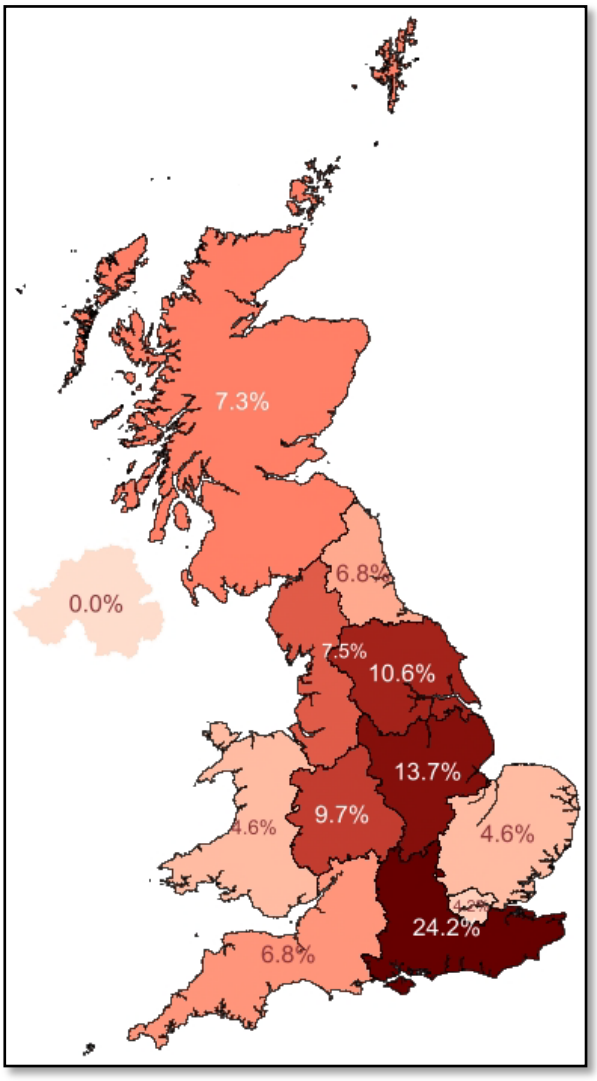



**Figure 5 Proportion of NMS regularly supported firms in NUTS regions**

**Table 9 Proportion of NMS regularly supported firms Vs. GDP proportions**

| NUTS Region | Regularly supported | GDP Proportion |
|---|---|---|
| North East | 7% | 3% |
| North West | 7% | 10% |
| Yorkshire and the Humber | 11% | 7% |
| East Midlands | 14% | 6% |
| West Midlands | 10% | 7% |
| East of England | 5% | 8% |
| London | 4% | 23% |
| South East | 24% | 15% |
| South West | 7% | 7% |
| Wales | 5% | 4% |
| Scotland | 7% | 7% |
| Northern Ireland | 0% | 2% |
| **Total** | **100%** | **100%** |

### 2.5.2 Quotient analysis

This is a quotient analysis modelled on regional or location quotients. To compute the quotient for each NUTS region, the proportion of NMS regularly supported firms is divided by the GDP proportions.

**Table 10 Quotient analysis for NMS regularly supported firms in the UK**

| NUTS Region | Regularly supported | GDP Proportion | Quotient | % change[4] |
|---|---|---|---|---|
| North East | 7% | 3% | 2.4 | 137% |
| North West | 7% | 10% | 0.8 | -23% |
| Yorkshire and the Humber | 11% | 7% | 1.6 | 59% |
| East Midlands | 14% | 6% | 2.3 | 133% |
| West Midlands | 10% | 7% | 1.3 | 35% |
| East of England | 5% | 8% | 0.5 | -45% |
| London | 4% | 23% | 0.2 | -82% |
| South East | 24% | 15% | 1.6 | 64% |
| South West | 7% | 7% | 0.9 | -9% |
| Wales | 5% | 4% | 1.3 | 33% |
| Scotland | 7% | 7% | 1.0 | -2% |
| Northern Ireland | 0% | 2% | 0.0 | -100% |

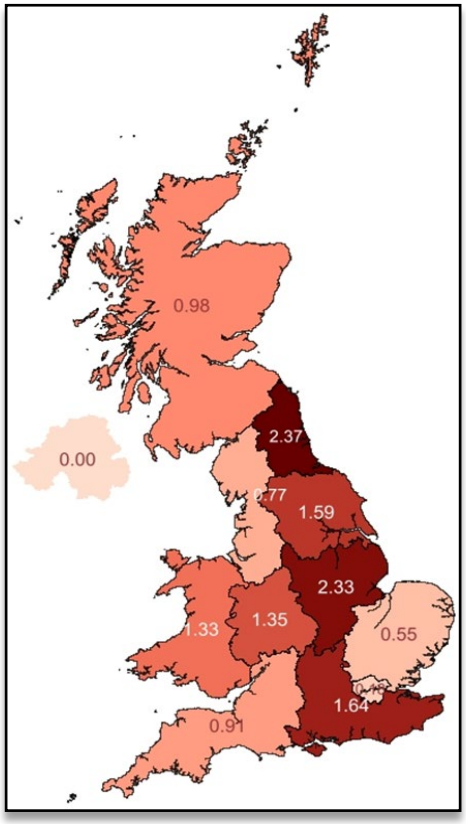



**Figure 6 Regional quotients**

The quotient shows the presence of NMS regularly supported firms across the NUTS region in comparison to the respective regional products. North East England, East Midlands, South East England, and Yorkshire & the Humber hold a higher concentration of the NMS regularly supported firms, thereby contributing to more business activity in those respective regions, in contrast to the regional products. On the other hand, there is room to strengthen our userbase in Northern Ireland.

[4] The percentage change was calculated using the formula: $\frac{Regularly\ supported - GDP\ proportion}{GDP\ proportion}$

## 2.6 CUSTOMERS' VIEW ON THEIR RELATIONSHIP WITH THE NMS LABS

To understand, why customers choose to work with the NMS labs, they were asked about the benefits of working with the NMS labs over other suppliers. A substantial proportion of our customers (65%) trust that the labs help increase confidence in measurements, which highlights the key role that is played by the NMS labs in the field of measurement in the UK economy. Many also choose to work with the NMS labs over other suppliers as they are convinced that it helps expand the capabilities of their businesses and also increase the satisfaction of their customers.

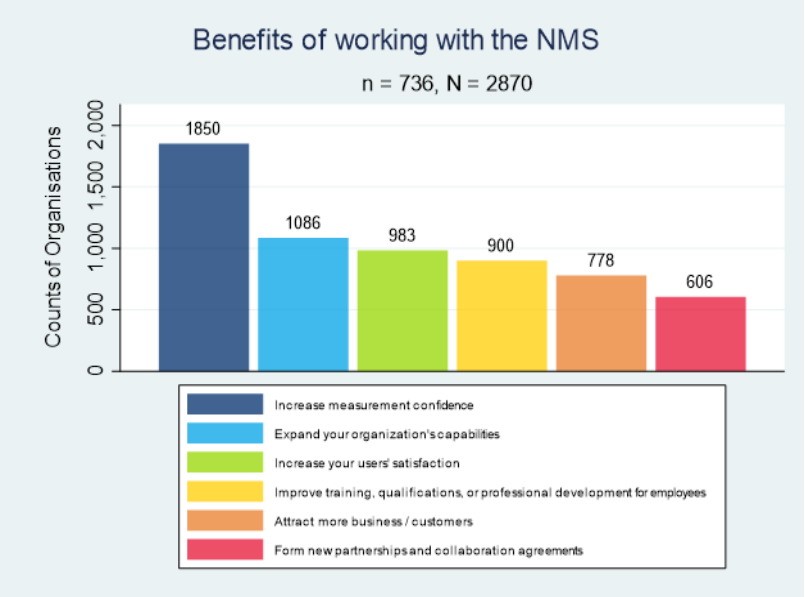



**Figure 7 Perceived benefits of working with the NMS labs**

# 3 INNOVATION CHAPTER

The focus of this chapter is to:

1. **Understand the categories of innovation activities and the role NMS labs play to support their users.**

   The NMS labs look to draw out the main areas of support, scale of innovation change they help achieve and estimate the contribution split between the labs and the users.

2. **Understand three streams of impact from the innovation activities: Revenue; Employment and Spillovers.**

   Customers who use the NMS labs are often active innovators, using the support they receive to create and improve products and processes. The aim is to quantify the:
   - annualised revenue generated from the sale of products which business customers think would not exist without the support they received from the NMS labs.
   - impact of innovation activities on employment level and basic wages.
   - spillovers (indirect benefits) generated from the innovations.

A set of conditions are used for this section. Where applicable, the results have been restricted to users that have done some form of innovation activity with the NMS labs and made some change to their innovation[5].

## 3.1 OVERVIEW OF INNOVATION ACTIVITIES

The chapter is divided into three subsections where the first subsection provides an overview of the categories of innovation project users utilise, the second subsection explains the role of the NMS labs in the innovation activities and the third subsection calculates the contribution split between the NMS labs and the users in a project.

### 3.1.1 Categories of innovation activities

The respondents were asked about the category of the innovation project they worked most closely with the NMS labs. It is evident that **the support of the labs stands out for two main categories: 'compliance with standards and regulation' and 'developing new products and services'**. It can be observed that there is a skewness to product innovation. This is discussed further in section 3.2.2.

[5] Questions used for these conditions are:
- Thinking about the innovation project that you worked most closely with NMS on, which category did it belong to?
- What level of innovation change was achieved by the project?

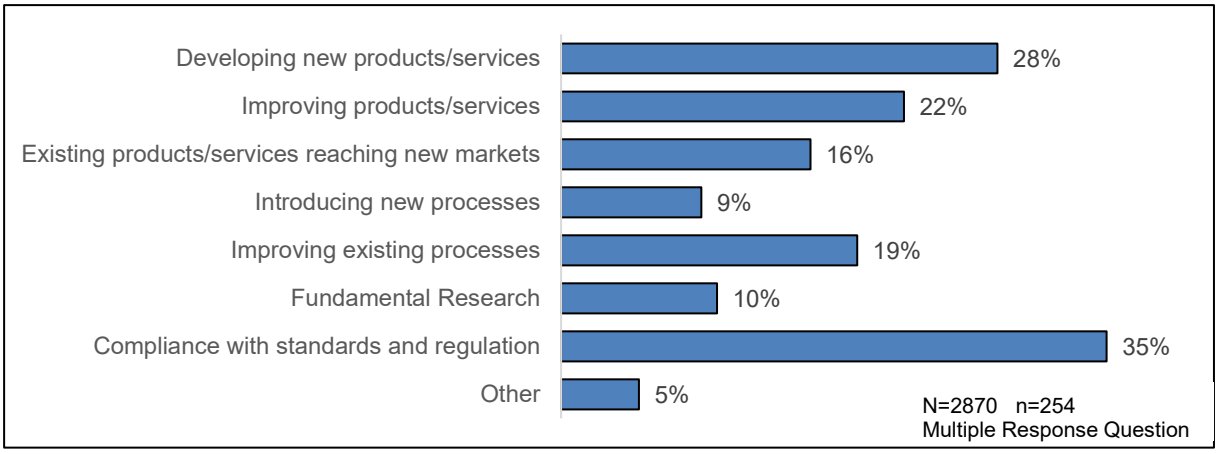



**Figure 8 Categories of Innovation Project worked with NMS labs**

It is noteworthy that the proportion of users that come to the labs for developing new products and improving existing ones is higher than the national average of **19% as reported in UK Innovation survey**[6].

Moreover, the table below includes the users who rated the innovation activities important[7] and used the NMS labs for them, using conditional probabilities.

The Venn diagram sets the context for the subsequent analysis:

- Set A – refers to the importance associated to innovation activities by the firm.
- Set B – refers to the assistance received by the NMS labs for innovation activities.
- Intersection (A∩B) – refers to the firms that view innovation activities as important and have received assistance from the NMS labs for these activities.

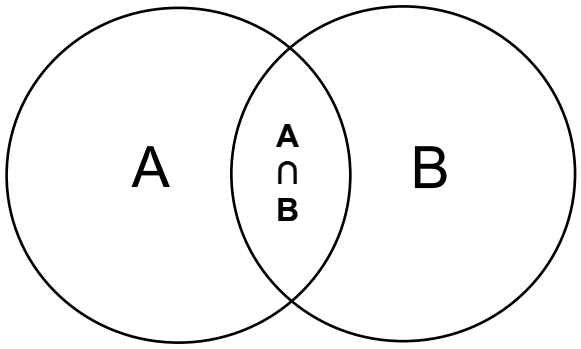



**Figure 9 Venn diagram for conditional probabilities**

In this case, the conditional probability of assistance received by the NMS labs (event B) is the probability that it will occur, given the knowledge that the firm deems innovation activities important (event A). This probability is written as $\boldsymbol{P(B|A)}$**,** notation for the probability of B given A.

[6] UK Innovation Survey 2023 – Statistical Annex

[7] The question 'How important is innovation to your organisation for each of the following business as usual activities?' is answered using a grid which includes 'Very important', 'Moderately important' and 'Not important'. The categories very important and moderately important are classed as important in this case.

The equation for conditional probability is as follows:

$$P(B|A) = \frac{P(A \cap B)}{P(A)}$$

**Table 11 Conditional probabilities for importance for innovation activities and labs' assistance**

| **Business-as-usual activities** | $P(A \cap B)$ | $P(A)$ | $P(B\|A)$ |
|---|---|---|---|
| Developing new products and services | 25% | 91% | 27% |
| Improving products and services | 19% | 93% | 20% |
| Introducing new processes | 7% | 88% | 8% |
| Improving existing processes | 16% | 91% | 18% |
| Fundamental Research | 9% | 92% | 10% |
| Compliance with standards | 31% | 96% | 32% |

The users come to the NMS labs predominantly for 'Compliance with Standards' and 'Developing new products and services'.

**96% of the users deem compliance with standards as an important innovation activity. And 31% of these businesses have received support from the NMS labs.**

**Similarly, 91% of the users deem developing new products and services as an important innovation activity. And 25% of these businesses have received support from the NMS labs.**

On the other hand, although 88% of the users deem introducing new processes as an important innovation activity, only 7% of these businesses have received support from the NMS labs.

Furthermore, it can be seen that irrespective of the size, compliance with standards and developing new products are the two most supported categories of innovation. However, the third most supported category slightly varies by size groups. For **SMEs and micro firms**, the third most important category is **improving products and services** as shown in Figure 10.

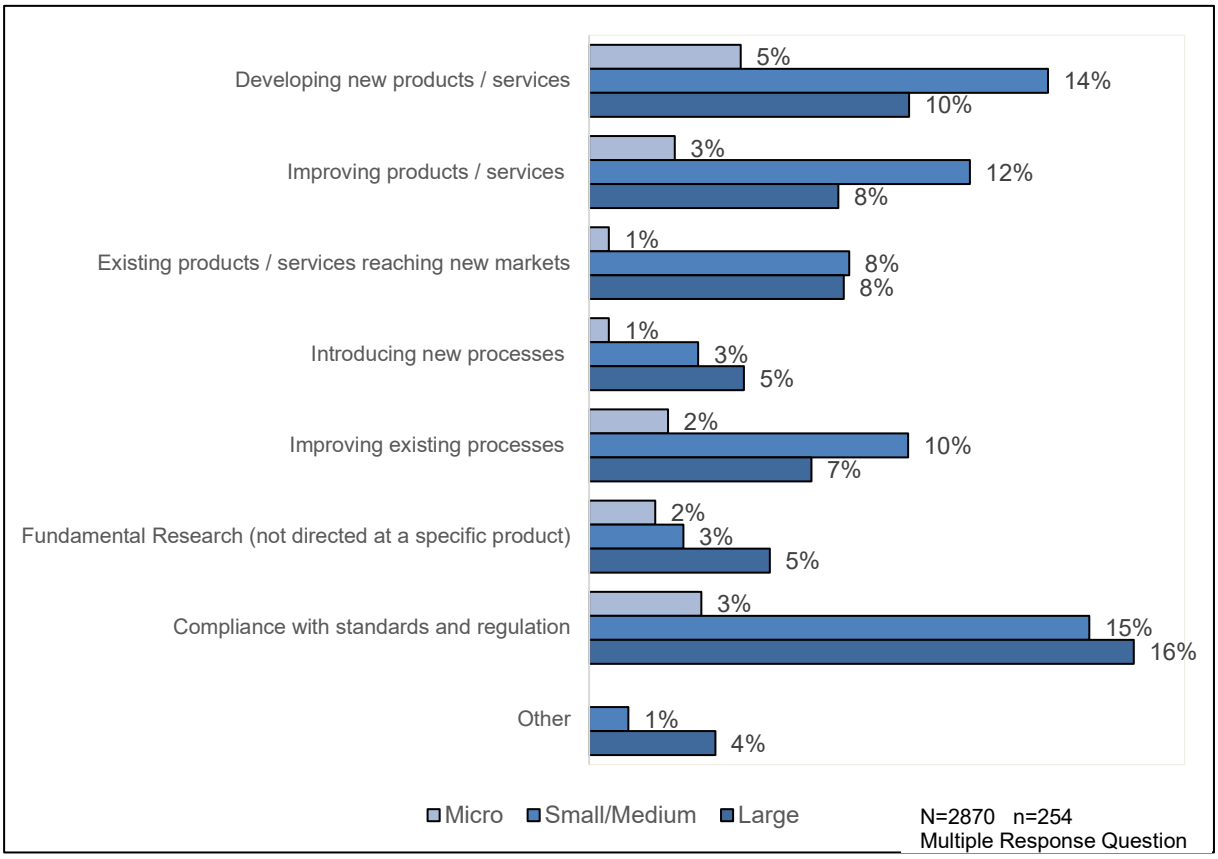



**Figure 10 Categories of Innovation Project worked with NMS labs by size**

In addition, the figure below analyses the innovation categories by whether the organisation belongs to the manufacturing or the non-manufacturing sector. It is noteworthy that for support with compliance to standards and regulation, and for introducing new processes, users who belong to the non-manufacturing sector have a higher proportion than those belonging to the manufacturing sector.

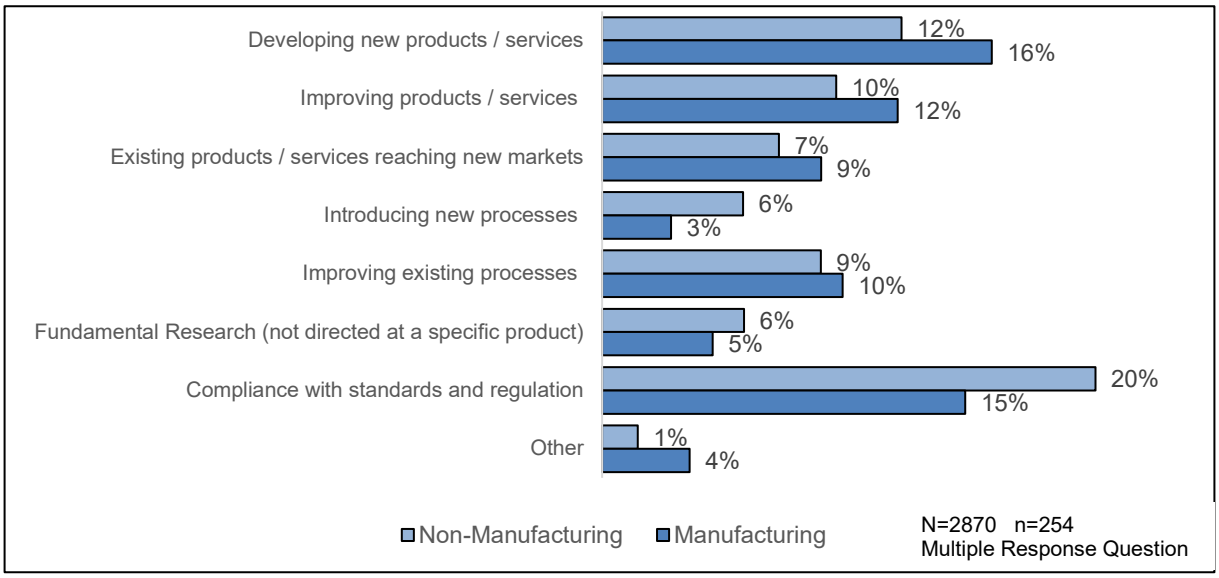



**Figure 11 Categories of Innovation Project worked with NMS labs by SIC section**

### 3.1.2 Role of NMS labs in innovation activities

The users report that the major support they receive by the NMS labs is through **helping them reduce risks** and **by enabling more effective improvements**.

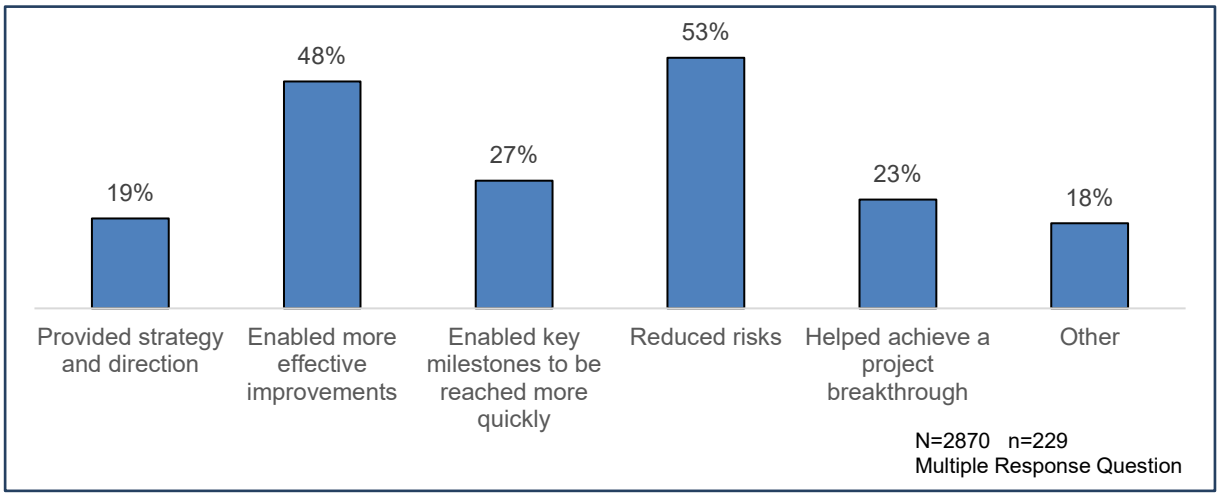



**Figure 12 Ways in which NMS labs support its users**

The table below shows a correlation table to see if the categories are interlinked. The results show that most of these categories load up together positively. Some of these categories can be bundled and further work can be done by applying the Principal Components Analysis method.

**Table 12 Correlation of categories of support**

| | Provided strategy and direction | Enabled more effective improvements | Enabled key milestones to be reached more quickly | Reduced risks | Helped achieve a project breakthrough |
|---|---|---|---|---|---|
| Provided strategy and direction | 1 | | | | |
| Enabled more effective improvements | 0.28*[8] | 1 | | | |
| Enabled key milestones to be reached more quickly | 0.18* | 0.31* | 1 | | |
| Reduced risks | 0.09 | 0.25* | 0.26* | 1 | |
| Helped achieve a project breakthrough | 0.16* | 0.28* | 0.34* | 0.08 | 1 |

[8] The * shows that these components are significant at the 5% level

The next figure looks at ways the labs support its users, by size of companies. The general pattern is that NMS labs are most helpful in reducing risks and enabling more effective improvements. However, for **micro and SMEs**, NMS labs' contribution **to enabling milestones to be reached more quickly** is also very important.

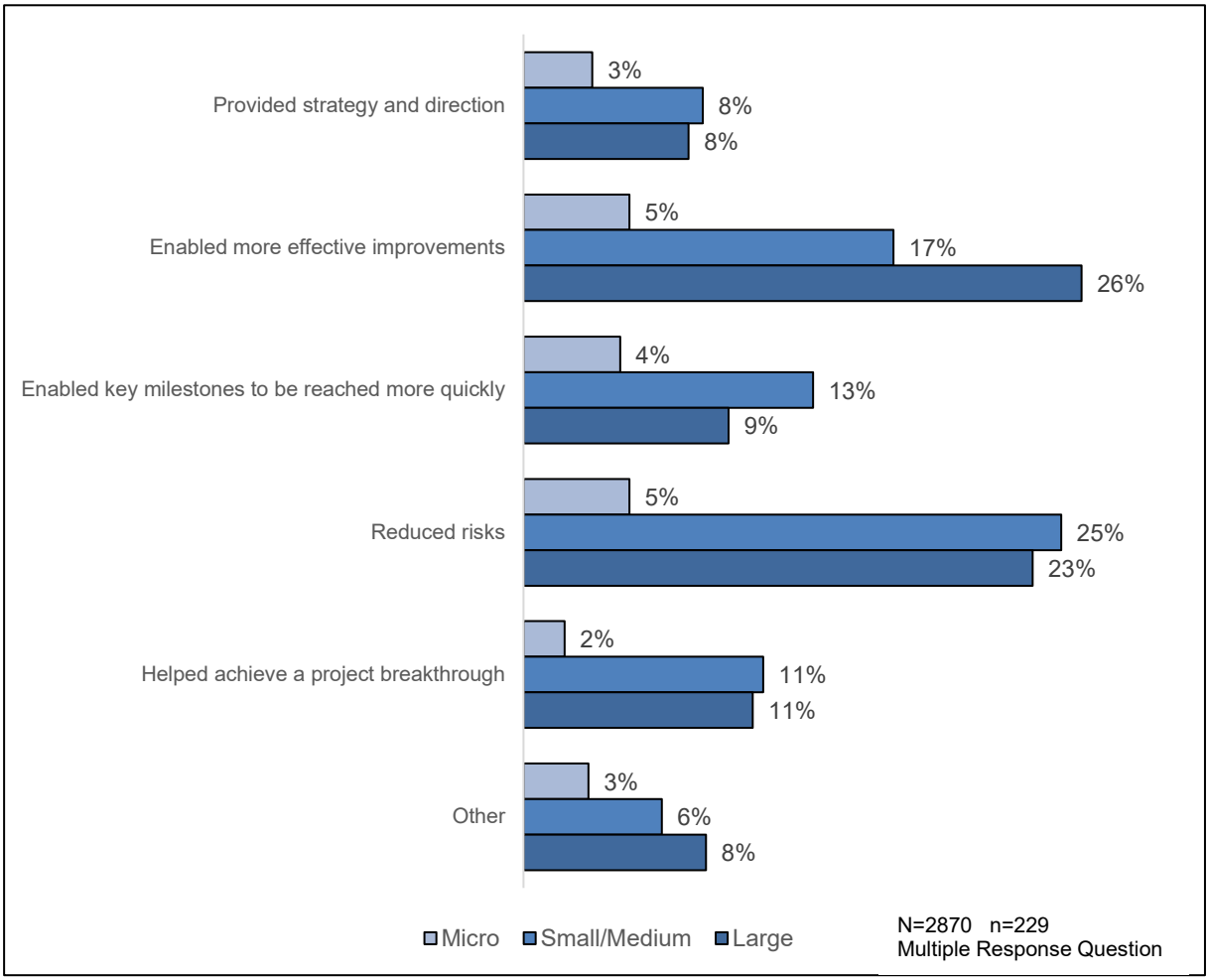



**Figure 13 Ways in which NMS labs support its users by size**

### 3.1.3 Level of Innovation Change

The following figures help guage the scale of the innovation change[9] experienced by users and the attribution to the NMS labs. They suggest that nearly **60% of the users experience a breakthrough change from their innovation and a third attribute this change to the NMS labs. 20% experience a transformational change and two thirds attribute it to the NMS labs.** This implies that the more radical the scale of innovation, the more importance users attach to the support they receive from the NMS labs.

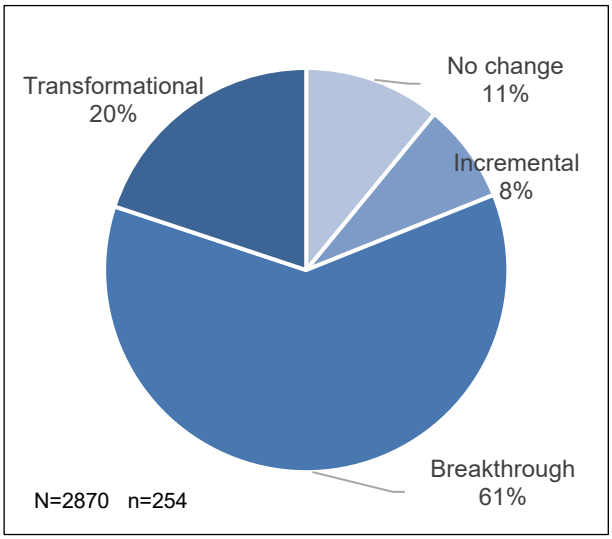



**Figure 14 Level of innovation change experienced by users**

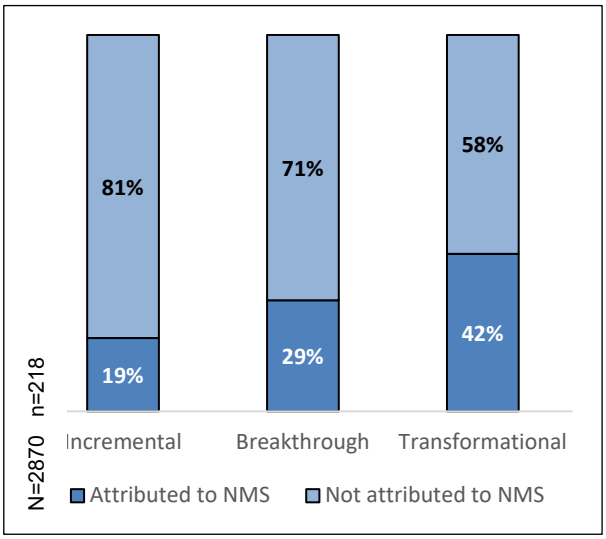



**Figure 15 Level of innovation change and attribution to the NMS labs**

As discussed above that a skewness to product innovations can be observed. This is because process innovations may as well require incremental innovation changes whereas product innovations require more radical changes. It can be seen from the figures above that almost **80% of our users experience a groundbreaking and transformational change**. Also, the support of NMS labs becomes ever more important as the scale of innovation change becomes radical.

[9] The respondents were asked, what level of innovation change was achieved by the project? They were given a scale of 0 to 10 with 0 referring to no change and 10 referring to disruptive or transformational change. Broad categories have been formed for 'No change (scale = 0)', 'Incremental (scale = 1-4)', 'Breakthrough (scale = 5-8)' and 'Transformational (scale = 9-10)'.

In addition, **25% of the respondents reported that they experienced projects being abandoned**. According to the UKIS, **3%** of businesses say they experience abandoned activities. In comparison, the proportion of NMS users that report abandoned projects is high but then again, it is seen that a greater proportion of users come to the labs for product innovations compared to the national average.

The figure below looks at the relationship between scale of innovation change and the proportion of users that report abandoned projects. **A significant proportion of those that experience abandoned projects report groundbreaking and transformational change for their innovation**, implying that users engage in riskier projects.

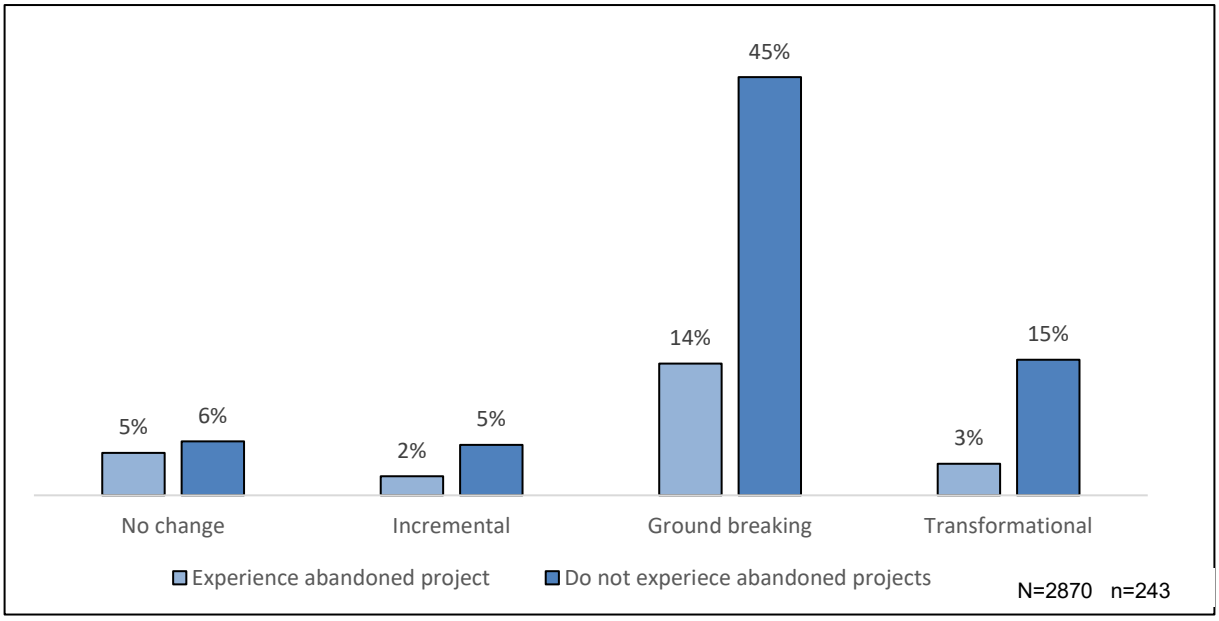



**Figure 16 Scale of innovation change experienced by users who report if they experience abandoned project**

In addition, it can be observed that the highest proportion of users that experience abandoned projects come to the labs for developing new products / services.

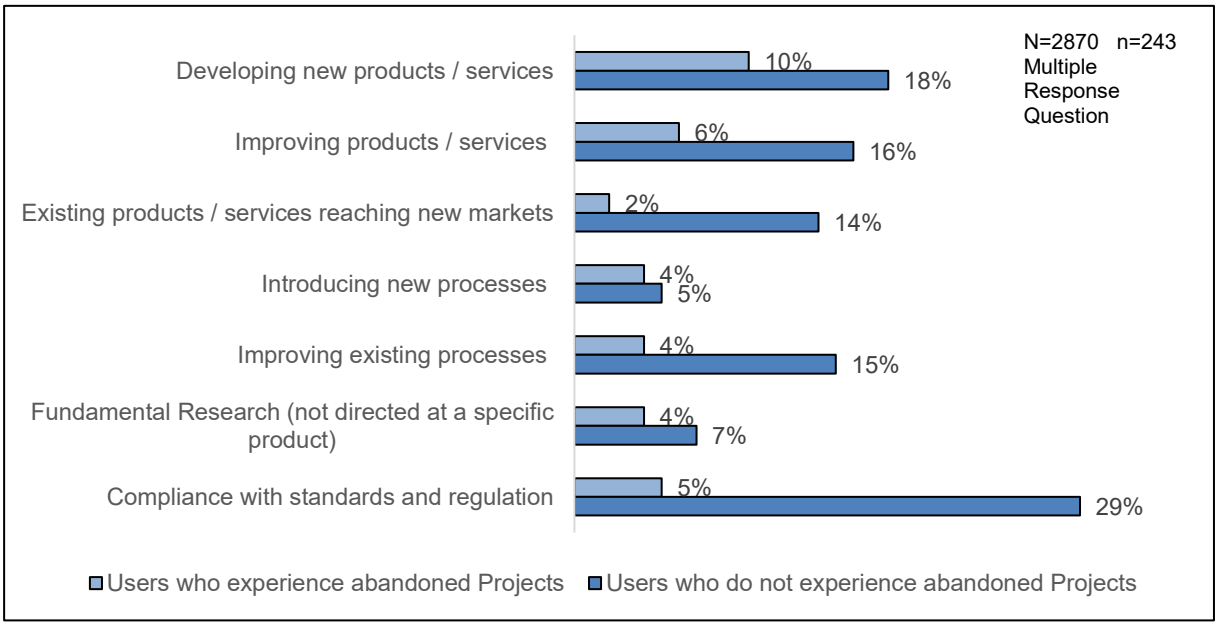



**Figure 17 Relationship between types of innovation activities and abandoned projects**

And as discussed above product innovation requires more radical changes. These statistics imply that NMS users are involved in risky projects for which the probability of a project being abandoned is also higher. Hence, the high proportion of users reporting abandoned projects.

Also, looking at the figure below, it can be observed that the highest proportion of users that experience abandoned projects report NMS helps reduce risks. It may be argued that NMS labs help by reaching the 'fail' stage faster.

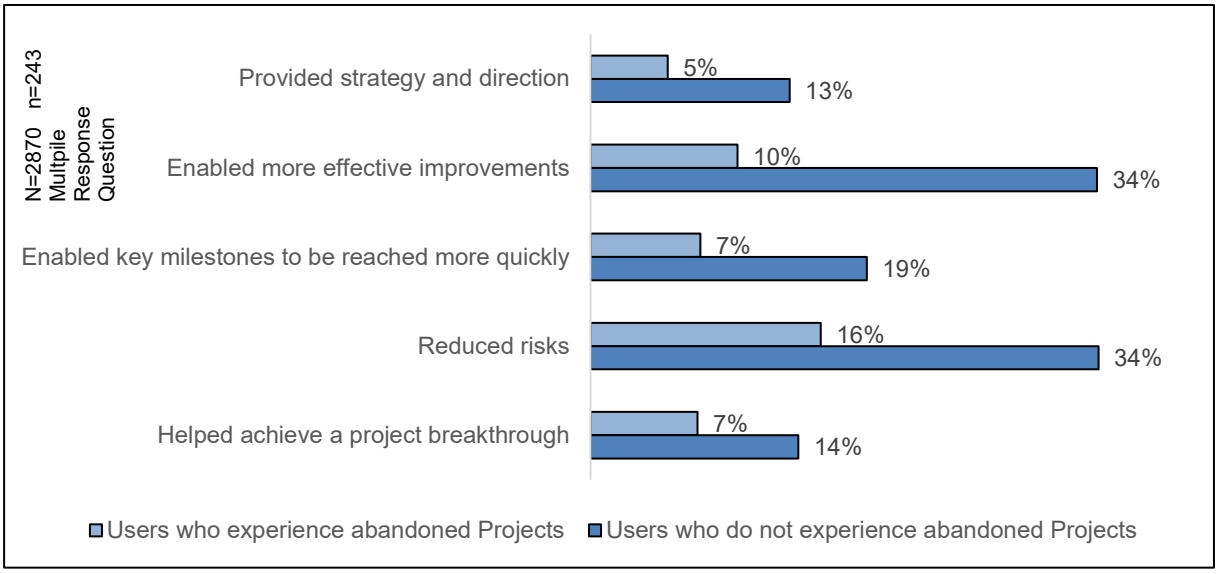



**Figure 18 Relationship between ways of support by the labs and abandoned projects**

Moreover, a regression is conducted to infer whether standards have a connection with abandoned projects. It can be deduced that standards almost act as an insurance policy for innovation projects i.e., the compliance with standards and regulations lead to a lesser abandonment of innovation projects as shown in the negative coefficients.

```
. svy : reg d_aban ino1g if nmi1!=4
(running regress on estimation sample)
note: regress reduced the estimation sample, rerunning regress with poststratification adjustment accounting for new estimation sample.

Survey: Linear regression

Number of strata =   1                         Number of obs   =     280
Number of PSUs   =  280                        Population size =   2,870
N. of poststrata =    8                        Design df       =     279
                                               F(1, 279)       =    9.12
                                               Prob > F        =  0.0028
                                               R-squared       =  0.0265

                             Linearized
      d_aban |  Coefficient  std. err.      t    P>|t|     [95% conf. interval]
-------------+------------------------------------------------------------------
       ino1g |   -.150474   .0498402    -3.02   0.003    -.2485845   -.0523634
       _cons |   .2880365   .0351811     8.19   0.000     .2187824    .3572907

. svy : reg d_aban st_vimp if nmi1!=4
(running regress on estimation sample)
note: regress reduced the estimation sample, rerunning regress with poststratification adjustment accounting for new estimation sample.

Survey: Linear regression

Number of strata =   1                         Number of obs   =     280
Number of PSUs   =  280                        Population size =   2,870
N. of poststrata =    8                        Design df       =     279
                                               F(1, 279)       =    4.44
                                               Prob > F        =  0.0361
                                               R-squared       =  0.0242

                             Linearized
      d_aban |  Coefficient  std. err.      t    P>|t|     [95% conf. interval]
-------------+------------------------------------------------------------------
     st_vimp |  -.1731764   .0822298    -2.11   0.036     -.335046   -.0113068
       _cons |   .3831458   .0795705     4.82   0.000     .2265112    .5397805
```

**Figure 19 Regression results**

### 3.1.4 Alternative Support

The survey entails a series of questions on whether users could have carried out their innovation project without NMS labs' support and if so, do they have access to alternative support? **The results suggest that 32% of the userbase deem the labs important and report that they couldn't have done it without their support.**

The figure below shows a breakdown of where the rest of the **68%** get alternative support from.

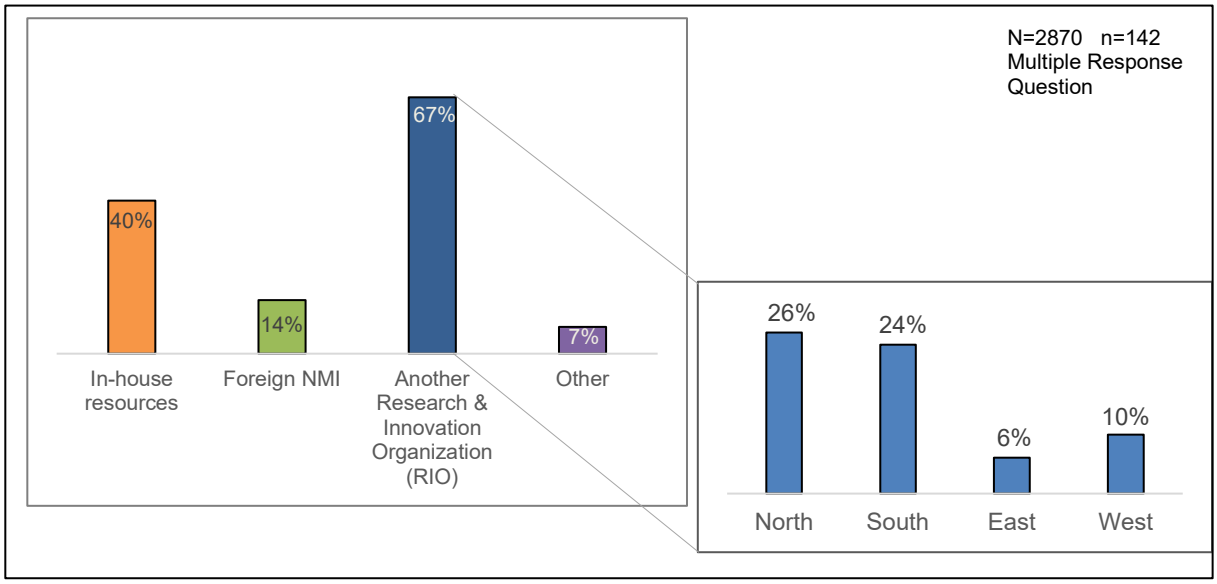



**Figure 20 Type of alternative support used and the location of the users**

It can be observed that the major source of alternative support are other RIOs. It also shows that it is mostly the users based in the north and the south region that go to other RIOs. Note that the regions shown in the RHS of the figure equate to 67%.

On the other hand, to gauge which sources of knowledge do NMS users rely on, they were asked what fraction of knowledge they acquire from firms, and universities/ PSREs. The median suggests that 7% acquire knowledge from firms and 10% acquire from universities. These numbers are very close to the national average found in the UKIS, where nearly 7% regard commercial firms as important sources of information, 4% regard universities and 6% regard public research institutes as important sources of information. The arrows in the figure below highlight the relevant areas.

A point worth noting is that there are various other sources from which knowledge is acquired. With a bit more work this could be further analysed and in upcoming surveys, more categories of knowledge sources can be included.

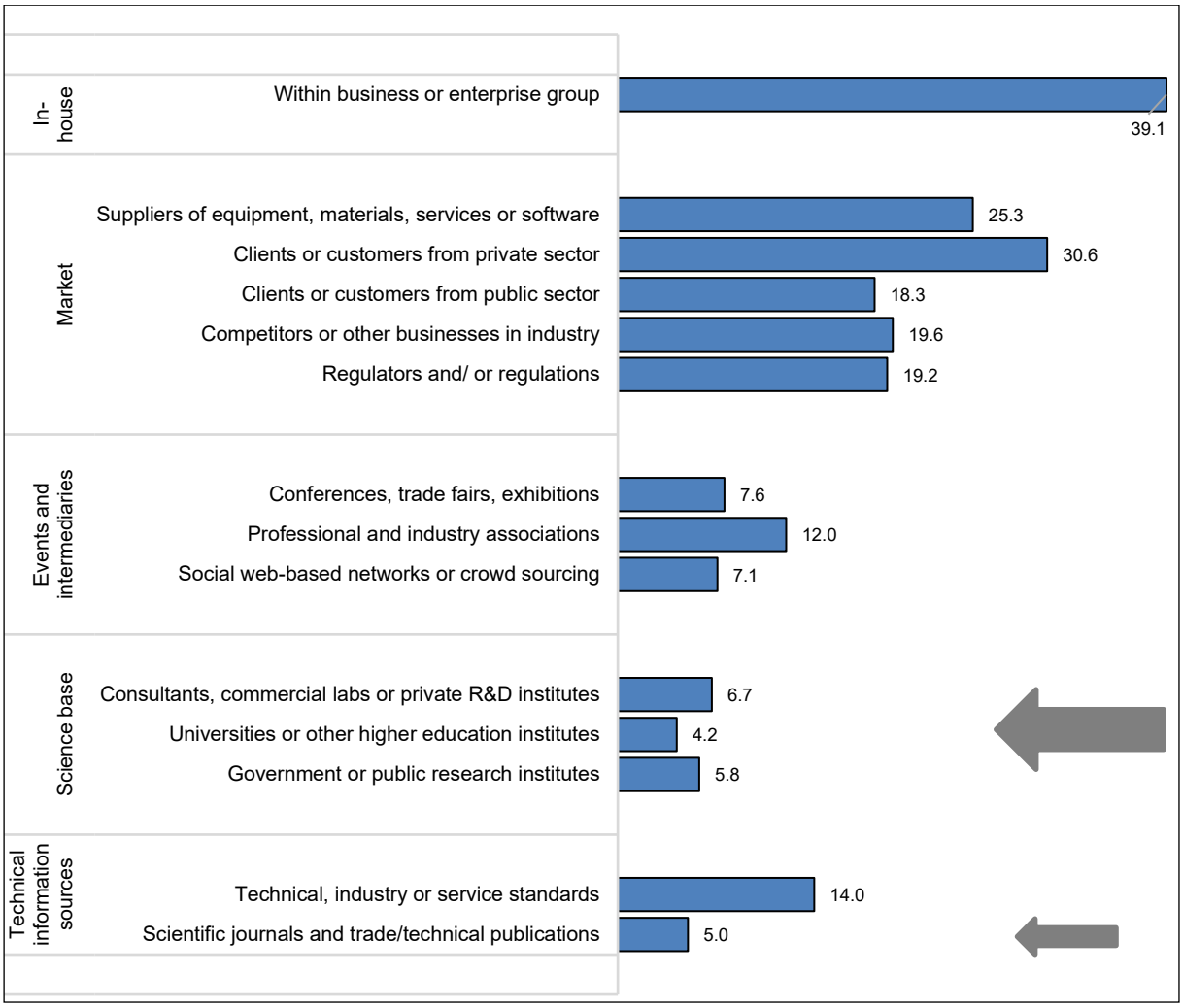


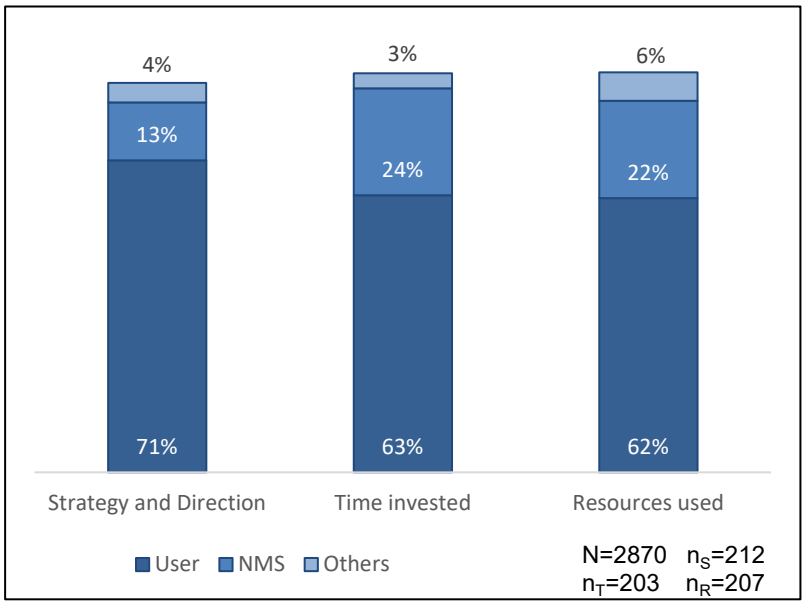

**Figure 21 Sources of information (Percentage of broader innovators rating listed information sources as "highly important" to innovation activities), 2020 to 2022**

### 3.1.5 Contribution split between NMS labs and the organisations

For this round of the NMS survey, to better understand the contribution split in an innovation activity between a user, the NMS labs and other organisations, three aspects were looked at:

- Strategy and direction
- Time invested
- Resources used

The figure below summarises the results obtained.




Note that the three contributors should equate to 100%. The reason why It doesn't equate to 100% is that the data contains some missing values. The software used for analysis 'Stata' treats these missing values independently even though the three categories (NMS, you and others) are connected. Since the proportion of the missing values is minimal, any approach like the multiple imputation method will not give very different results. Therefore, the data is kept as it is.

**Figure 22 Contributors in an Innovation activity**

The figure shows that for both 'Time invested' and 'Resources used' there is a one third two thirds split between the labs and the users, respectively. The support by other organisations is very minimal. In terms of strategy and direction, less contribution from the labs is required compared to the other two categories.

The next key step is to aggregate the three components to compute the overall split between NMS labs and the user. Strategy and direction can be described as more qualitative while the other two are more quantitative. It is, therefore, sensible to use the time invested and resources used, to compute the split between the three contributors. Nevertheless, the table below uses both approaches to compute the overall split. Geometric mean is used for calculating the split in both scenarios.

**Table 13 Contribution Split**

| | User | NMS labs | Others |
|---|---|---|---|
| Geometric Mean with all three components | 65% | 19% | 5% |
| Geometric Mean with Time invested, and Resources used | 62% | 23% | 5% |

The two results are not very different but since the second split is based on the nature of the variable, it is sensible to go with that split. This implies that **for a particular project, users are contributing 2.7 times more (in terms of their time invested, cost and other resources) into making these innovation changes compared to the NMS labs.** The previous NMS survey report found that the users contributed twice as much of their own resources into innovation changes than the NMS labs.

## 3.2 IMPACT FROM INNOVATION ACTIVITIES

This chapter connects to the support from the NMS labs which enables the development, improvement and production of products and processes. There are numerous ways in which the NMS labs support companies when developing new products/ processes and improving existing ones. This support frequently results in companies enjoying economic benefits. This report focuses on three main streams of impact that stem from the innovation activities: revenue impact; employment impact and spillovers generated from innovation activities.

### 3.2.1 Revenue impact

This section is divided into four sub sections. Firstly, a description is provided on the headline turnover numbers. Then the revenue impact from innovation activities is explained in detail starting from defining it, explaining the methodology and finally presenting the results.

#### 3.2.1.1 Background

The respondents were asked questions relating to the turnover at their business sites[10]. This helps the NMS labs understand the contribution that their customers make to the UK economy.

The business sites that use the NMS labs have **an aggregate turnover of £154 billion**[11]. It is noteworthy to mention that the sites that work with the NMS labs hold great importance as they create considerable economic value. It is possible that some proportion of this economic activity could be at risk if they do not continue receiving support from the NMS labs.

Furthermore, **the revenue per employee for the sites that work with the NMS labs is ~£216,450**. This roughly measures the revenue generated by each employee for the site. The sites that use the NMS labs have a higher revenue per employee when compared to the national average of £136,843 for the professional, scientific, and technical activities industry; and a lower revenue per employee when compared to the national average of £263,328 for the manufacturing sector[12].

In 2018, the business sites that used the NMS labs had an aggregate turnover of around £188 billion. Even though a decrease can be observed in the turnover figures within the last 4 years, it is important to recollect that this period experienced economic shocks.

In addition, they were asked to report a minimum rate of return their companies have set on a project. With a 25% response rate the median hurdle rate is found to be 20%. This is in line with the minimum rate of return required on a project by most organisations. Bank of England reports an average hurdle rate of 12% across UK businesses.

[10] Of the site that you work at, what was your financial turnover/revenue in tax year ending in 2022?
[11] 95% confidence interval [~128 billion, ~181 billion]. Respondents who could not provide financial information based on a site-level (around 20% of the total survey respondents) were asked to provide information on company-level. The aggregate turnover for companies that use the NMS labs is ~£152 billion.
[12] The benchmark figures for revenue per employee are calculated from the Annual Business Survey and the Business Register & Employment Survey in the UK in 2022.

**Table 14 Hurdle rate – NMS Users**

| | |
|---|---|
| Micro | 50% |
| SMEs | 17% |
| Large | 20% |
| Manufacturing companies | 20% |
| Non-manufacturing companies | 15% |

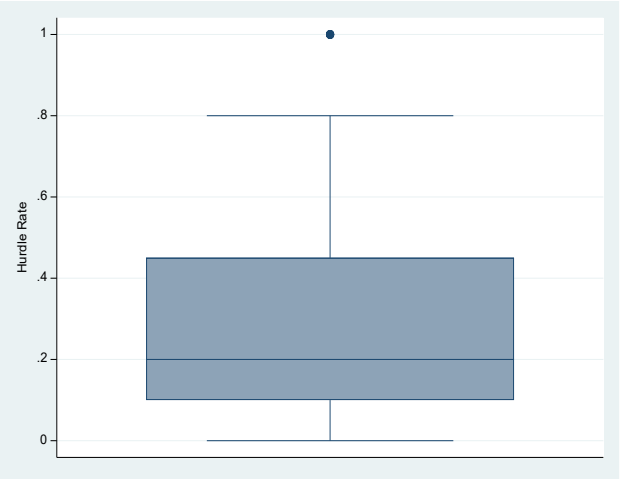



**Figure 23 Boxplot of Hurdle rate**

3.2.1.2 Definition of revenue impact

The revenue impact is a financial figure representing the income generated by private businesses from developing or improving new products and reaching new markets using the labs' support. Revenue impact is essentially the portion of 'innovation impact' covering the benefits from product innovation. Quantifying the revenue that the NMS labs help generate for their customers allows the labs to understand the amount and expanse of this impact.

3.2.1.3 Data & Methodology

The revenue impact number from the previous survey included data collected from surveys conducted in the years 2012, 2015, and 2018. However, the following analysis only uses the data collected from this survey. The respondents were asked to choose one option from the set revenue bands. This shift in the revenue impact analysis allows the NMS labs to track this metric in future surveys.

The NMS users who have used the labs to make an innovation change were asked questions about their recent economic impact of this innovation[13]. The revenue impact estimate is calculated from the following components:

- The sale of new products or services
- The sale of improved products or services
- The sale of existing products or services reaching new global markets

Estimates are calculated separately for each component and are later summed up to devise the final revenue impact number. As this survey was designed for sites that have worked with the labs on measurement related activities, it is likely that the respondents would provide answers for the revenue from products or services that are dependent on measurement. Customers were also asked if the innovation changes made would have been possible in the absence of support from the NMS labs[14]. If the customers reported that the support provided

[13] As a result of the innovation you worked on with NMS in financial year 2022, what were the annual sales of your product or service?
[14] Would the changes made have been possible without the support of NMS? If 'yes', where could you have obtained this alternative support?

by the labs was essential and unavailable elsewhere, that revenue was attributed to the NMS labs.

However, it is essential to note that approximately 25% of the respondents have told that they do not know or they prefer not to answer these questions, and we consider those responses as 'missing' values. Therefore, to deal with non-response bias in the analysis, **multiple imputation**[15] technique has been used to fill in the missing values. For all the components, fifty imputations have been performed such that every imputation represents the proportion of population that would fall in each revenue band. It was then observed that this data best fits a **pareto distribution**.

The pareto distribution is a power-law probability distribution which can be described by two parameters, alpha ($\alpha$) and $x_m$. The value of $\alpha$ determines the slope of the distribution, and $x_m$ represents the minimum possible value for the distribution which helps determine the spread of the distribution. When this function is plotted across a range of x[16] values, it can be observed that the distribution slopes downward as x increases. In simple terms, as observed in the following figure, the majority of the distribution's density is concentrated on the left-hand side near $x_m$ with only a small proportion of the density on the right-hand side.

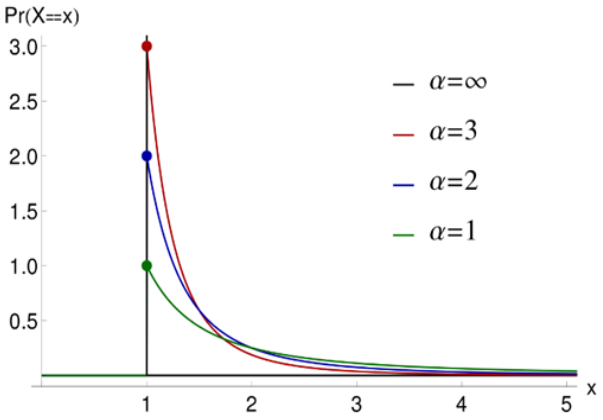



**Figure 24 Pareto distribution with various $\alpha$ values**[17]

Applying the calculated values of $\alpha$ and $x_m$, revenue numbers for the missing values have been generated at random using inverse transform sampling. For each component, the revenue estimates for each individual site in the population are calculated and summed up at the end to represent the total revenue number. This process was repeated and ordered such that the total values are represented as percentiles. **The 50th percentile, also known as the median, is used to compute the headline number.** The 25th and the 75th percentiles form the lower and upper bounds of the confidence intervals, respectively.

#### 3.2.1.4 Results

In the year 2022, 2870 private businesses in the UK that interacted with the NMS labs collectively created a **total annual revenue impact of £1.56 billion before accounting for attribution**. It is important to note that these numbers have been restricted to a certain level

[15] Multiple imputation represents several sets of plausible values. It helps reduce bias and overcome incorrect estimates of standard errors and tests of statistical significance.
[16] In this instance, 'x' values are the highest points of each revenue band.
[17] Danvildanvil, CC BY-SA 3.0, via Wikimedia Commons

of *innovation change*[18] and to the *real values*[19] provided by the respondents. It is noteworthy to mention that **88% of the NMS users made a change to their products or processes. Three quarters of them are product innovations and a quarter of them are process innovations. Moreover, 18% of the customers have reported that they disrupted or transformed the industry through an innovation change**. When the NMS survey was last conducted in 2018, the total revenue impact number was £1.4 billion before accounting for attribution[20]. Therefore, it can be observed that there has been an increase of £160 million for total revenue impact within the last 4 years.

**Table 15 Total annual revenue impact without attribution to the NMS labs**

| *All values in £m* | **Total revenue** | **Lower bound** | **Upper bound** |
|---|---|---|---|
| New product or service | 432 | 403 | 641 |
| Improved product or service | 637 | 533 | 1740 |
| Reaching new markets | 421 | 407 | 818 |
| **Total** | **1564** | **1413** | **3390** |

Even though it is important to be informed on the above figure, it however does not account for attribution. This would mean a few customers hold the opinion that some of the revenue benefits would have been possible to achieve without the support provided by the NMS labs. Therefore, it is necessary to calculate another headline number that accounts for attribution. As a consequence of excluding the non-attributed revenue numbers, the score would be necessarily lower.

The results show that about **32% of the revenue benefits has been attributed to the NMS labs**. This shows that the NMS labs contribute to a significant proportion of income for its customers. Though the attribution level for each component does not vary excessively, it should be noted that sales from new products or services hold the highest level of attribution of 34.3% and sales from improved products or services hold the lowest level of attribution of 30.6%.

In the year 2022, **when accounting for attribution, the annual revenue impact of ~£500 million**. In the previous NMS survey, the attributed revenue impact number was £539 million[21]. Even though a decrease of £39 million can be observed within the last 4 years, it should be recalled that this period witnessed a series of economic shocks such as the covid crisis. Refer to Appendix B to gain a detailed understanding on the calculation of the revenue impact numbers.

**Table 16 Total annual revenue impact attributed to the NMS labs**

| *All values in £m* | **Attributed revenue** | **Lower bound** | **Upper bound** |
|---|---|---|---|
| New product or service | 148 | 138 | 220 |
| Improved product or service | 195 | 163 | 533 |
| Reaching new markets | 136 | 131 | 264 |
| **Total** | **500** | **452** | **1083** |

[18] On a scale of 0-10, the customers were asked what level of innovation change was achieved by their project. The respondents who have selected zero were excluded in the calculation of the total revenue impact number.
[19] Customers who have selected N/A were classified as the sites that had not made any sales in the year 2022. Therefore, they were excluded in the calculation of the total revenue impact number.
[20] The real value (after adjusting for inflation) of this revenue impact number is ~£1.8 billion.
[21] The real value (after adjusting for inflation) of this revenue impact number is ~£700 million.

### 3.2.2 Employment impact

#### 3.2.2.1 Background

The respondents were asked questions relating to the employment at their business sites[22]. This helps the NMS labs understand the contribution that their customers make to the UK economy.

The total number of employees that work at the sites that are supported by the NMS labs amounts to **~711,000 people**[23] **and this accounts for around 2.15% of the UK's labour force**[24]. When this number is broken down by industries, it can be observed that more than 85% of the private sector customers operate within profession, scientific, and technical activities, or the manufacturing sector. The employment at manufacturing sites that are supported by the NMS labs account for **13% of the manufacturing sector workforce in the UK**[25].

In 2018, the business sites that used the NMS labs collectively employed just under 1 million people in the UK. Even though a decrease can be observed in the employment figures within the last 4 years, it is important to recollect that this period experienced economic shocks.

#### 3.2.2.2 Impact from innovation activities

The respondents were asked if the innovation project they worked with the NMS labs had an impact on their employment level. **15% of the respondents reported that the employment increased because of the project**, 2% reported decrease and 83% reported no change.

By weighting the responses with respect to the employment the respondents reported for their site/organisation, additional jobs were computed for the 15% that reported an increase in employment. The calculation suggests that there is **3% increase in employment by working with NMS labs on innovation projects**. This figure does not refer to a single year. It may correspond to multiple years dependent on the nature of the innovation project.

Additionally, 15% of the respondents reported an increase in the basic wage as a result of the innovation project worked with the labs. Moreover, the calculations show that there is a **7.5% increase in the basic wages**[26] through the labs' support on the innovation project.

The table below shows the regional spread of the additional jobs created as a percentage of the reported level of employment in that region. Through the labs' support, the highest level of additional jobs created are in the North.

**Table 17 Average increase in additional jobs as a result of the innovation**

| | |
|---|---|
| North | 5.80% |
| East & South | 0.90% |
| West & Midlands | 2.60% |

[22] Currently, how many employees are present at the site that you work at?
[23] 95% confidence interval [~622,125, ~800,854]
[24] UK labour market statistics
[25] UK manufacturing sector workforce
[26] The value 7.5% refers to the median of the data points.

The following table shows the classification used for each of the three broad regions:

**Table 18 Broad Region classification**

| | |
|---|---|
| **North** | North East, North West, Yorkshire and the Humber, Scotland & Northern Ireland |
| **East & South** | South East, East of England & London |
| **West & Midlands** | West Midlands, East Midlands, South West & Wales |

### 3.2.3 Spillover Impact of innovation activities

#### 3.2.3.1 Scale of spillovers from innovation activities

The respondents were asked if their innovation change had any spillovers. Approximately half of the userbase provided a response for this question, **reporting major spillovers within and outside the organisation**. The figure below shows the proportion of responses for each category ignoring those that didn't respond.

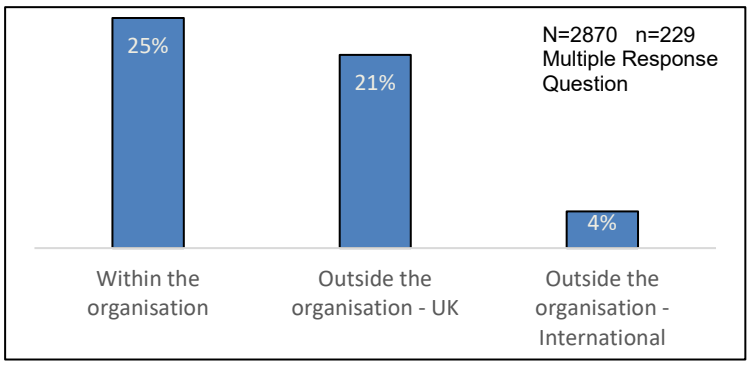



**Figure 25 Spillover from an Innovation Change**

The level of spillover experienced is also categorised by the scale of innovation change. The figure below shows that **within the organisation, breakthrough innovations have the highest spillover**. Transformational innovations have similar levels of spillover outside the organisation both nationally and internationally.

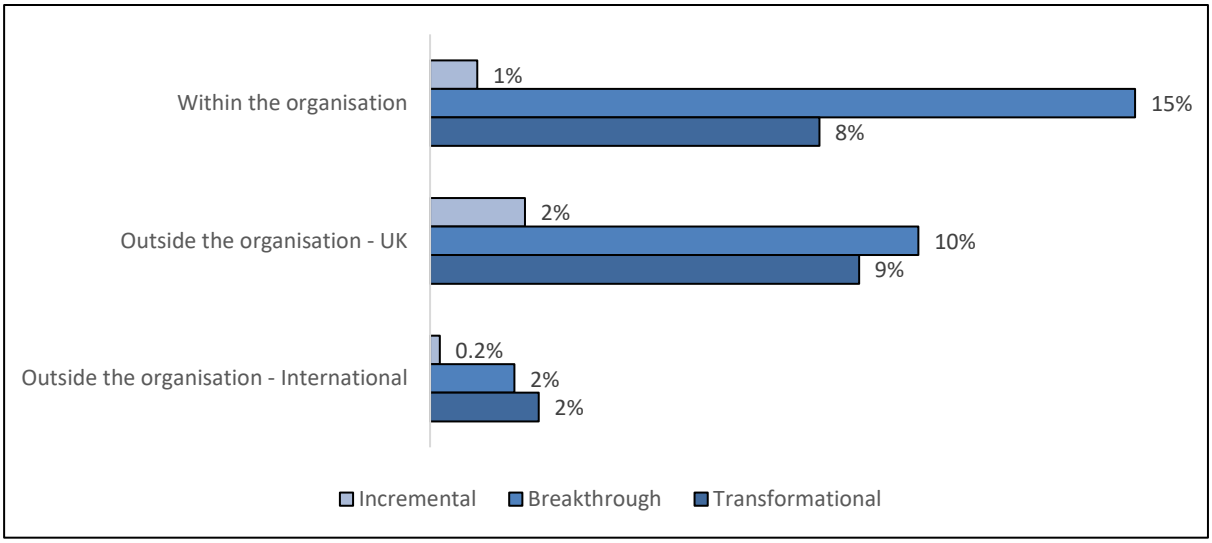



**Figure 26 Level of Spillover categorised by the scale of innovation**

#### 3.2.3.2 Spillovers from Product Innovation

Product innovation refers to the creation of new products or the improvement of existing ones. This section explains the indirect benefits of product innovation through the route of product diffusion. Product diffusion refers to the indirect benefits generated as a result of pre-defined standards and commercialisation of innovations/newly developed projects.
Here the questions asked on lifetime of products are used to compute the ratio of direct and indirect benefits from product innovations.

The respondents were asked to estimate the lifetime of the products they deal with, within their firm and within the industry. The table below summarises the results obtained. To calculate the mean, the midpoints were calculated. One thing that had to be looked at were the bounds given in the question. The last bound is open ended which based on a patent life and average life of machinery and equipment in these sectors couldn't be greater than 20. The category, therefore, was improvised to '11-20 years' as opposed to 'greater than 10 years'.

The mean and median are calculated for both the lifetime of product within the industry and the firm and are presented in the table below. Generally, the product lifetime appears to be higher for the manufacturing sector. This is supported by the fact that products and services that live in it are generally long-lasting and are not subject to becoming obsolete rapidly. While other sectors for instance the telecommunications are rapidly evolving according to the needs of the industry.

**Table 19 Product Lifetime**

| | **Total product lifetime within the industry** | | **Total product lifetime within the firm** | |
|---|---|---|---|---|
| | Mean | Median | Mean | Median |
| Total | 11.8 | 11.6 | 9.3 | 8.5 |
| Manufacturing | 13.2 | 12 | 10 | 10 |
| Non-Manufacturing | 10.4 | 13.6 | 8.6 | 7.5 |

Qureshi and King, 2025[27] sets out another approach to calculating the lifetime of products within a firm and within the industry through the concept of **product diffusion**. Product diffusion is explained through a **model** based on **firms' portfolio of products**. The lifecycle of product creation, entrance to the portfolio and obsoletion/ displacement is shown through a conveyor belt. Below are a few equations that are used to calculate the lifetime of a product within a firm and within the industry. Furthermore, using these numbers, the ratio between direct and indirect benefits is calculated.

The approach uses the data from a set of questions asked on the percentage of turnover that comes from the sale of goods and services new to the market and percentage of turnover that comes from the sale of improved goods and services[28]. (Such data corresponds to similar data obtained in the UK Innovation Survey.) These two percentages are used to compute the lifetime of a product within a firm and the industry, with the help of a simple formula (Please refer to the paper for the derivation).

[27] A framework for assessing the economic significance of NPL's spillovers
[28] In the NMS Survey 2022-23, two questions were asked regarding percentage of turnover from goods and services; one for goods and service new to the market and the other for goods and services that remain unchanged. The third category which is goods and services that were improved / new to the firm was calculated as a residual.

$$T = \frac{100\%}{X\%}$$

This equation shows that a portfolio of products last for T years. During this time, the portfolio will give a certain $X_t$% of turnover each year which is assumed to be constant for the years. Across the lifetime, this should intuitively equate to 100%.

To compute the total lifetime of the portfolio of products in an industry, only the percentage of turnover that comes from the sale of new goods and services is used. To compute the lifetime of the portfolio within the firm, both components; percentage of turnover that comes from the sale of new products and services and those that were improved, are used. The calculations suggest that **23%** of the turnover is for goods and services new to the market and **19%** for goods and services that were improved. These results are for the three years combined (2020-2022). Therefore, to compute the annual value, it is divided by 3.
The total lifetime of a portfolio within the industry is calculated as:

$$T_{total} = \frac{100\%}{\frac{23\%}{3}}$$

$$T_{total} = 13.04$$

The total lifetime of a portfolio within the firm is calculated as:

$$T_{firm} = \frac{100\%}{\frac{(23\%+19\%)}{3}}$$

$$T_{firm} = 7.14$$

Table below summarises the results, breaks it down by the sectors and calculates the ratio of direct and indirect benefits.

**Table 20 Ratio of Direct and Indirect Benefits**

| | Total product lifetime within the industry | Version lifetime within the firm | Direct (Original Version) | Indirect (Follow-on Versions) |
|---|---|---|---|---|
| Total | 13.04 | 7.14 | 55% | 45% |
| Manufacturing | 13.39 | 8.11 | 61% | 39% |
| Non-Manufacturing | 11.24 | 5.86 | 52% | 48% |

The table shows that **the products have a lifetime of 7 years within the firm that first created it, and a lifetime of 13 years within the firm's industry. It finds a 55-45[29] split between direct and indirect benefits**. The idea is that new products would have a certain lifetime within the firm (direct benefit generated) after which they will be adopted in some form within the industry. In other words, any leftover from the total product lifetime, must have entered the system, and by way, to other firms which essentially is the indirect effect of product innovation.

[29] The percentage split found is very close to the 50-50 split found in the study commissioned by the Department for Science, Innovation and Technology (DSIT).

# 4 MEASUREMENT CHAPTER

The measurement chapter aims to address the following research statements:

1. **Understand the factors influencing the private sector to use the NMS laboratories for measurement services.**
   The NMS is interested in identifying the key drivers that drive the private businesses to utilise the labs and enable an understanding of their rationale behind performing measurements.

2. **Establish the scale and value of measurement activities based on spending.**
   Customers who use the NMS labs often work in core measurement roles within organisations that allocate a budget for measurement activities. The survey aims to quantify measurement spending as a percentage of business turnover across different size classes and industries.

3. **Assess the fanout and traceability of calibration services in the UK economy.**
   The NMS labs calculate a 'fanout' number to estimate how far their direct reach extends. This headline number assists in tracking the indirect impact generated by the labs.

4. **Evaluate the impact of calibration and reference materials on measurement accuracy.**
   The survey uses an existing micro economic model to evaluate the benefit created by using calibrations to reduce the uncertainty of the measurement process. This further seeks to analyse how calibrations enhance measurement accuracy and contribute to cost savings.

## 4.1 OVERVIEW OF MEASUREMENT ACTIVITIES

This section explains the categories of measurement activities used by the respondents, their sources of measurement services for testing & analysis and calibration/reference materials, and their reasons for performing measurements.

### 4.1.1 Categories of measurement activities

The respondents provided their answers to a range of measurement activities based on its importance to them and the assistance received from the NMS labs. Table 21 includes the users who rated the measurement activities important[30] and use the NMS labs using conditional probabilities.

The Venn diagram sets the context for the subsequent analysis:

- Set A – refers to the importance associated to measurement activities by the firm.
- Set B – refers to the assistance received by the NMS labs for measurement activities.
- Intersection (A∩B) – refers to the firms that view measurement activities as important and have received assistance from the NMS labs for these activities.

[30] The question 'How important is measurement to your organisation for each of the following business as usual activities?' is answered on a scale of importance. The respondents who have selected 'Very important' and 'Moderately important' are classified as important in this case.

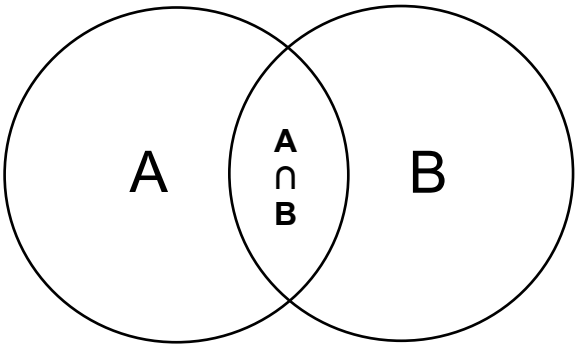



**Figure 27 Venn diagram for conditional probabilities**

In this case, the conditional probability of assistance received by the NMS labs (event B) is the probability that it will occur, given the knowledge that the firm deems measurement activities important (event A). This probability is written as $\boldsymbol{P(B|A)}$**,** notation for the probability of B given A.

The equation for conditional probability is as follows:

$$\boldsymbol{P(B|A) = \frac{P(A \cap B)}{P(A)}}$$

**Table 21 Conditional probabilities for importance for measurement activities and labs' assistance**

| **Business-as-usual activities** | $\boldsymbol{P(A \cap B)}$ | $\boldsymbol{P(A)}$ | $\boldsymbol{P(B\|A)}$ |
|---|---|---|---|
| Calibration | 55% | 96% | 57% |
| Achieving accreditation | 21% | 92% | 23% |
| Maintaining a consistent product / service | 32% | 97% | 33% |
| Compliance with standards and regulation | 37% | 96% | 38% |
| Quality assurance of products and services | 42% | 97% | 43% |

The most popular measurement activities with the NMS labs are 'Calibration' and 'Quality assurance'.

**96% of the measurement users deem calibration as an important measurement activity. Moreover, 57% of these businesses have received assistance from the NMS labs.**

**97% of the measurement users deem quality assurance of products and services as an important measurement activity. Moreover, 43% of these businesses have received assistance from the NMS labs.**

On the other hand, although 92% of the measurement users deem achieving accreditation as an important measurement activity, only 23% of these businesses have received assistance from the NMS labs.

### 4.1.2 Sources of measurement services

Measurement services comprise testing & analysis and calibration/reference materials.

- Testing & analysis refers to the rigorous process of evaluating and examining measurements using specialised equipment and techniques.
- Calibration/reference materials ensures that measurements are accurate, reliable, and comparable to national standards.

For testing and analysis, 71% of the respondents conduct it in-house and 57% of them use commercial labs. NMS labs are used by a fifth of the respondents[31].

For calibration/reference materials, only 46% of the respondents conduct it in-house and 67% of them use commercial labs. NMS labs are used by more than a quarter of the respondents. This shows that calibration/reference materials are NPL's area of expertise or specialisation.

It can be observed that NMS users majorly rely on external providers such as commercial or NMS labs for calibration/reference materials. In contrast, three quarters of the NMS users conduct their testing and analysis in-house. Foreign NMIs are less commonly used for either of the measurement services.

Furthermore, it is evident that the **NMS labs are twice as important for the customers when sourcing measurement services from foreign NMIs.** This highlights the uniqueness and national importance of the NMS labs.

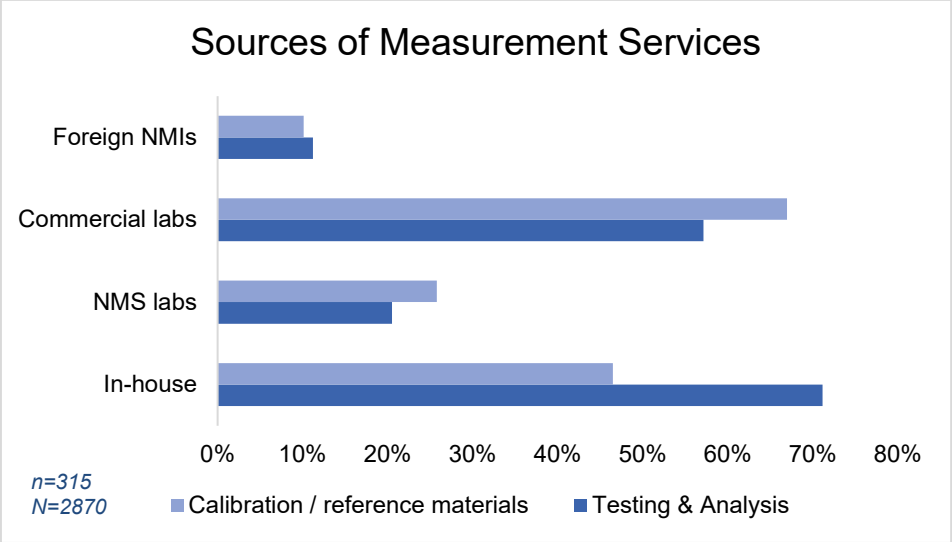



**Figure 28 Measurement service providers**

[31] The respondents are allowed to choose more than one response option for the question : 'Where do you go for testing and analysis (or) calibration / reference materials?

### 4.1.3 Reasons for performing measurements

Customers that participated in the survey were asked to provide their intentions for performing measurements and were allowed to choose more than one response option. To observe how these variables interact with each other, a correlogram was used to conduct the analysis. A correlogram (or a correlation matrix) allows for an analysis of the relationship between the pairs of numeric variables. The correlation coefficients in bold highlight the strong positive and negative correlations.

Strong positive correlations[32] could be observed for:

1. Compliance with standards & Provision of measurement services **(34%)**
2. Conformance testing & Experimental R&D **(32%)**
3. Calibration of instruments & Compliance with standards **(31%)**
4. Conformance testing & Compliance with standards **(31%)**
5. Process Control & Experimental R&D **(30%)**
6. Conformance testing & Process Control **(28%)**
7. Process Control & Business information **(28%)**
8. Process Control & Compliance with standards **(27%)**

Strong negative correlations could be observed for:

1. Calibration of instruments & Experimental R&D **(8%)**
2. Provision of measurement services & Business information **(7%)**
3. Process Control & Provision of measurement services **(5%)**

**Table 22 Correlogram of the reasons for performing measurements**

| Reasons | Code | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|---|
| Calibration of instruments | A | | | | | | | |
| Conformance testing | B | 17% | | | | | | |
| Process Control / Optimisation | C | 22% | 28% | | | | | |
| Compliance with standards and regulation | D | 31% | 31% | 27% | | | | |
| Provision of measurement services | E | 21% | 13% | 5% | 34% | | | |
| Experimental R&D / Trials | F | 8% | 32% | 30% | 24% | 16% | | |
| Business information / Taxation purposes | G | 12% | 15% | 28% | 22% | 7% | 22% | |

It is evident that ‘Compliance with standards and regulation’ plays a positive role for performing measurements.

This analysis also presents the initial findings that the above reasons for performing measurements broadly fit into the following components:

- Providing measurements as a primary function of the business.
- Producing outputs or results based on measurements.
- Developing novel or innovative products / services.

Cluster analysis or Principal Component Analysis (PCA) could be further conducted to explore these findings in detail.

[32] The strong positive correlations are significant at the 5% level or better.

## 4.2 SCALE AND VALUE OF MEASUREMENT

It is clear from the results in the introduction of the report that NMS users view measurement is important to them. Therefore, the NMS labs want to comprehensively understand the degree to which their users value measurement. This section details the value of measurement through measurement spending as a proportion of turnover.

Nearly 9 out of 10 respondents (88%) have measurement as part of their role. Overall, 37% these respondents work in core measurement related roles i.e., they dedicate more than 50% of their total working time to measurement. Therefore, this provides credibility to the values that arise in the measurement section.

### 4.2.1 Measurement spending

To understand the value of measurement to the users, an evaluation of measurement intensity and spending is required. It is considered that customers set their measurement budget based on the following parameters:

- The volume of measurements they need to undertake,
- The environment in which those measurements are made, and
- The precision and the accuracy a measurement requires.

Measurement intensity is defined as the proportion of business turnover spent on measurement. Businesses were asked to estimate the proportion of their annual turnover spent on measurement. The turnover associated with a respondent's site was also directly answered in the survey.

When assessing spending on measurement across the 2018-2022 period, it is estimated that **businesses working with the NMS labs spend 5% of their turnover on measurement**[33] annually. This figure equates to **£7.7 billion of spending each year** among private sector users of the NMS.

In the 2014-2017 period, it was estimated that, on average, businesses working with the NMS labs spend 5.4% of their turnover on measurement annually. This figure equates to £10.2 billion of spending each year among private sector users of the NMS.

#### 4.2.1.1 Measurement budget split across industries in the private sector

Spending on measurement can be broken down to show differences between the budgets of NMS users. Perhaps unsurprisingly, the survey found that **calibration laboratories that utilise the NMS labs allocate the largest share of their turnover to measurement, with 4 in 10 (43%) of them dedicating over 20% of their turnover on measurement** in the year 2022. This shows a marginal increase in comparison to the previous survey.

The results from the NMS survey in 2018 revealed that 41% of the calibration laboratories who use the NMS labs spend more than 20% of their turnover on measurement.

Note that **a fifth (20%) of NMS businesses' total measurement spending is for calibration and reference materials, and four-fifths (80%) is for testing and analysis.** Furthermore, 63% of the total measurement spending is for conformance testing.

[33] The estimate is based on the median value for proportion of turnover spent on measurement.

Therefore, in financial terms, it is estimated that the **NMS users spend £1.5 billion on calibration and reference materials, and £6.2 billion on testing and analysis.** Within the measurement spend for testing and analysis, £4.8 billion is allocated for conformance testing.

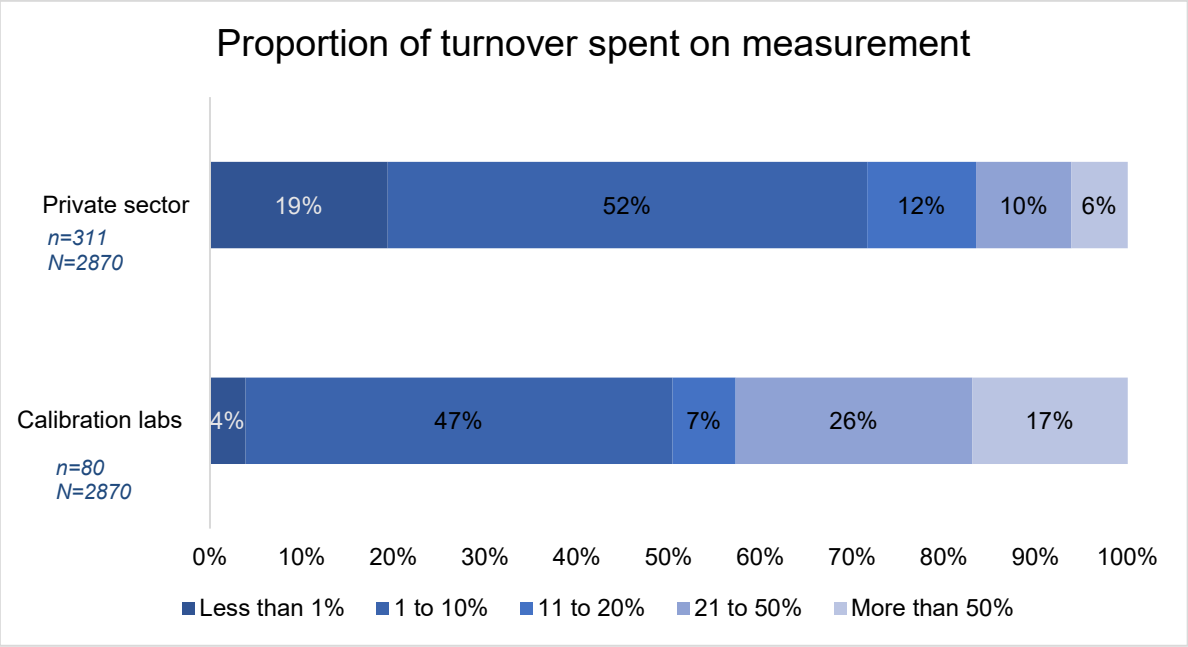



**Figure 29 Proportion of resources spent on measurement split by calibration labs and other private businesses**[34]

In addition to calibration labs, private businesses also need staff with measurement expertise for various developmental projects involving aspects of innovation, compliance, and quality.

The nature of innovations that take place within firms that heavily invest in metrology leads to 16% of them dedicating more than 20% of their turnover on measurement. This indicates a significant decrease in comparison to the previous survey.

The results of the previous NMS survey in 2018 revealed that 25% private businesses spend more than 20% of their turnover on measurement.

#### 4.2.1.2 Measurement budget distributed across different company sizes

In terms of company sizes, it can be observed that larger companies appear to be spending a considerable proportion of their turnover on measurement. **Over a fifth (21%) of the large firms spent more than 20% of their turnover on measurement, compared to around 16% of the SMEs.**

In contrast to the results from this survey, the 2018 NMS survey revealed that almost a third (31%) of the SMEs spent more than 20% of their turnover on measurement, compared to around a fifth (19%) of the larger organisations[35]. While variability was noted in the previous survey, the current survey results appear consistent for both SMEs and large firms.

[34] The population estimate (N) amounts to 2870. The sample size (n) is 80 calibration labs and 311 businesses in the private sector.
[35] As the 2018 NMS survey contains calibration laboratories within these sub-groups, who are naturally measurement intensive, the current results also reflect the same composition for

## 4.3 FANOUT OF TRACEABILITY IN THE UK ECONOMY

The NMS labs recognise that it is important to understand the number of commercial calibration labs that they work with to estimate how far their direct reach extends. This survey shows that a fifth of the total survey respondents are commercial calibration labs. It has been estimated that **the NMS labs work with 564**[36] **calibration labs in the UK**.

Among the customers who are commercial calibration labs:

- **The NMS labs work with 35% of all the accredited calibration labs in the UK**[37].
- 83% of the labs that work with the NMS labs are UKAS accredited for testing and analysis or calibration and reference materials.
- A majority of the customers use the NMS labs to increase their confidence in measurements and maintain accuracy of their instruments, so that it makes it possible for them to reliably calibrate instruments for their own customers.

### 4.3.1 Indirect reach: beyond direct customers

The direct reach of NMS labs could be extended to calculate the fanout of calibration services provided by our customers. The accuracy in the first-hand calibrations provided by the NMS is in-turn transferred through follow on calibration services provided to other firms by the NMS users, and this effect spreads out across the economy. The calculation of fanout as a headline number is valuable as it helps monitor the indirect impact generated by the NMS labs. Refer to Appendix A to gain a detailed understanding on the calculation of fanout.

The 151 firms that self-identified as commercial calibration labs were asked to provide the number of firms to which they provide calibration services or reference materials[38]. All the respondents were able to provide a reasonable answer to this question. The analysis found that **the calibration services provided by the NMS labs have a fanout to ~75,500 organisations**[39].

It should be noted that this estimate represents the ‘first level’ of fanout where the NMS labs provide services to their direct users, and they in turn provide services to their own customers. It does not include the services that are further provided by these recipients. It is within reason to assume that the ‘second level’ fanout would be significantly higher.

The following table shows the spilt between UKAS and non-UKAS accredited labs. The previous NMS survey conducted in 2018; the NMS labs had a fanout to 74,000 organisations. Therefore, it can be observed that there is an increase of ~1500 organisations within the last 4 years.

comparability. If we exclude calibration labs, the results are : 16% of the large firms spent more than 20% of their turnover on measurement, compared to around 13% of the SMEs.

[36] The population estimate (N) amounts to 564 calibration labs. The sample size (n) is 151 calibration labs.

[37] There are 364 UKAS accredited calibration laboratories in the UK.

[38] To understand the fanout of traceability in the economy, how many laboratories do you provide calibration services/reference materials to?

[39] It should be noted that this is an upper estimate as it does not account for the overlap of labs that receive calibration services/reference materials from the NMS userbase.

**Table 23 Number of labs that the NMS users provide traceability to**

| | Sample | Population | Fanout |
|---|---|---|---|
| UKAS accredited | 127 | 465 | 62,313 |
| Non-UKAS accredited | 24 | 99 | 13,209 |
| **Total** | **151** | **564** | **75,522** |

Respondents were also asked what proportion of their measurements were made using externally calibrated instruments or reference materials.

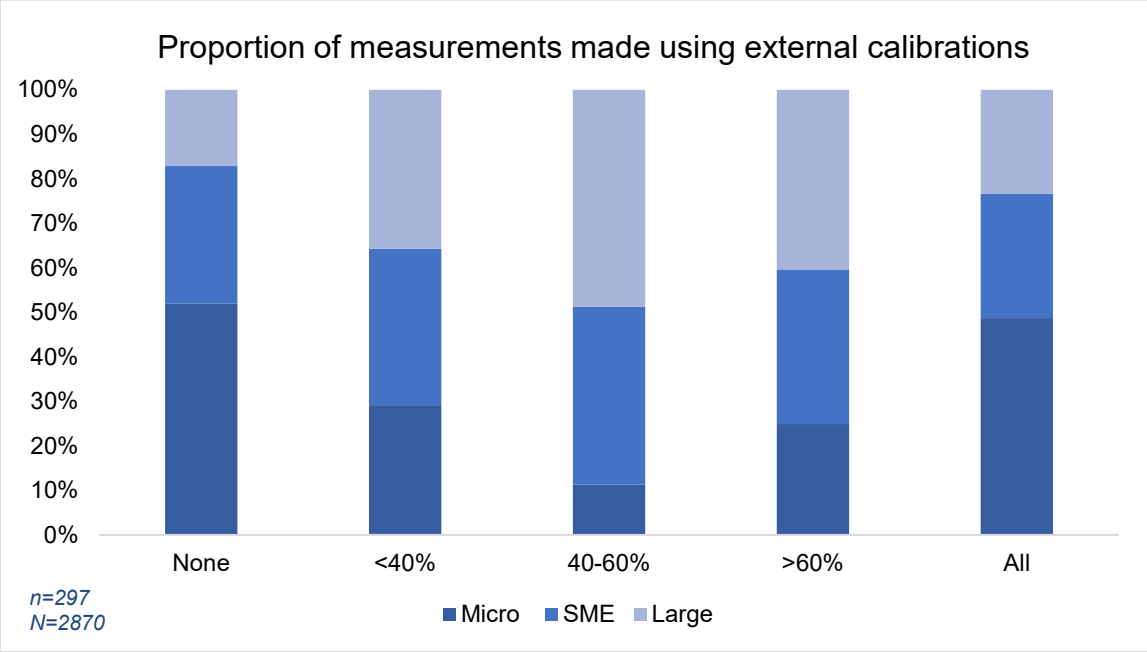



**Figure 30 Proportion of measurements made using externally calibrated instruments or reference materials**

**On an average, 50% of the measurements by private sector users are conducted using externally calibrated instruments or reference materials.** In financial terms, it is estimated that the measurements conducted by the NMS users using externally calibrated instruments or reference materials equate to **£3.85 billion.**

Most notably, 41% of micro businesses reported that all their measurements rely on externally calibrated instruments or reference materials. Interestingly, micro businesses also maintained the highest proportion (14%) for none of their measurements relying on externally calibrated instruments or reference materials.

The results of the previous NMS survey in 2018 indicated that for nearly 60% of NMS users (including both private sector and healthcare industry users), more than 40% of their measurements are made using externally calibrated instruments or reference materials.

## 4.4 UNDERSTANDING ERRORS, UNCERTAINTIES, AND DEFECTS IN CONFORMANCE TESTING

This section presents calculations derived from the survey, including estimates for Type 1 errors, Type 2 errors, measurement uncertainty in the absence of calibrations, scrap rates, and service failures.

### 4.4.1 Measurement errors

There are two types of measurement errors:

- Type 1 error (False Positive) is where a product is good but fails the test which makes you think it is defective and is scrapped.
- Type 2 error (False Negative) is where a product is defective but passes the test which makes you think that it is good and enters the supply chain.

The survey respondents were asked to provide an estimate for their firm's probability of:

- mistakenly rejecting an item or batch that does meet specification i.e., committing a type 1 error[40].
- mistakenly accepting an item or batch that does not meet specification i.e., committing a type 2 error[41].

**Table 24 Measurement errors**

| | Mean | Median |
|---|---|---|
| Type 1 error | 0.022 | 0.01 |
| Type 2 error | 0.019 | 0.01 |

The statistical analysis of the values provided by the respondents revealed that the occurrence rates of type 1 and type 2 errors are relatively similar. While theory suggests that type 2 errors should be more damaging than type 1 errors, the results above show that firms don't perceive them as significantly different. That said, in the box plots below, the upper whisker for type 1 errors extends to ~9%, whereas it only reaches ~5% for type 2 errors.

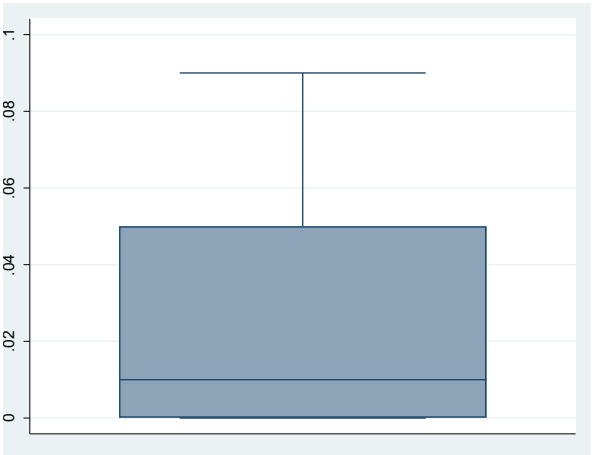



**Figure 31 Box plot for Type 1 error**

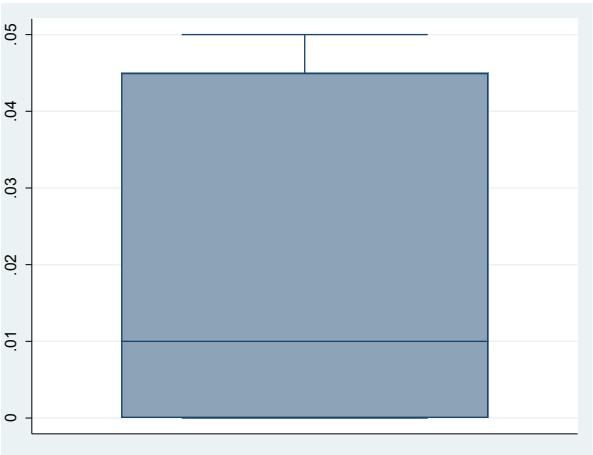



**Figure 32 Box plot for Type 2 error**

[40] Type 1 error: n=136, N=2870.
[41] Type 2 error: n=145, N=2870.

Consequently, although the mean values and box plot whiskers for the measurement errors show slight variation, it is more reliable to focus on the median values. Therefore, according to the survey, **firms working with the NMS report a 1% probability for both type 1 and type 2 errors**.

### 4.4.2 Calibration-related uncertainty

Businesses depend on calibration services to eliminate measurement related uncertainties. To explore this further, the survey aims to estimate the additional uncertainty[42] introduced when firms conducting conformance testing do not perform calibrations.

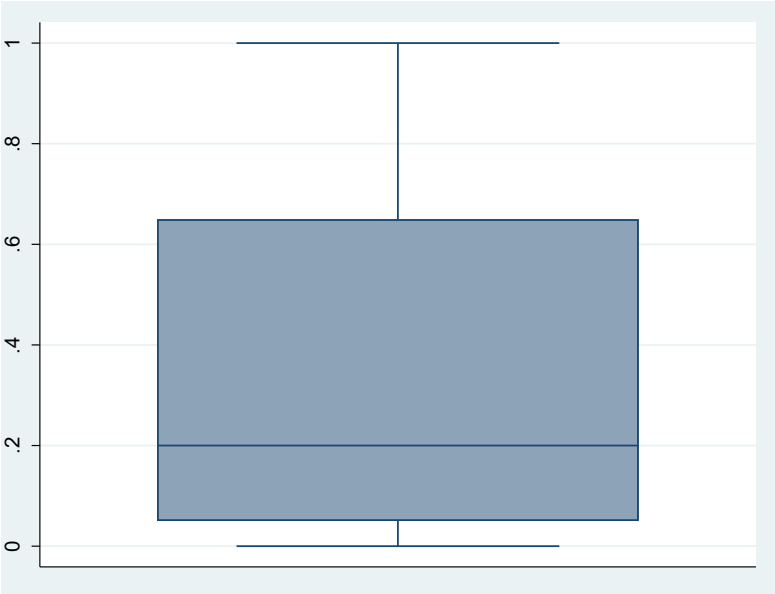



**Figure 33 Box plot for the increase in uncertainty**

The statistical analysis of the survey responses suggests that the median value stands at 20%, which aligns with the box plot above, while the mean is slightly higher at 37%. Given that the median is generally more reliable, it should be considered more significant in this context. Thus, **if companies fail to calibrate their instruments or utilise reference materials, there is an associated 20% increase in measurement uncertainty**.

### 4.4.3 Scrap rate

Another key indicator that is often relevant in manufacturing is the scrap rate or yield loss. This measure reflects production quality and represents the proportion of goods that are discarded or scrapped due to defects. A firm may discard its produced goods in two scenarios:

- It can make a type-1 error and mistakenly discard a perfectly good product (or)
- It can correctly discard a defective one.

[42] Increase in uncertainty: n=112, N=2870.
The question is: In the context of conformance testing, if you do not calibrate your instruments and/or use reference materials, what is the attributable percentage increase in measurement uncertainty, in your testing and analysis?

The survey directly asks respondents to provide their firm's scrap rate or yield loss as a percentage of total output[43].

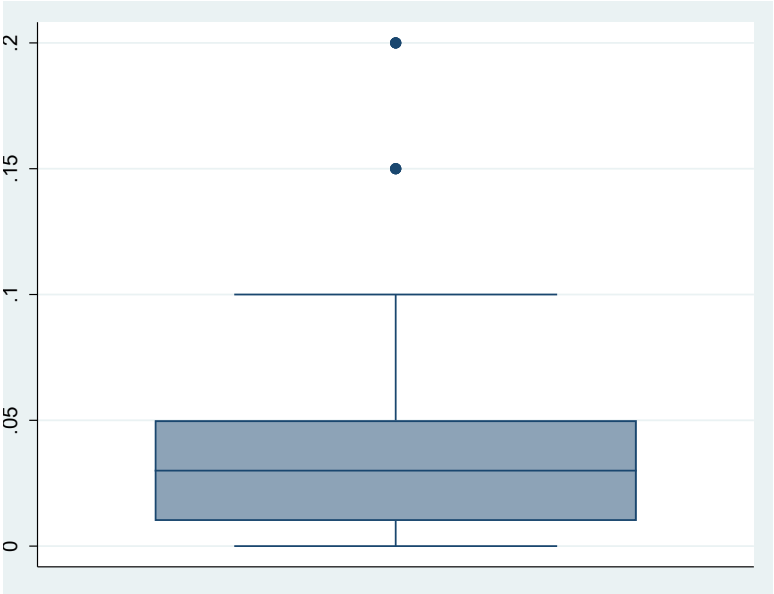



**Figure 34 Box plot for scrap rate**

The statistical analysis of the values provided by the respondents revealed that the median value stands at 3%, which aligns with the box plot above, while the mean is slightly higher at 4%. As noted previously, since the median is typically more dependable, it should be regarded as more meaningful in this context. Therefore, **firms working with the NMS report a 3% scrap rate as a percentage of total output**.

#### 4.4.4 Service failures

Service failures can encompass a various issues that impact a business's operational efficiency, legal standing, and customer experience. The survey includes questions directed at private businesses regarding malfunctions, product returns, compensation, and the regulatory consequences of selling defective products. The following sub-sections provide a closer look at each of these aspects.

##### 4.4.4.1 Malfunctions

Notably, over a third (36%) of non-manufacturing firms report that their production process never malfunctions, compared to just a quarter (26%) of manufacturing firms.

Conversely, more than a third (40%) of manufacturing firms indicate that their production process malfunctions 1% of the time, while only a quarter (23%) of non-manufacturing firms report the same.

[43] Scrap rate: n=119, N=2870.

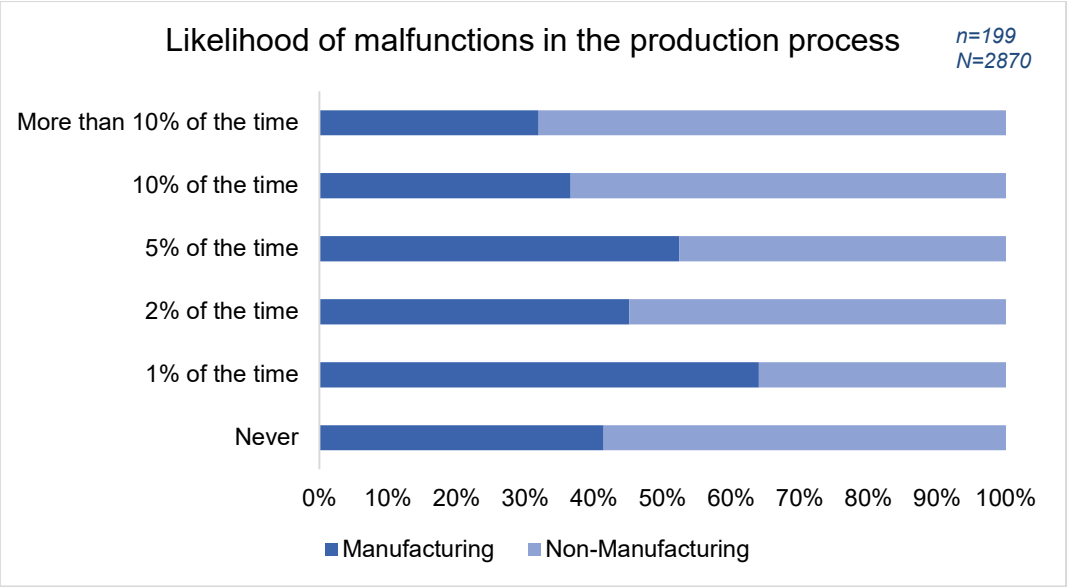



**Figure 35 Malfunctions within Manufacturing Vs. Non-Manufacturing**

Based on the survey results, we can infer that the production process is likely to malfunction and result in a defective output **2% of the time for manufacturing businesses**, while **non-manufacturing businesses have a slightly higher rate at 2.4%**.

#### 4.4.4.2 Product Returns

The survey asked respondents what proportion of their product sales are returned due to defects or failures during the warranty period. Half **(48%) of the firms reported that returns occur less than 1% of the time**, while a quarter **(24%) stated that returns never occur**.

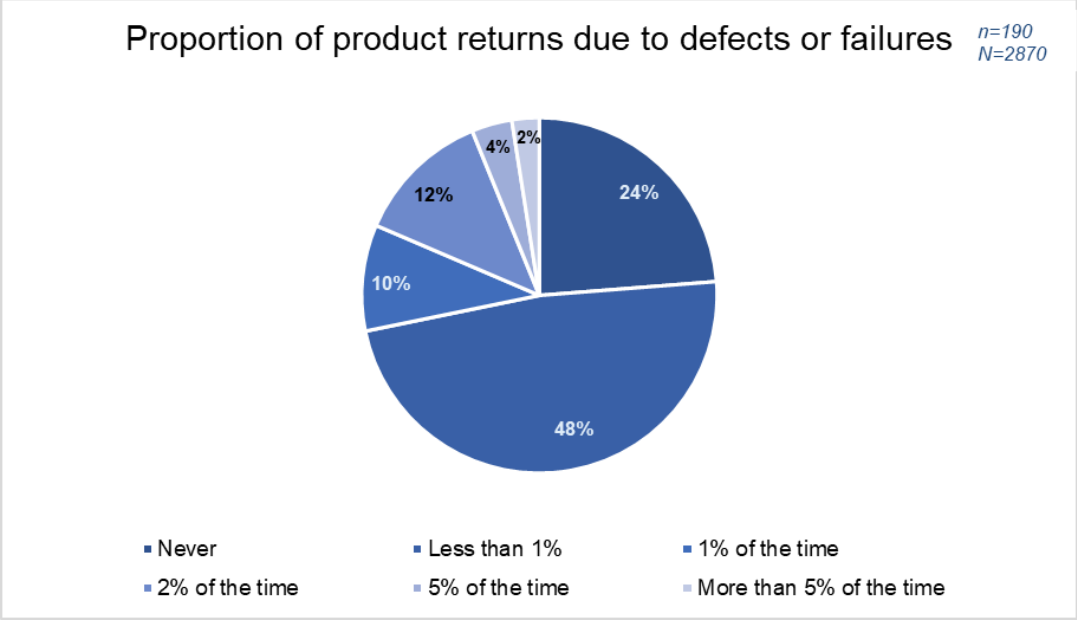



**Figure 36 Product sales returned due to defects or failure during the warranty period**

Based on the survey results, we can infer that **0.9% of the product sales are returned** due to defects or failure during the warranty period.

#### 4.4.4.3 Compensations

Businesses were questioned on how they would compensate customers if they sold a defective product. **SMEs seem to have the most balanced and flexible approach**, providing various solutions. In contrast, micro businesses are less inclined to offer resource-heavy solutions, likely due to their limited resources.

Across the board, **businesses prefer offering product replacements over refunds or discounts**, suggesting they prioritise customer satisfaction while limiting the financial impact.

**Table 25 Compensations split by the size of firm**

| | Micro | SME | Large |
|---|---|---|---|
| Replace the product | 6% | 26% | 21% |
| Provide a refund | 2% | 10% | 6% |
| Discount on future sales | 1% | 9% | 6% |

Moreover, three-fourths (73%) of the NMS users consider that selling a defective product could result also in regulatory or compliance consequences[44].

[44] Compensations: n=257, N=2870.

## 4.5 VALUE ATTRIBUTABLE TO CALIBRATIONS BY REDUCING MISTAKES IN CONFORMANCE TESTING

### 4.5.1 Introduction to the micro model

The NMS laboratories offer calibration services to companies willing to pay a premium for high-quality "primary" calibrations. In contrast, some businesses opt for "secondary" calibrations, which are less accurate but available at a lower cost. However, it's crucial to note that secondary calibrations depend on the primary calibrations provided by the NMS labs. These traceable calibrations are known as "fanout." As shown in the previous section, the NMS labs' calibration services have a fanout extending to 75,500 organisations.

Currently, the NMS revenue only reflects income from customers who directly purchase calibration services. The economic benefit generated by the fanout, however, is not captured. This value is estimated using an established economic model that has been developed by NPL analysts. This model attempts to value calibration services by measuring how high-quality calibrations help businesses reduce mistakes derived from measurement errors.

The study endogenizes the probabilities of making type 1 and type 2 errors. Therefore, the firm aims to reduce the total cost resulting from these errors, while considering the trade-off between them. Moreover, if a customer returns a defective product, the firm only compensates them by providing a free replacement. Therefore, a type-2 error is presumed to be twice as costly as a type-1 error.

The stylised model provides the formulae for:

- Probability of type-1 error ($\boldsymbol{\alpha}$)
- Probability of type-2 error ($\boldsymbol{\beta}$)
- The relative uncertainty of the measurement process ($\boldsymbol{\sigma}$)
- The cost ratio ($\boldsymbol{\tau}$) i.e., the cost of making type 2 errors as a proportion of maximum attainable output.
- Probability of the production process operating correctly in a certain period ($\boldsymbol{p_A}$)
- Probability that the production process has malfunctioned ($\boldsymbol{p_B}$)

This analysis aims to adapt the developed formula that calculates the economic benefit of using primary calibrations to reduce uncertainty in the measurement process. The report published by NPL analysts[45], which serves as a reference for this section, outlines the mathematical framework behind the calculations that estimate the benefit of primary calibrations, based on the assumptions about the parameters.

However, the survey does not ask the respondents to specify whether their calibrations are primary or secondary. Instead, the responses indicate whether they calibrate their instruments or use reference materials.

Therefore, the economic model will need to be adapted to align with the questions in the survey:

- In the baseline scenario, the firm depends on calibrations provided by the NMS laboratories to eliminate calibration-related uncertainties. Furthermore, the survey

[45] King, M; Nayak, S (2023) An Economic Model for the Value Attributable to High-Quality Calibrations by Reducing Mistakes in Conformance Testing. NPL Report. IEA 19

also provides an estimate for the additional uncertainty introduced when the firms that conduct conformance testing do not perform calibrations.

The question from the survey that calculates the increase in uncertainty is: In the context of conformance testing, if you do not calibrate your instruments and/or use reference materials, what is the attributable percentage increase in measurement uncertainty, in your testing and analysis?

- In the baseline scenario, the survey also provides probability estimates for the type 1 and type 2 errors.

  The questions from the survey are:

  - What is the probability of mistakenly rejecting an item or batch that does meet specification? (Type 1 error)
  - What is the probability of mistakenly accepting an item or batch that does not meet specification? (Type 2 error)

### 4.5.2 Numerical based on survey estimates

Baseline Scenario: In this scenario, we assume that the firm uses calibrations for the measurement process in conformance testing. The data from the survey provides us with as computed in section 4.4.1:

$$\alpha = 0.01 \text{ and } \beta = 0.01$$

To get the corresponding relative standard deviation, we plug the values of $\alpha$ and $\beta$ into the below equation that we take Equation 9 from the model[46]:

$$\sigma = \sigma_0 = \frac{1}{\Phi^{-1}(1-\alpha) - \Phi^{-1}(\beta)} = \frac{1}{\Phi^{-1}(0.99) - \Phi^{-1}(0.01)} = 0.21$$

We would also need to obtain a relative cost ratio i.e., the relative cost of making type 2 errors as a proportion of the maximum attainable output. As the values of $\alpha$ and $\beta$ are equal in this scenario, it can be said that:

$$\tau = 1$$

Next, we will obtain the values of $\wp_A$ and $\wp_B$ based on the survey results from the likelihood of a malfunction in the production process computed in section 4.4.4.1:

$$\wp_B = 0.02$$

$$\wp_A = 1 - \wp_B = 1 - 0.02 = 0.98$$

[46] King, M; Nayak, S (2023) An Economic Model for the Value Attributable to High-Quality Calibrations by Reducing Mistakes in Conformance Testing. NPL Report. IEA 19

Finally, the values of scrap rate ($\mathcal{s}$) and rebate rate ($\mathcal{r}$) can be obtained using the following Equation 43:

$$\mathcal{s} = \mathcal{p}_A \cdot \alpha + \mathcal{p}_B \cdot (1 - \beta)$$
$$= 0.98 \times 0.01 + 0.02 \times (1 - 0.01) = 0.029$$

$$\mathcal{r} = \mathcal{p}_B \cdot \beta = 0.02 \times 0.01 = 0.0002$$

Therefore, the scrap rate derived from the model is 3% (similar to the scrap rate observed in section 4.4.3 from the survey) and the rebate rate is 0.02% (similar to the rebate rate observed in section 4.4.4.2 from the survey with a value of less than 1%). It is also important to highlight that the survey estimates of $\alpha$ and $\beta$ disregard one of the main assumptions in the model, which states that a type-2 error is twice as costly as a type-1 error.

Now, we consider a counterfactual scenario in which the firm does not calibrate its instruments.

Counterfactual scenario: It is reasonable to assume that not calibrating the instruments increases the uncertainty in the measurement process undertaken by the firm. This increase in uncertainty, compared to the baseline given by $\frac{\epsilon}{\sigma_0}$, represents the proportion of uncertainty that is removed through calibration.

This value can be calculated directly from the Equation 52 in the model:

$$\frac{\Delta\sigma}{\sigma_0} \approx \frac{1}{2}\left(\frac{\epsilon}{\sigma_0}\right)^2$$

By substituting the value of $\frac{\epsilon}{\sigma_0}$ obtained from the survey, in section 4.4.2, we get:

$$\frac{\Delta\sigma}{\sigma_0} \approx \frac{1}{2}(0.2)^2$$

$$\frac{\Delta\sigma}{\sigma_0} = 0.02$$

The value of $\Delta\sigma$ can be obtained by:

$$\Delta\sigma = \frac{\Delta\sigma}{\sigma_0} \times \sigma_0 = 0.02 \times 0.21 = 0.004$$

Therefore, this implies that:

$$\sigma = \sigma_0 + \Delta\sigma = 0.21 + 0.004 = 0.22$$

In contrast to the relative standard deviation, $\tau$ is determined solely by exogenous factors and is unlikely to be affected by a change in measurement uncertainty due to calibration. Therefore, we can consider $\tau$ to remain fixed at the same value as in the baseline scenario:

$$\tau = 1$$

The new values of $\alpha$ and $\beta$ can be obtained by plugging the values of $\sigma$ and $\tau$ into Equation 33 and Equation 34 in the model:

$$\alpha^*(\sigma,\tau) = 1 - \Phi\left(2\sigma.\ln\left(1/\sqrt{\tau}\right) + (1/2\sigma)\right)$$
$$= 1 - \Phi\left(2 \times 0.22 \times \ln\left(1/\sqrt{1}\right) + (1/2 \times 0.22)\right) = 0.011$$

$$\beta^*(\sigma,\tau) = \Phi\left(2\sigma.\ln\left(1/\sqrt{\tau}\right) - (1/2\sigma)\right)$$
$$= \Phi\left(2 \times 0.22 \times \ln\left(1/\sqrt{1}\right) - (1/2 \times 0.22)\right) = 0.011$$

Note that the values of $\mathcal{p}_A$ and $\mathcal{p}_B$ will also remain the same as the baseline scenario. However, new values of scrap rate ($\mathcal{s}$) and rebate rate ($\mathcal{r}$) can be obtained:

$$\mathcal{s}^* = \mathcal{p}_A \cdot \alpha^*(\sigma,\tau) + \mathcal{p}_B \cdot \left(1 - \beta^*(\sigma,\tau)\right)$$
$$= 0.98 \times 0.011 + 0.02 \times (1 - 0.011) = 0.03$$

$$\mathcal{r}^* = \mathcal{p}_B \cdot \beta^*(\sigma,\tau) = 0.02 \times 0.011 = 0.00023$$

Now, the probability of the expected cost of mistakes due to measurement errors can be expressed as:

$$\mathcal{E} = \mathcal{p}_A \cdot \alpha + \mathcal{p}_B \cdot \beta$$

$$\mathcal{E} = (0.98 \times 0.01) + (0.02 \times 0.01) = 0.01$$

Therefore, 1% of the output is lost due to type 1 and type 2 errors ($\mathcal{E}$). The first part of the equation ($\mathcal{p}_A \cdot \alpha$) represents the likelihood of making a type 1 error. It is clear that **a third of the scrap rate comes from the cost of type 1 errors, which is avoidable**. The second part of the question ($\mathcal{p}_B \cdot \beta$), as established previously, is the rebate rate.

Moreover, the survey results revealed that the manufacturing firms that engaged with the NMS labs represent around 13% of the UK's manufacturing workforce and have an aggregate turnover of around £73.20 billion[47].

$$\underbrace{\mathbf{£73.2\ billion}}_{\substack{Turnover\ of\ our\ users \\ in\ manufacturing}} \times \underbrace{\mathbf{1\%}}_{\substack{Lost\ output \\ due\ to\ mistakes}} = \underbrace{\mathbf{£732\ million}}_{\substack{Cost\ incurred\ by \\ users\ in\ manufacturing}}$$

Assuming that the absolute theoretical maximum value of goods produced is approximately equal to the aggregate turnover of the manufacturing firms working with the NMS labs, we can infer that these **firms will incur an additional cost of £732 million if they forego calibrations**.

The Office for National Statistics (ONS) releases annual data on the UK's non-financial businesses through the Annual Business Survey[48]. In 2022, the total turnover of the UK's manufacturing sector was about £648 billion, with an approximate gross value added (GVA) of £198 billion. This gives the ratio of GVA to total turnover as $0.3$ ($\approx 198/648$).

[47] The business sites that use the NMS labs have an aggregate turnover of £154 billion. 48% of the NMS users belong to the manufacturing sector. Therefore, the calculation $= 48\% \times 154\ \text{billion} \approx £73.2\ \text{billion}$.

[48] For the analysis, the numbers from the year 2022 of the ONS dataset for Manufacturing sector (SIC "C") are used.

$$\underbrace{\mathbf{£732\ million}}_{\substack{Cost\ incurred\ by \\ users\ in\ manufacturing}} \times \underbrace{\mathbf{33\%}}_{\substack{GVA\ dial \\ down\ factor}} = \underbrace{\mathbf{£220\ million}}_{\substack{GVA\ safeguarded\ for \\ users\ in\ manufacturing}}$$

We can estimate **that the GVA safeguarded through supplying calibrations to manufacturing firms that work with the NMS labs is approximately £220 million**.

The change in the measurement errors can be obtained by:

$$\Delta\alpha = \alpha^* - \alpha = 0.011 - 0.01 = 0.001$$

$$\Delta\beta = \beta^* - \beta = 0.011 - 0.01 = 0.001$$

Similarly, the change in the probability of the expected cost of mistakes due to measurement errors can be expressed as:

$$\Delta\mathcal{E} = \mathcal{p}_A \cdot \Delta\alpha + \mathcal{p}_B \cdot \Delta\beta$$

$$\Delta\mathcal{E} = (0.98 \times 0.001) + (0.02 \times 0.001) = 0.001$$

It is evident that as the measurement uncertainty rises, the likelihoods of making type-1 and type-2 errors also increases. Therefore, to compute the increase in the cost of mistakes, we get:

$$\frac{\Delta\mathcal{E}}{\mathcal{E}} = \frac{0.001}{0.01} = 0.1$$

Consequently, we can say that:

$$\frac{\Delta\mathcal{E}}{\mathcal{E}} = \frac{\mathcal{p}_A \cdot \Delta\alpha + \mathcal{p}_B \cdot \Delta\beta}{\mathcal{p}_A \cdot \alpha + \mathcal{p}_B \cdot \beta}$$

Therefore, **if calibrations that are traceable to the measurement standards did not exist, the cost of mistakes in the conformance testing process ($\Delta\mathcal{E}$) would increase by a tenth of a percentage point i.e., 0.1 percentage points**.

So far, we only have values that are direct estimates for private businesses that work with the NMS. As these firms represent around 13% of the UK's manufacturing workforce, we can now estimate a value for manufacturing sector as a whole, which is an upper bound. Note that these values as indicative in this case.

$$\underbrace{\mathbf{£220\ million}}_{\substack{GVA\ safeguarded\ for \\ users\ in\ manufacturing}} \div \underbrace{\mathbf{13\%}}_{\substack{Userbase\ as\ a\ fraction \\ of\ manufacturing}} = \underbrace{\mathbf{£1.7\ billion}}_{\substack{Manufacturing\ GVA \\ safeguarded}}$$

It is worth noting that similar scrap rates are also observed in the services sector. Therefore, this analysis sets context for a technical report that will be published in the in the near future to address this matter. The report will be based on a macroeconomic model to provide a robust foundation for the conformance testing aspects of National Quality Infrastructure, using estimates of the core parameters derived from these findings.

## 5 NATIONAL CHALLENGE AREAS

The national challenge areas aim to align with the UK's current and future requirements. The private businesses that the NMS labs work with connect to four strategic areas: Prosperity, Environment, Health, and Security & resilience.

- **Prosperity** aims to shift the UK's industrial landscape towards achieving net-zero carbon emissions, prioritizing societal wellbeing, driving the need for innovation and investment in measurement infrastructure to unlock market opportunities and ensure economic growth, and align with government strategies such as the Industrial Strategy and the Clean Growth Strategy.
- **Environment** aims to minimise environmental damage caused by greenhouse gas emissions, utilize national science and metrology to aid the transition to a net-zero emissions economy, ensure sustainability, and align with government strategies such as the Net-zero Strategy and Climate Change Act.
- **Health** aims to enhance and provide metrology expertise to support faster disease detection, sustainable bioeconomy development, reliable data for early diagnosis and precision medicine, and align with government strategies and global life sciences & health sector trends.
- **Security & resilience** aims to deliver a robust digital measurement infrastructure, support innovation, ensure a resilient infrastructure, and foster public trust in transformative technologies like self-driving vehicles, quantum computing, and Artificial Intelligence.

In the following chart, the lightest shade represents micro firms; the medium shade represents SMEs, and the darkest shade represents large firms.

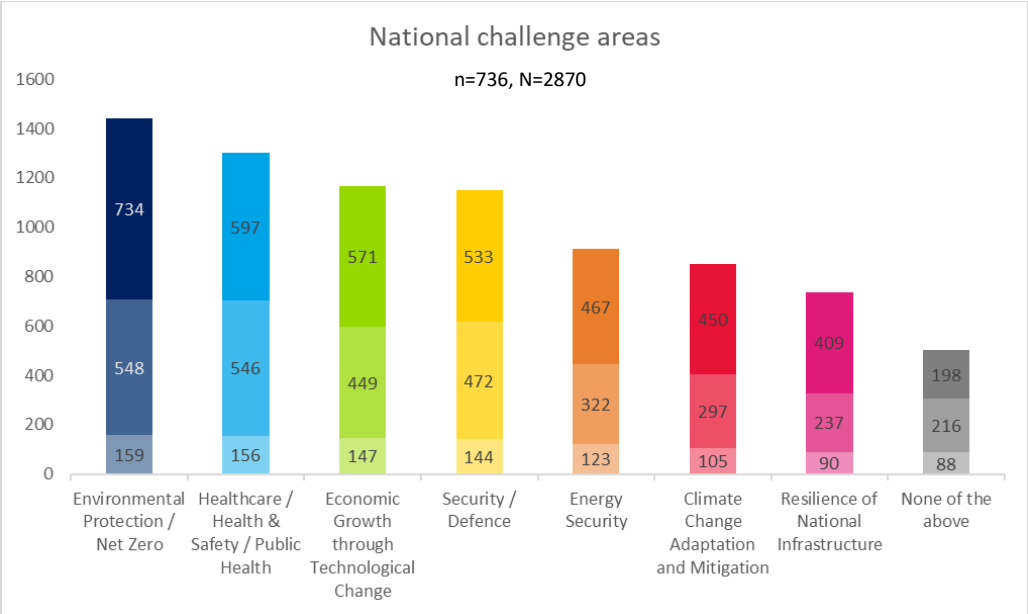



**Figure 37 Count of the NMS users that connect to national challenge areas by size of sites[49]**

[49] The firm's line-of-business can connect to more than one national challenge area.

## 5.1 ATTRIBUTION TO THE NMS LABS' SUPPORT

This section details on attribution to the NMS labs through conditional probabilities. The Venn diagram sets the context for the analysis to follow:

- Set A – refers to a firm's connection to a technological or challenge area[50].
- Set B – refers to the attribution to the NMS labs for an innovation project[51].
- Intersection (A∩B) – refers to the firms that work in a technological or challenge area and have attributed their innovation project to the NMS labs.

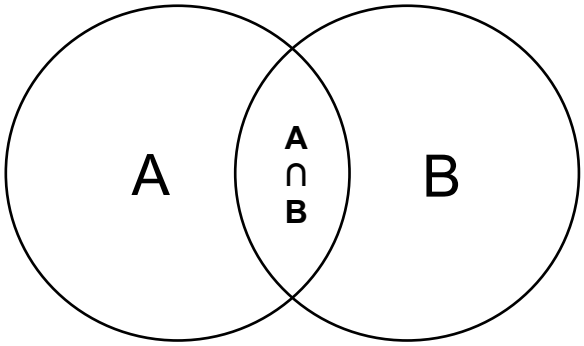



**Figure 38 Venn diagram for conditional probabilities**

In this case, the conditional probability of attributing the innovation project to the NMS labs (event B) is the probability that it will occur, given the knowledge that the firm's line-of-business lies in that particular challenge area or technological area (event A). This probability is written as $\boldsymbol{P(B|A)}$, notation for the probability of B given A.

The equation for condition probability is as follows:

$$\boldsymbol{P(B|A) = \frac{P(A \cap B)}{P(A)}}$$

In economic terms, the above equation can be re-written as:

$$\boldsymbol{Criticality\ of\ NMS\ labs'\ support\ in\ an\ area = \frac{Impact\ attributed\ in\ an\ area}{Relevance\ of\ an\ area\ to\ users}}$$

Alternatively, it could also be said that the impact of the NMS labs on the attributed innovations is the multiplicative combination of the relevance of a particular challenge/ technological area to the userbase and the criticality of the labs' support to advances in innovations in that a particular challenge / technological area.

| | | | | |
|---|---|---|---|---|
| ***Impact attributed in an area*** | **=** | ***Criticality of NMS labs' support in an area*** | **×** | ***Relevance of an area to users*** |

[50] This question has been answered by all the 736 survey respondents.
[51] This question appears in the innovation question set and is only answered by 343 respondents. This complexity might result in small sample sizes for certain challenge or technological areas. The sample sizes (n) that are lower than 30 are mentioned in the tables.

It should be noted that the sampling weights are not assigned in the following analysis i.e., it is not representative of the entire population of the survey.

49% of the userbase has a line-of-business (or activity) that's connected to improving environmental protection. Moreover, 37% of these businesses attributed innovations to support from the NMS labs.

44% of the userbase has a line-of-business that's connected to security/defence. Moreover, 34% of these businesses attributed innovations to support from the NMS labs.

47% of the userbase has a line-of-business that feeds into the provision of healthcare services or connects to the fields of public health. Moreover, 31% of such businesses attributed innovations to support from the NMS labs.

**Table 26 Conditional probabilities for national challenge areas**

| **National Challenge Areas** | $P(A \cap B)$ | $P(A)$ | $P(B\|A)$ |
|---|---|---|---|
| Environmental Protection / Net Zero | 18% | 49% | 37% |
| Security / Defence | 15% | 44% | 34% |
| Healthcare / Health & Safety / Public Health | 15% | 47% | 31% |
| Economic Growth through Technological Change | 11% | 41% | 28% |
| Climate Change Adaptation and Mitigation *(n=29)* | 10% | 29% | 36% |
| Energy Security *(n=24)* | 9% | 32% | 28% |
| Resilience of National Infrastructure *(n=19)* | 7% | 25% | 26% |
| **Any national challenge area** | **44%** | **85%** | **52%** |
| None of the above *(n=19)* | 8% | 15% | 53% |

In the above table, the row highlighted in bold showcases the values for respondents who have selected at least one of the mentioned national challenge areas as their response. **85% of the userbase has a line-of-business that's connected to at least one national challenge area. Moreover, around half (52%) of these businesses attributed innovations to support from the NMS labs.**

This can be explained in simple terms using an analogy of a ball in a bucket. For example, let's consider that a **green** ball represents **environmental protection**, and a **red** ball represents **security**. In this case, *only* the **green** ball can fall into the **environmental protection** bucket and *only* a **red** ball can fall into the **security** bucket. However, *both* the **red** *and* **green** ball can fall into the "**any national challenge area**" bucket. Therefore, the probabilities for belonging to any national challenge area are much higher than probabilities for specific national challenge areas.

## 5.2 ADDITIONAL ANALYSIS FOR ATTRIBUTION TO NMS LABS' SUPPORT

This section details the additional analysis performed to showcase the attribution to the NMS labs using a regression approach. The regression line tells how the dependant variable changes as the independent variable changes. In this case, 'innovation attribution to the NMS labs' is the dependant variable and 'connection to the firm's line-of-business' is the independent variable. It can be observed from the below figure that sections of the Environment and Health sectors have registered maximum contribution from the NMS labs.

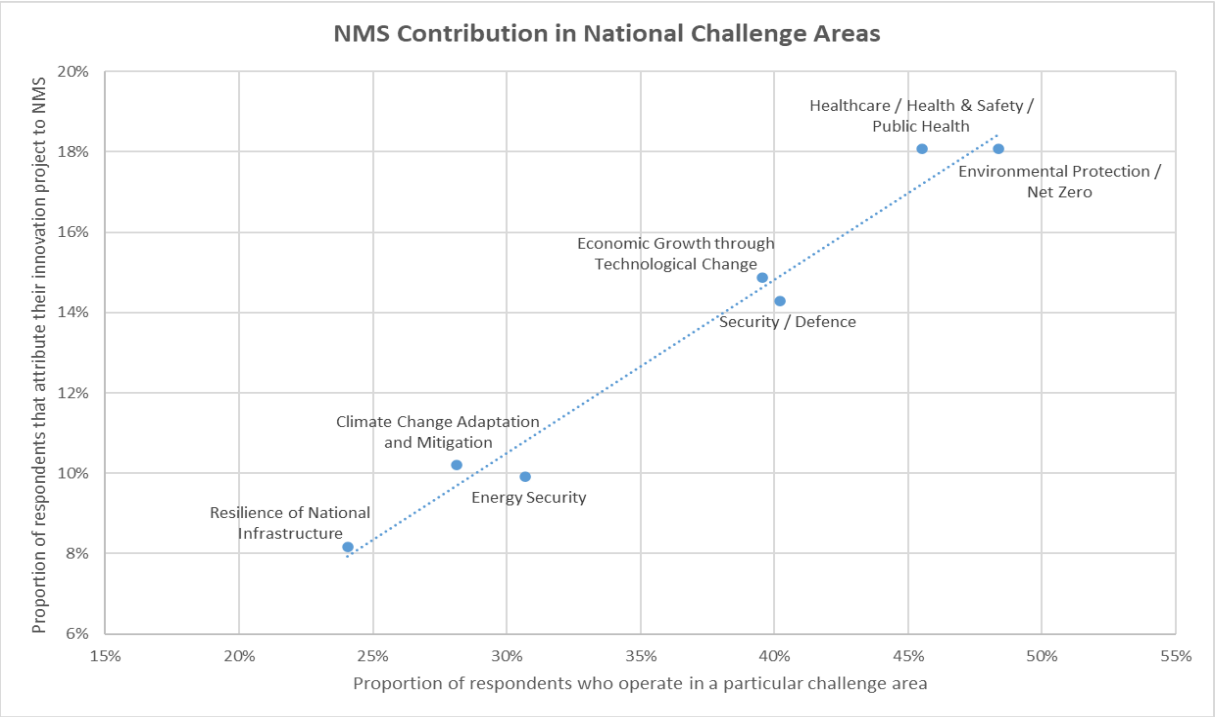



**Figure 39 Scatter plot for NMS labs' support provided within national challenge areas**

The below table showcases a quotient analysis modelled on regional quotients, using the regression[52] approach. The quotient shows the significance of the NMS labs' contribution to innovations in a challenge area. Out of all the challenge areas, the Health sector stands out at the highest i.e., when the predicted outcome is at 17%, the actual outcome is 18%, which is ~5% more. The same value also resonates with a section of the Environment sector. This shows that the firms that operate in the Environment and Health challenge areas in the UK consider the NMS labs as an important factor to help develop their innovations.

**Table 27 Quotient analysis for national challenge areas**

| National Challenge Areas | Actual outcome | Predicted outcome | Residuals | Quotient | % change[53] |
|---|---|---|---|---|---|
| Economic Growth through Technological Change | 0.15 | 0.15 | 0.00 | 1.02 | 2% |
| Environmental Protection / Net Zero | 0.18 | 0.18 | 0.00 | 0.98 | -2% |
| Healthcare / Health & Safety / Public Health | 0.18 | 0.17 | 0.01 | 1.05 | 5% |
| Security / Defence | 0.14 | 0.15 | -0.01 | 0.96 | -4% |
| Resilience of National Infrastructure | 0.08 | 0.08 | 0.00 | 1.03 | 3% |
| Energy Security | 0.10 | 0.11 | -0.01 | 0.92 | -8% |
| Climate Change Adaptation and Mitigation | 0.10 | 0.10 | 0.01 | 1.05 | 5% |

[52] A caveat for this regression (as it assumes a linear relationship) is when observations are either too big or too small, the estimates produced might not be quite right.

[53] The percentage change was calculated using the formula: $\frac{Residuals}{Predicted\ outcome}$

## 6 SIGNIFICANT TECHNOLOGY AREAS

The respondents were asked if their firm's line-of-business connects to any significant technological areas. It can be observed that a high number of respondents chose areas that broadly connect to 'Environment' and 'Health'.

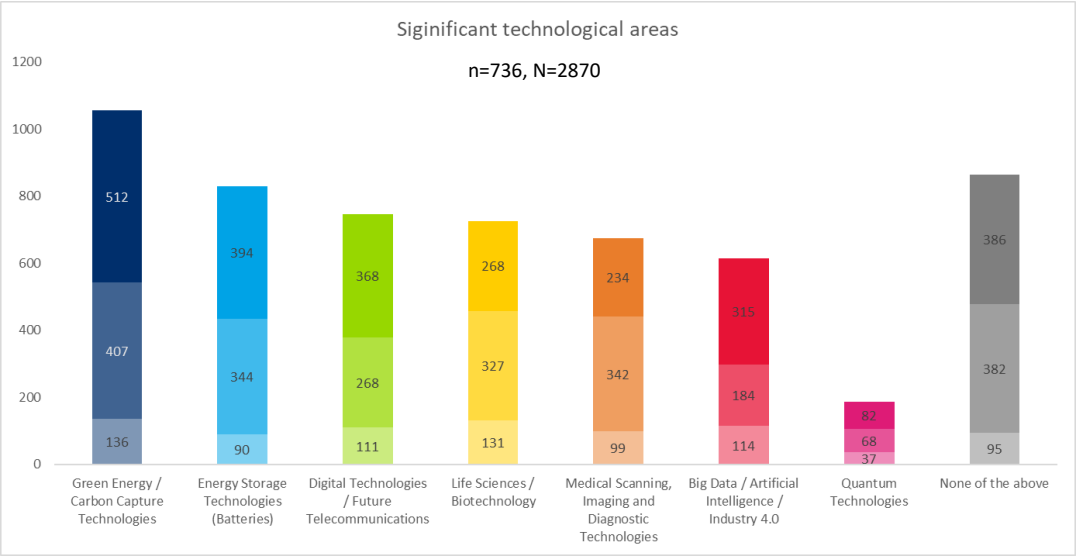



**Figure 40 Count of the NMS users that connect to significant technological areas by size of sites[54]**

The below figure compares the proportion of the technological areas that function in the GSE region and other regions in the UK. The most striking observation is that the businesses that connect to nascent areas such as quantum technologies and artificial intelligence seem to work more in the GSE region in comparison to other existing technological areas.

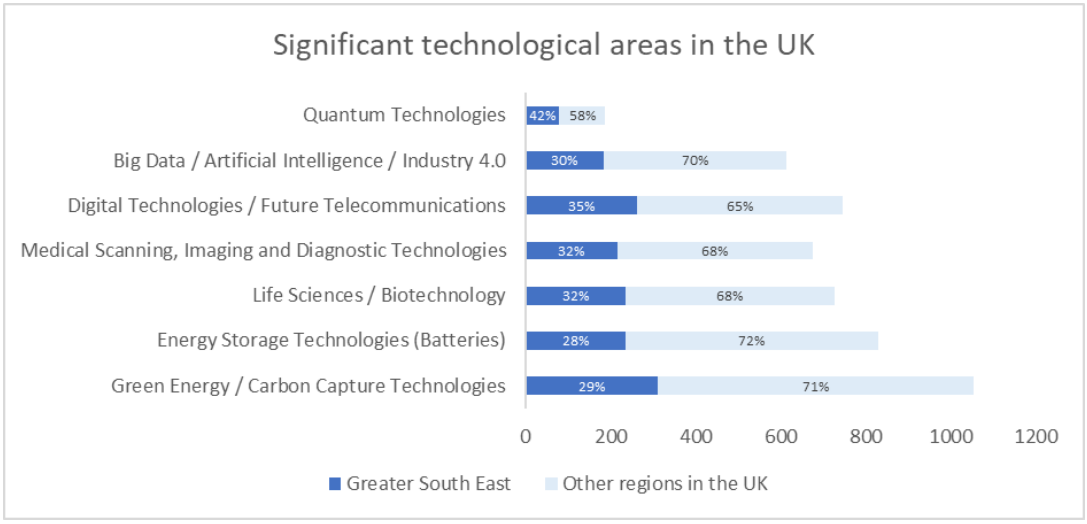



**Figure 41 Proportion of regions in the UK broken down by technological areas**

[54] The firm's line-of-business can connect to more than one significant technological area.

### 6.1 ATTRIBUTION TO THE NMS LABS' SUPPORT

It is important to note that sampling weights are not assigned in this analysis i.e., it is not representative of the entire population of the survey.

7% of the userbase has a line-of-business connected to the development of quantum technologies. 28% of the userbase has a line-of-business connected to the development of biotechnology. Moreover, ~38% of these businesses attributed innovations to support from the NMS labs. However, it is important to exercise caution while interpreting technological areas with very low sample sizes.

Quantum technologies have a small impact because it is a nascent area, but the support from the NMS labs is of long-term importance. Future impact is driven by the growth in quantum. Therefore, if the NMS labs continue to play a critical role by providing support, they will remain vital to growth in this area.

**Table 28 Conditional probabilities for significant technological areas**

| **Significant technological areas** | $P(A \cap B)$ | $P(A)$ | $P(B\|A)$ |
|---|---|---|---|
| Green Energy / Carbon Capture Technologies | 12% | 38% | 30% |
| Life Sciences / Biotechnology *(n=26)* | 11% | 28% | 39% |
| Energy Storage Technologies / Batteries *(n=21)* | 9% | 29% | 30% |
| Digital Technologies / Future Telecommunications *(n=21)* | 8% | 26% | 32% |
| Medical Scanning, Imaging and Diagnostic Technologies *(n=19)* | 7% | 27% | 26% |
| Big Data / Artificial Intelligence / Industry 4.0 *(n=16)* | 6% | 20% | 29% |
| Quantum Technologies *(n=9)* | 3% | 7% | 38% |
| **Any significant technological area** | **33%** | **72%** | **45%** |
| None of the above | 18% | 28% | 66% |

In the above table, the row highlighted in bold showcases the values for respondents who have selected at least one of the mentioned significant technological areas as their response.

**72% of the userbase has a line-of-business that's connected to at least one significant technological area. Moreover, 45% of these businesses attributed innovations to support from the NMS labs.**

It is notable that 28% of the respondents chose 'None of the above', with the remaining 72% of respondents declaring that their line-of-business connects to at least one of our selected technological areas. In other words, more than one quarter of the respondents have a line-of-business that doesn't connect to any of our selected technological areas.

This suggests that there are other up-and-coming technological areas that the NMS labs should be looking into so that it can better support its userbase. Some of these might be 'whizzy' technological areas that are not yet established and have not acquired a commonly used label. On the other hand, it is possible that traditional areas in manufacturing (where a large fraction of the userbase lies) may have become so mature that they are better classified as an industry rather than as a technological area.

## 6.2 ADDITIONAL ANALYSIS FOR ATTRIBUTION TO NMS LABS' SUPPORT

Similar to the regression analysis performed to showcase the attribution to the NMS labs using a regression approach in the national challenge areas, this section highlights the observation that Quantum technologies is a significant technological area. Despite making up a small fraction of the technological sphere, quantum has registered maximum contribution from the NMS labs.

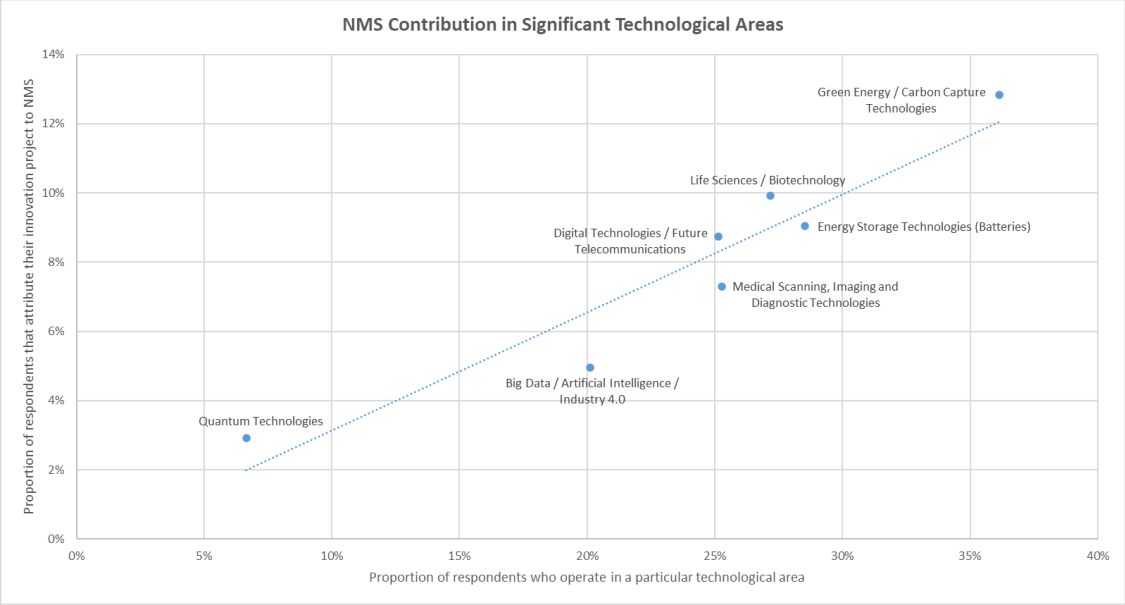



**Figure 42 Scatter plot for NMS labs' support provided within technological areas**

In the quotient analysis, out of all the technological areas, Quantum technologies stand out at the highest i.e., when the predicted outcome is at 2%, the actual outcome is 3%, which is ~50% more. This shows that the nascent quantum sector in the UK consider the NMS labs as an important factor to help develop their innovations.

**Table 29 Quotient analysis for significant technological areas**

| Significant technological areas | Actual outcome | Predicted outcome | Residuals | Quotient | % change |
|---|---|---|---|---|---|
| Green Energy / Carbon Capture Technologies | 0.13 | 0.12 | 0.01 | 1.06 | 6% |
| Energy Storage Technologies (Batteries) | 0.09 | 0.09 | 0.00 | 0.96 | -4% |
| Life Sciences / Biotechnology | 0.10 | 0.09 | 0.01 | 1.10 | 10% |
| Medical Scanning, Imaging and Diagnostic Technologies | 0.07 | 0.08 | -0.01 | 0.87 | -13% |
| Digital Technologies / Future Telecommunications | 0.09 | 0.08 | 0.00 | 1.05 | 5% |
| Big Data / Artificial Intelligence / Industry 4.0 | 0.05 | 0.07 | -0.02 | 0.75 | -25% |
| Quantum Technologies | 0.03 | 0.02 | 0.01 | 1.46 | 46% |

## 7 MULTIPLE PERSPECTIVE APPROACH FOR CHALLENGE AREAS

CONTEXT SETTING WITH DEFINITIONS

**Userbase** refers to a firm's connection to an area.

**Employment** refers to the total number of employees that work at the sites that engage with the NMS labs in an area.

**Turnover** refers to the financial turnover in tax year ending in 2022 at the business sites that use the NMS labs in an area.

**Revenue per employee** roughly measures the revenue generated by each employee for the sites that work with the NMS labs in an area.

**Indirect reach** refers to the number of commercial calibration labs that the NMS customers work with to estimate how far their direct reach extends in an area.

**Introduced products/processes** refers to the proportion of NMS customers that have introduced new and improved products/processes in an area.

**Disruptive innovations** refer to the proportion of innovations introduced by the NMS customers that have transformed the market or industry in an area.

**Net Promoter Score** refers to the likeliness of customers recommending the NMS labs to a colleague or other organisation in an area.[55]

**Attributed innovations** refer to the proportion of innovations by the firms that work in an area and have attributed their innovation project to the NMS labs i.e., $\boldsymbol{P(A \cap B)}$.

**Propensity to attribute** refers to the proportion of innovations that are attributed to the NMS labs, given the knowledge that the firm's line-of-business lies in that particular area i.e., $\boldsymbol{P(B|A)}$.

**Likelihood of connection** refers to the proportion of attributing firms identifying with a particular area i.e., $\boldsymbol{P(A|B)}$.

**Attributed sales revenue** refers to the revenue from sales that is attributed to an area. The steps undertaken to calculate these numbers are mentioned below.

Irrespective of an area, a third (**32%**) of users from the private sector believe that their new and improved products would not exist without the support they received from the NMS labs. Therefore, each year, around 920 of the UK-based businesses who've used the NMS labs, collectively attribute **£500 million** in sales revenue to innovations that wouldn't have succeeded without the NMS labs.

[55] Customers are classified as 'promoters' if they answer 9 or 10, 'passives' if they answer 7 or 8, and 'detractors' if they answer 6 or under. The NPS is calculated by subtracting the percentage of detractors from the percentage of promoters.

In equation terms:

$$\boldsymbol{Attributed\ Sales\ Revenue} = \frac{\boldsymbol{P(B|A)}}{\boldsymbol{P(B)}} * \boldsymbol{P(A)} * \boldsymbol{Overall\ sales\ revenue}$$

Substituting the known values:

$$Attributed\ Sales\ Revenue = \frac{P(B|A)}{P(B)} * P(A) * £500m$$

The equation can also be re-written as:

$$Attributed\ Sales\ Revenue = \frac{P(A \cap B)}{P(B)} * £500m$$

In simple terms:

$$\boldsymbol{Attributed\ Sales\ Revenue\ for\ an\ area} = \boldsymbol{P(A|B)} * \boldsymbol{£500m}$$

## 7.1 DIFFERENT VIEWS OF THE CHALLENGE AREAS

Different questions from the survey could be retrofitted into the four broad challenge areas i.e., Prosperity, Environment, Health, and Security. This analysis therefore presents multiple viewers through which the numbers can be interpreted.

### 7.1.1 National challenge areas

Under this perspective of 'National Challenge Areas', the viewer is the user or customer. Therefore, it is an external perspective of the challenge areas i.e., the demand pool.

**Table 30 Perspective of National Challenge Areas**

**PROSPERITY**

| **Userbase** | **43%** |
|---|---|
| Employment | 777,814 |
| Turnover | 173 billion |
| Revenue per employee | 222,418 |
| Indirect reach | 112,506 |
| Introduced products/processes | 92% |
| Disruptive innovations | 14% |
| Attributed innovations | 12% |
| Propensity to attribute | 28% |
| Likelihood of connection | 38% |
| Attributed sales revenue | 188 million |
| Net Promoter Score | 50% |

**HEALTH**

| **Userbase** | **46%** |
|---|---|
| Employment | 723,666 |
| Turnover | 162 billion |
| Revenue per employee | 223,860 |
| Indirect reach | 77,565 |
| Introduced products/processes | 94% |
| Disruptive innovations | 20% |
| Attributed innovations | 17% |
| Propensity to attribute | 37% |
| Likelihood of connection | 53% |
| Attributed sales revenue | 266 million |
| Net Promoter Score | 53% |

**ENVIRONMENT**

| **Userbase** | **60%** |
|---|---|
| Employment | 739,568 |
| Turnover | 155 billion |
| Revenue per employee | 209,582 |
| Indirect reach | 84,385 |
| Introduced products/processes | 93% |
| Disruptive innovations | 18% |
| Attributed innovations | 24% |
| Propensity to attribute | 40% |
| Likelihood of connection | 75% |
| Attributed sales revenue | 375 million |
| Net Promoter Score | 48% |

**SECURITY**

| **Userbase** | **51%** |
|---|---|
| Employment | 651,016 |
| Turnover | 136 billion |
| Revenue per employee | 208,904 |
| Indirect reach | 81,299 |
| Introduced products/processes | 92% |
| Disruptive innovations | 21% |
| Attributed innovations | 19% |
| Propensity to attribute | 37% |
| Likelihood of connection | 59% |
| Attributed sales revenue | 297 million |
| Net Promoter Score | 51% |

The survey respondents were asked to choose the national challenge areas that their firm's line of business (or activity) connects to.

**Table 31 Survey response options for national challenge areas**

| Response options in the survey | Challenge area |
|---|---|
| Economic Growth through Technological Change | Prosperity |
| Environmental Protection / Net Zero | Environment |
| Healthcare / Health & Safety / Public Health | Health |
| Security / Defence | Security |
| Resilience of National Infrastructure | Security |
| Energy Security | Environment |
| Climate Change Adaptation and Mitigation | Environment |

The following are the main highlights from the 'National Challenge Areas' viewer:

- Environment stands out in all aspects of attribution to the NMS labs; it has the highest proportion of attributed innovations and propensity to attribute, and also the largest attributed sales revenue. Moreover, three quarters of attributing firms connect to Environment.
- Although employment and turnover of firms are the lowest in Security, this challenge area produces the highest number of innovations that transform the market or industry.
- In comparison to all the challenge areas, the users that operate in Health are most satisfied with the NMS labs, however, have the lowest indirect reach.
- On the other hand, although Prosperity has the highest indirect reach amongst all challenge areas, it has the lowest level of attributions, especially for innovations.

### 7.1.2 Science areas for measurement activities

Under this perspective of 'Science Areas for Measurement Activities', the viewer is the NMS labs itself. Therefore, it is an internal perspective of the challenge areas.

**Table 32 Perspective of Science Areas**

**PROSPERITY**

| **Userbase** | **75%** |
|---|---|
| Employment | 751,252 |
| Turnover | 158 billion |
| Revenue per employee | 210,316 |
| Indirect reach | 99,556 |
| Introduced products/processes | 93% |
| Disruptive innovations | 18% |
| Attributed innovations | 25% |
| Propensity to attribute | 33% |
| Likelihood of connection | 78% |
| Attributed sales revenue | 391 million |
| Net Promoter Score | 50% |

**HEALTH**

| **Userbase** *(n=61)* | **10%** |
|---|---|
| Employment | 1,006,669 |
| Turnover | 161 billion |
| Revenue per employee | 159,933 |
| Indirect reach | 10,274 |
| Introduced products/processes | 74% |
| Disruptive innovations | 18% |
| Attributed innovations | 3% |
| Propensity to attribute | 30% |
| Likelihood of connection | 9% |
| Attributed sales revenue | 47 million |
| Net Promoter Score | 38% |

**ENVIRONMENT**

| **Userbase** | **32%** |
|---|---|
| Employment | 671,568 |
| Turnover | 220 billion |
| Revenue per employee | 327,592 |
| Indirect reach | 94,608 |
| Introduced products/processes | 88% |
| Disruptive innovations | 19% |
| Attributed innovations | 11% |
| Propensity to attribute | 34% |
| Likelihood of connection | 34% |
| Attributed sales revenue | 172 million |
| Net Promoter Score | 50% |

**SECURITY**

| **Userbase** *(n=64)* | **10%** |
|---|---|
| Employment | 424,253 |
| Turnover | 290 billion |
| Revenue per employee | 683,554 |
| Indirect reach | 104,994 |
| Introduced products/processes | 93% |
| Disruptive innovations | 27% |
| Attributed innovations | 2% |
| Propensity to attribute | 20% |
| Likelihood of connection | 6% |
| Attributed sales revenue | 31 million |
| Net Promoter Score | 52% |

The survey respondents were asked to choose the science area in which they conduct the majority of their measurement activity. It should be noted that 'Data Science' is not mentioned as a response option as it does not connect to any measurement activity even though it strongly connects to 'Security'. Therefore, the lack of data science may affect the security numbers.

**Table 33 Survey response options for science areas**

| Response options in the survey | Challenge area |
|---|---|
| Mass & Dimensional | Prosperity |
| Material Properties | Prosperity |
| Thermal & Radiometric Metrology | Prosperity, Environment |
| Electromagnetic & Electrochemical Technologies | Prosperity, Environment, Security |
| Other Engineering Metrology | Prosperity |
| Chemical & Biological Sciences | Prosperity, Health |
| Medical, Marine & Nuclear | Health, Environment |
| Atmospheric Environmental Science | Environment |
| Time & Frequency / Quantum Metrology | Security |

The following are the main highlights from the 'Science Areas for Measurement' viewer:

- More than three quarters of the attributing firms connect to Prosperity. This area also introduced many new and improved products/processes. Moreover, it has the highest proportion of attributed innovations and the largest attributed sales revenue.
- In comparison to all the challenge areas, Environment has the highest propensity to attribute and a significant revenue per employee. After Prosperity, a sizeable number of firms that engage with the NMS labs operate in Environment.
- However, Environment also has the least attributed innovations and sales revenue.
- Health and Security have a low sample size (n~60) and therefore the numbers should be interpreted with caution.

### 7.1.3 Significant technological areas

Under this perspective of 'Significant Technological Areas', the viewer is the innovator and therefore is an external view of the challenge areas. Moreover, challenge areas under this perspective are forward looking i.e., relate to the future.

**Table 34 Perspective of Significant Technological Areas**

**PROSPERITY**

| **Userbase** | **58%** |
|---|---|
| Employment | 753,972 |
| Turnover | 182 billion |
| Revenue per employee | 241,388 |
| Indirect reach | 68,075 |
| Introduced products/processes | 91% |
| Disruptive innovations | 15% |
| Attributed innovations | 19% |
| Propensity to attribute | 33% |
| Likelihood of connection | 59% |
| Attributed sales revenue | 297 million |
| Net Promoter Score | 50% |

**HEALTH**

| **Userbase** | **35%** |
|---|---|
| Employment | 655,750 |
| Turnover | 119 billion |
| Revenue per employee | 181,472 |
| Indirect reach | 96,620 |
| Introduced products/processes | 91% |
| Disruptive innovations | 17% |
| Attributed innovations | 10% |
| Propensity to attribute | 29% |
| Likelihood of connection | 31% |
| Attributed sales revenue | 156 million |
| Net Promoter Score | 56% |

**ENVIRONMENT**

| **Userbase** | **47%** |
|---|---|
| Employment | 737,085 |
| Turnover | 182 billion |
| Revenue per employee | 246,919 |
| Indirect reach | 80,202 |
| Introduced products/processes | 92% |
| Disruptive innovations | 17% |
| Attributed innovations | 15% |
| Propensity to attribute | 32% |
| Likelihood of connection | 47% |
| Attributed sales revenue | 234 million |
| Net Promoter Score | 48% |

**SECURITY**

| **Userbase** | **36%** |
|---|---|
| Employment | 691,860 |
| Turnover | 154 billion |
| Revenue per employee | 222,588 |
| Indirect reach | 84,748 |
| Introduced products/processes | 94% |
| Disruptive innovations | 24% |
| Attributed innovations | 13% |
| Propensity to attribute | 36% |
| Likelihood of connection | 41% |
| Attributed sales revenue | 203 million |
| Net Promoter Score | 58% |

The survey respondents were asked to choose the significant technological areas their firm's line of business (or activity) connects to.

**Table 35 Survey response options for significant technological areas**

| Response options in the survey | Challenge area |
|---|---|
| Green Energy / Carbon Capture Technologies | Prosperity, Environment |
| Energy Storage Technologies (Batteries) | Prosperity, Environment |
| Life Sciences / Biotechnology | Health |
| Medical Scanning, Imaging and Diagnostic Technologies | Prosperity, Health |
| Digital Technologies / Future Telecommunications | Security |
| Big Data / Artificial Intelligence / Industry 4.0 | Security |
| Quantum Technologies | Security |

Although the numbers look rather similar across all the challenge areas, the following are the main highlights from the 'Significant Technological Areas' viewer:

- More than half of the attributing firms connect to Prosperity. This area also has the highest proportion of attributed innovations and largest attributed sales revenue when compared to other challenge areas. However, it also has a low indirect reach.
- Environment performs well predominantly, but the users that operate in this challenge area are the least satisfied in comparison to other areas.
- The users that operate in Security introduce many new and improved products or processes and contributed substantially to creating disruptive innovations for the industry or market. This users in this area are also the most satisfised with the NMS labs.
- Overall, Health performs poorly, especially in terms of attributed innovations and sales revenue.

### 7.2 FINDINGS

The four challenge areas can be interpreted differently when viewed through multiple perspectives. Each perspective represents a certain viewer. While 'National Challenge Areas' present the customer's view of the NMS programme, in contrast, the 'Science Areas for Measurement' present the NMS's view of itself. This in turn highlights the dual nature of the challenge areas, especially for Prosperity.

The table below shows the likelihood of connection i.e., the proportion of attributing firms identifying with a particular challenge area. It has three columns representing the viewer's perspective on what a challenge area is; and four rows representing the challenge areas.

- In National Challenge Areas, the viewer is the user or customer and therefore is an external view. The concept of Prosperity in this view relates to the "Economic growth through technological change" i.e., the "Future", whereas the rest of the challenge areas in this view relate to the "Current".
- In Science Areas for Measurement, the viewer is the NMS labs and therefore is an internal view. The concept of Prosperity in this view relates to "Advanced manufacturing" i.e., the "Current", whereas the rest of the challenge areas in this view relate to the "Future".
- In Significant Technological Areas, the viewer is the innovator and therefore is an external view. The numbers in this view look rather similar across all the challenge areas.

**Table 36 Likelihood of Connection**

| | | VIEWER | | |
|---|---|---|---|---|
| | | External | Internal | External |
| | | User | NMS labs | Innovator |
| PROJECTION | Challenge Areas | $P(A\|B)$ | **National Challenge Areas** | **Science Areas for Measurement** | **Significant Technological Areas** |
| | | Environment | 75% | 34% | 47% |
| | | Health | 53% | 9% | 31% |
| | | Prosperity | 38% | 78% | 59% |
| | | Security | 59% | 6% | 41% |

Based on the above, the following table showcases the rankings of these challenge areas. Overall, in terms of attributing firms identifying with the challenge areas, Environment comes out as the best, followed by Prosperity.

**Table 37 Rankings of Challenge Areas**

| $P(A\|B)$ | National Challenge Areas | Science Areas for Measurement | Significant Technological Areas |
|---|---|---|---|
| Environment | 1 | 2 | 2 |
| Health | 3 | 3 | 4 |
| Prosperity | 4 | 1 | 1 |
| Security | 2 | 4 | 3 |

Furthermore, a ternary plot is the best graphical representation that can be used to visualise a system that has three components i.e., viewers in this case. The ternary plot below visualises the four challenge areas in one system from the perspective of three viewers, and it clearly showcases that Prosperity is a distinctive challenge area.

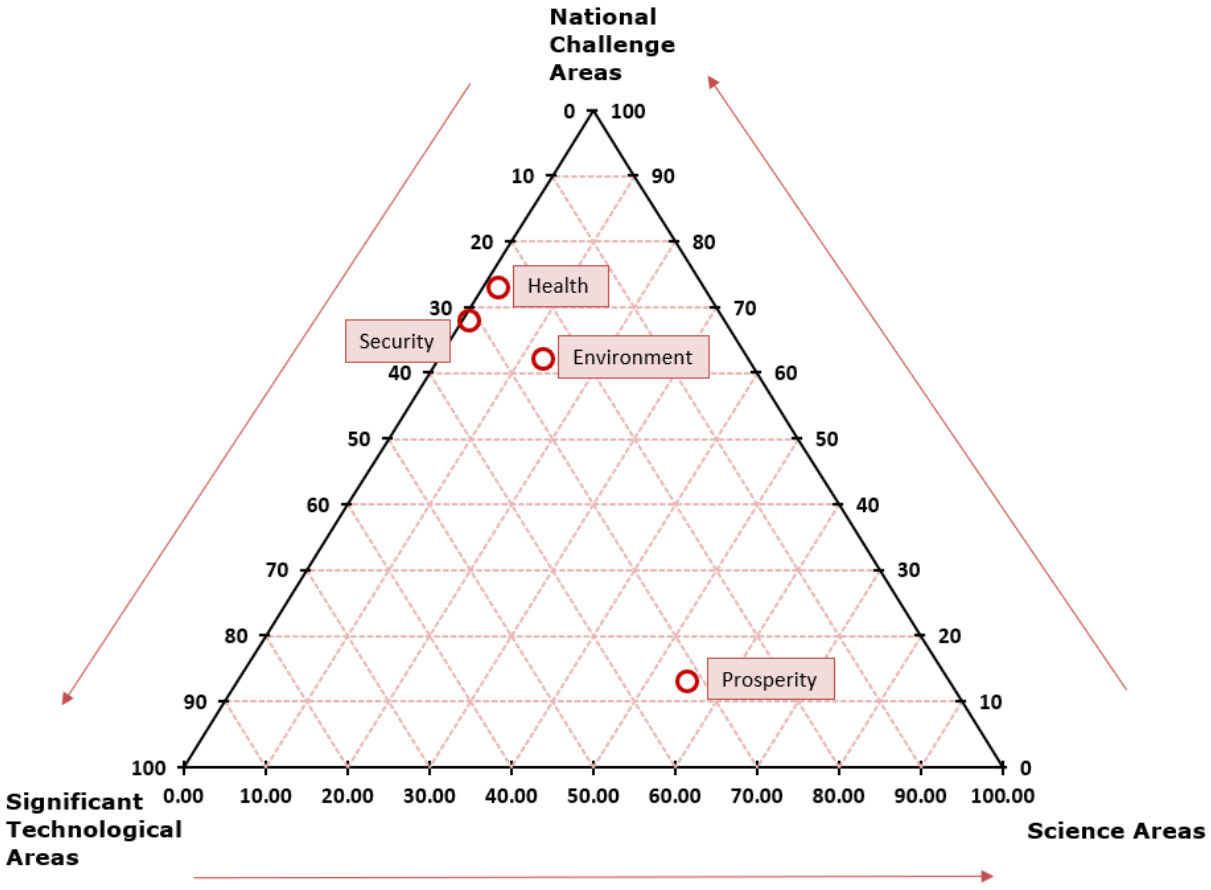



**Figure 43 Ternary Plot for Challenge Areas**

It is therefore evident that Prosperity is underpinning the other three challenge areas and provides the capability that enables them to deliver impact.

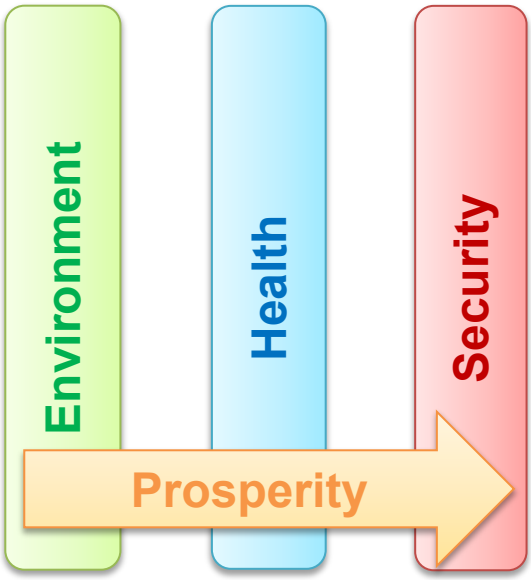



**Figure 44 Challenge Areas**

## 8 SATISFACTION WITH THE NMS LABORATORIES

Customer satisfaction is monitored by the NMS to understand how their users view the relationship with the NMS labs. This also helps the labs to reflect on their current ways of working and strive to deliver the best value for their users in the future.

To measure satisfaction, customers were asked how likely they were to recommend the NMS labs to a colleague or other organisation. Based on the results, a **Net Promoter Score** (NPS)[56] is calculated to measure customers' loyalty and satisfaction with the products or services provided by the NMS labs. With 55% of the respondents identified as promoters and 8% as detractors, NMS labs achieved **an overall NPS score of 47** which is considered 'good' and indicates that there are more happy customers than unhappy ones.

When the score is split into two sections, private sector has a score of 50 and calibration labs have a score of 36. The results from the previous NMS survey conducted in 2018 shows that the private sector had a score of 62 and calibration labs had a score of 59. It should be noted that the scores in the previous survey were calculated based on the sample, not the population. A reasonable drop can be observed in the NPS within the last 4 years, and it is noticeable that the decrease is more significant in the calibration labs.

**Table 38 Net Promoter Score**

| | Sample | Population | NPS | Lower bound | Upper bound |
|---|---|---|---|---|---|
| Private sector | 461 | 2270 | 50% | 44% | 55% |
| Calibration laboratories | 133 | 600 | 36% | 21% | 52% |
| **Total** | **594** | **2870** | **47%** | **42%** | **52%** |

The NPS has also been configured to represent national challenge areas in the below table. When the challenge areas are in comparison with one another, it can be observed that customers in the Life Sciences & Health are better satisfied and Energy & Environment are least satisfied. However, it should be noted that these NPS are not statistically different.

**Table 39 NPS for challenge areas**

| National Challenge Areas | NPS | Lower bound | Upper bound |
|---|---|---|---|
| Prosperity | **50%** | 41% | 58% |
| Life Sciences & Health | **53%** | 44% | 61% |
| Energy & Environment | **48%** | 41% | 55% |
| Security & Resilience | **51%** | 43% | 59% |

Within the UK's public sector, the National Health Service (NHS) has the NPS of 23.9, and public services has the NPS of 18.3 [57]. In comparison, this highlights the moderately strong performance of the NMS labs.

[56] On a scale of 0-10, the customers were asked how likely they are to recommend the NMS laboratories to a colleague or other organisation. Customers are classified as 'promoters' if they answer 9 or 10, 'passives' if they answer 7 or 8, and 'detractors' if they answer 6 or under. The NPS is calculated by subtracting the percentage of detractors from the percentage of promoters.
[57] These values were taken from the 'Business Benchmarking' study conducted by The Institute of Customer Services for NPL in 2023.

When the scores of other private sector organisations are considered, it can be observed that the NMS laboratories have a lot of scope for improvement. Moreover, over the years, the NPS for organisations such as Amazon and Google have followed an upward trajectory, but the NPS for the NMS labs has declined by 16% for the private sector and by 22% for the calibration labs[58].

**Table 40 Benchmarks in the private sector[59]**

| Organisation | NPS |
|---|---|
| Tesla | 97 |
| Amazon | 73 |
| Lloyds | 62 |
| Apple | 61 |
| Google | 58 |
| **NMS laboratories** | **47** |
| Samsung | 47 |
| IBM | 27 |
| Dell | 24 |
| Barclays | 13 |
| HSBC | 7 |

The customers were also asked how satisfied they were with the products or services provided by the NMS labs in terms of timeliness of delivery, quality, and price. In this case, we could adapt the technique used to calculate the NPS by considering *Very satisfied* as 'Promoters', *Somewhat satisfied* as 'Passives', and *Somewhat dissatisfied* and *Very dissatisfied* as 'Detractors'. Therefore, the highest NPS can be clearly observed by quality, followed by timeliness of delivery, and price at the lowest.

**Table 41 Satisfaction scores**

| | Detractors | Passives | Promoters | NPS |
|---|---|---|---|---|
| Timeliness of delivery | 5% | 29% | 66% | **61%** |
| Quality | 3% | 23% | 74% | **72%** |
| Price | 8% | 37% | 55% | **46%** |

[58] These values are calculated based on the NPS (n) from 2018 and 2023 NMS surveys.
[59] Customer Gauge Report 2023

# 9 CONCLUSION

The NMS labs have a substantial reach in the UK and the businesses that work with the labs make great contributions to the UK's economy. These businesses **employ ~711,490 people** in the UK and collectively have an **aggregate turnover of £154 billion**. 50% of these businesses operate within the manufacturing sector, and this accounts for **13% of the manufacturing sector workforce in the UK**.

It is believed that there are many products or services that would not exist without support from the NMS labs, and these generate a substantial sales revenue for their customers. Around 88% of the NMS users made a change to their products or processes. **18% of the customers have disrupted the industry with the innovation change**. **Two thirds** of which is attributable to the NMS laboratories. Furthermore, the calculation for the contribution split between the users and the NMS labs shows that for a particular project the **users contribute 2.7 times more** (in terms of their time invested, cost and other resources) into making the innovation changes compared to the NMS labs.

The support of NMS labs in innovations creates three main streams of impact.

- The **first one** is the **revenue impact**. This impact number shows that 2870 private businesses in the UK that interacted with the NMS labs collectively create a total annual revenue impact of **£1.56 billion** before accounting for attribution. **32%** customers mentioned that their products or services would not exist without the support from the NMS labs, and they collectively attribute **£500 million** in revenue to the labs.
- The **second one** is the **employment impact**. 15% of the users report they experienced an increase in employment and basic wages as a result of the project they worked with the NMS labs. The calculations show a **3% increase in employment** level and a **7.5% increase in the basic wage** as a result of the support given by the NMS labs.
- The **third one** is the **spillovers** generated from the innovation activities. 21% reported their innovation spilled over outside their organisation within the UK and 4% spilled over internationally. This part also calculates the ratio of direct and indirect benefits from product innovation through the concept of product diffusion. Product diffusion is defined as the indirect benefits arising from the commercialisation of newly developed products. It finds that **products have a lifetime of 7 years within the firm** that first created it, and a **lifetime of 13 years within the firm's industry**. There is a **55-45 split between direct and indirect benefits** that arise from product innovations.

Approximately 68% of the users report they have access to alternative support for their innovation projects. Of those majority report they can go to other Research and Innovation organisations (RIOs) and it is mostly users based in the North that report having access to other RIOs. There is perhaps scope to increase presence of the labs in regions like the North.

When assessing spending on measurement across the 2018-2022 period, it is estimated that **businesses working with the NMS labs spend 5% of their turnover on measurement** annually. This figure equates to **£7.7 billion** of spending each year among private sector users of the NMS labs. In financial terms, it is estimated that the NMS users spend **£1.5 billion on calibration** and reference materials, and **£6.2 billion on testing** and analysis. Besides, the results also show that the **NMS labs are twice as important as the foreign NMIs** when sourcing measurement services, underscoring the national importance of the labs.

The labs work with 35% of all the United Kingdom Accreditation Service (UKAS) accredited calibration labs in the UK. By providing support to these labs, the reach of the NMS labs is extended. This survey found that **the NMS labs indirectly supported ~75,500 organisations in the UK through the "fanout" of calibration services** (UKAS labs provide calibrations that are traceable to measurement standards maintained by the NMS labs) provided by the customers.

The analysis also shows that neglecting calibrations would drive up costs in the conformance testing process for firms working with the NMS. The scrap rate derived from the model is 3%, which also equals the scrap rate estimated from the survey responses. Moreover, **a third of the scrap rate comes from the cost of type 1 errors**, meaning that good output is mistakenly scrapped, which is potentially avoidable with a perfect testing process. The other two-thirds (two percentage points) needs to be scrapped because they are defective, which is wholly unavoidable even with a perfect testing process.

The **proportion of uncertainty that is removed through calibration is 20% of the total uncertainty**. As the uncertainties are added in quadrature, this results in a 2% increase in the relative standard deviation (RSD) of the measurements. On average, the users report an RSD of 21%, which implies that **the cost of mistakes made during conformance testing would increase by 0.1 percentage points**, if the firm were to forego calibrations.

The NMS labs provide the strongest support to innovations in businesses related to environmental protection and those that may impact human health. Additionally, the labs are beginning to play a role for a select group of customers developing Quantum Technologies. Further analysis also revealed that the challenge area 'Prosperity' is essential in supporting and enabling the other key challenge areas, offering the capabilities required to drive significant impact.

It is important to understand how their users view the relationship with the NMS labs to deliver greater impact in the future. With 55% of the respondents identified as promoters and 8% as detractors, **NMS labs achieved an overall Net Promoter Score of 47** which is considered 'good' and indicates that there are more happy customers than unhappy ones. However, this also suggests that the NMS labs need to reflect on their current ways of working and strive to deliver the best value for their users. It was also noted that the NMS users are most satisfied with the quality and least satisfied with price.

Furthermore, a follow-on study will be conducted using the survey data to find parameters of a macroeconomic model for the benefits channelled through the UK's measurement infrastructure. Additionally, cluster and principal components analysis techniques can be used to further analyse the segments in the survey data.

## 10 REFERENCES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## APPENDIX A: CALCULATION OF HEADLINE NUMBERS

The headline numbers in this report have been calculated using the *svyset* command in Stata which allows the application of poststratification adjustments to the sampling weights for set variables. *Svyset* is an extremely useful command that declares the dataset as survey data and helps manage the analysis of that dataset. In this case, the *svyset* command used 'segments' as poststratum identifiers for respective population totals or sizes. The final step includes using the *svy* prefix command which fits statistical models for complex survey data by adjusting the results of a command for survey settings identified by *svyset*.

However, this process has also been mathematically replicated in Excel to ensure the alignment of headline numbers generated by Stata. For example, let us consider how to calculate the fanout number of ~75,500. The steps are as follows :

1. Calculate the below table to understand the how many responses could be actually used from the raw survey data. In this case, all the respondents have provided adequate answers that could be used for analysis. However, if that was not the case, the response weights would be higher and thereby the total weights would differ.

$$Response\ weight = \frac{Sample}{Usable\ responses}$$

$$Total\ weight = Sample\ weight * Response\ weight$$

When total weight is multiplied by usable responses, it should give us back the population. This is just to cross-check that we have performed the calculations in the right manner.

**Table A1 Assignment of weights based on responses to the question**

| Segment | Sample | Usable responses | Response weight | Sample weight | Total weight | Total weight * Usable responses |
|---|---|---|---|---|---|---|
| M-E | 63 | 63 | 1.0 | 3.8 | 3.8 | 241.0 |
| SME-E | 130 | 130 | 1.0 | 3.7 | 3.7 | 475.0 |
| L-E | 52 | 52 | 1.0 | 6.6 | 6.6 | 341.0 |
| M-S | 52 | 52 | 1.0 | 2.5 | 2.5 | 131.0 |
| SME-S | 174 | 174 | 1.0 | 2.8 | 2.8 | 481.6 |
| L-S | 86 | 86 | 1.0 | 5.1 | 5.1 | 440.0 |
| SME-R* | 97 | 97 | 1.0 | 2.5 | 2.5 | 246.4 |
| L-R | 82 | 82 | 1.0 | 6.3 | 6.3 | 514.4 |
| **Total** | **736** | **736** | | | | **2870** |

2. In the column that represents the number of laboratories that the self-identified commercial calibration laboratories provide calibration services/reference materials to[60], assign '0' to the respondents who have answered that they are not a commercial calibration laboratory[61].
3. Assign the calculated total weight to all the 736 respondents based on the segment they belong to.

[60] To understand the fanout of traceability in the economy, how many laboratories do you provide calibration services/reference materials to?
[61] Do you classify yourself as a commercial calibration laboratory?

4. Create the below table to calculate the total fanout number.
   - **x** refers to the number of labs that receive calibration services/reference materials from self-identified commercial calibration labs.
   - **f** refers to the number of sites in the population marked against their response to the number of labs.
   - The total product of **x** and **f** gives the final fanout number of 75,522.

**Table A2 Calculation of the fanout number**

| Number of labs (x) | Frequency (f) | Cumulative frequency (cf) | Cumulative distribution function (cdf) | x*f |
|---|---|---|---|---|
| 0 | 2410.7 | 2410.7 | 84% | 0.0 |
| 1 | 52.5 | 2463.2 | 86% | 52.5 |
| 2 | 16.7 | 2479.8 | 86% | 33.3 |
| 3 | 15.4 | 2495.2 | 87% | 46.1 |
| 4 | 14.4 | 2509.7 | 87% | 57.8 |
| 5 | 16.6 | 2526.3 | 88% | 83.1 |
| 6 | 2.5 | 2528.8 | 88% | 15.2 |
| 9 | 5.1 | 2533.9 | 88% | 46.0 |
| 10 | 34.2 | 2568.1 | 89% | 341.8 |
| 12 | 6.3 | 2574.4 | 90% | 75.3 |
| 13 | 2.5 | 2576.9 | 90% | 33.0 |
| 15 | 2.5 | 2579.4 | 90% | 37.8 |
| 20 | 28.0 | 2607.5 | 91% | 560.3 |
| 25 | 19.1 | 2626.6 | 92% | 477.9 |
| 30 | 2.5 | 2629.1 | 92% | 75.6 |
| 48 | 6.3 | 2635.4 | 92% | 301.1 |
| 50 | 29.7 | 2665.0 | 93% | 1483.2 |
| 75 | 14.1 | 2679.2 | 93% | 1059.2 |
| 80 | 5.1 | 2684.2 | 94% | 406.5 |
| 100 | 97.3 | 2781.5 | 97% | 9730.7 |
| 136 | 2.5 | 2784.1 | 97% | 345.5 |
| 150 | 7.8 | 2791.9 | 97% | 1174.0 |
| 200 | 18.9 | 2810.8 | 98% | 3778.0 |
| 400 | 7.9 | 2818.7 | 98% | 3153.3 |
| 500 | 14.3 | 2833.0 | 99% | 7174.7 |
| 600 | 2.8 | 2835.8 | 99% | 1660.5 |
| 620 | 2.5 | 2838.3 | 99% | 1575.1 |
| 800 | 2.5 | 2840.9 | 99% | 2032.4 |
| 1000 | 17.8 | 2858.7 | 100% | 17776.5 |
| 1400 | 2.5 | 2861.2 | 100% | 3556.8 |
| 2000 | 9.2 | 2870.4 | 100% | 18378.5 |
| | **2870** | | | **75522** |

The total number of labs to estimate the fanout generated by Stata using the *svy* command for that variable is the same as the number calculated in the above method. The very minor difference in the total between the two methods arises from how Stata rounds off the decimals. Therefore, it can be concluded that the NMS labs indirectly support ~75,500 organisations in the UK through the fanout of calibration services provided by the customers.

```
. svy linearized : total ccl3
(running total on estimation sample)

Survey: Total estimation

Number of strata =   1                Number of obs    =   736
Number of PSUs   = 736                Population size = 2,870
N. of poststrata =   8                Design df       =   735
```

| | Total | Linearized std. err. | [95% conf. | interval] |
|---|---|---|---|---|
| ccl3 | 75497.85 | 13049.47 | 49879.17 | 101116.5 |

**Figure A1 Results of the fanout number from Stata**

This same method has been repeated to produce the remaining headline numbers that appear in this report.

## APPENDIX B: PARETO DISTRIBUTION

For calculating the revenue impact headline number, the most important step was to figure out how to fill in the substantial number of missing values. To resolve this issue, multiple imputation technique has been used to impute missing values.

Multiple imputation is mostly used in clinical trials i.e. Randomised Controlled Trials (RCT). It is highly encouraged to use multiple imputation to fill in the missing values when compared to historical approaches such as complete case analysis, mean imputation, and single imputation. This is because multiple imputation helps overcome a potential result in bias, incorrect estimates of standard errors, and consequently incorrect tests of statistical significance, which the other techniques might not.

In this case, multiple imputation was the preferred method to handle missingness as it helps in maintaining the validity of the statistical inferences. If this method was not used, it could have led to less power, results restricted to those individuals without missing values, violation of the intent-to-treat principle, possible non-random loss, and ultimately to results that may not apply to the original full sample.

For example, let us consider how to calculate the revenue number of £148 million from the sales of new products or services. The steps are as follows:

1. In Stata, using the *mi* command, 50 imputations have been performed such that every imputation represents the proportion of population that would fall in each revenue band. It was then observed that this data best fits a pareto distribution.

**Table A3 Frequency distribution of revenue from new products or services**

| Revenue bands | Endpoint (x) | f | cdf | ln(x) | ln(1-cdf) |
|---|---|---|---|---|---|
| 0 | 100 | 70.7% | 70.7% | 4.6 | -1.2 |
| Up to £1,000 | 1000 | 6.2% | 77.0% | 6.9 | -1.5 |
| More than £1,000 and up to £5,000 | 5000 | 4.2% | 81.2% | 8.5 | -1.7 |
| More than £5,000 and up to £50,000 | 50000 | 7.3% | 88.4% | 10.8 | -2.2 |
| More than £50,000 and up to £150,000 | 150000 | 5.4% | 93.8% | 11.9 | -2.8 |
| More than £150,000 and up to £1,000,000 | 1000000 | 4.6% | 98.4% | 13.8 | -4.2 |
| More than £1,000,000 and up to £2,500,000 | 2500000 | 0.4% | 98.8% | 14.7 | -4.4 |
| More than £2,500,000 and up to £20,000,000 | 20000000 | 0.7% | 99.5% | 16.8 | -5.3 |
| More than £20,000,000 and up to £100,000,000 | 100000000 | 0.5% | 100.0% | 18.4 | #NUM! |

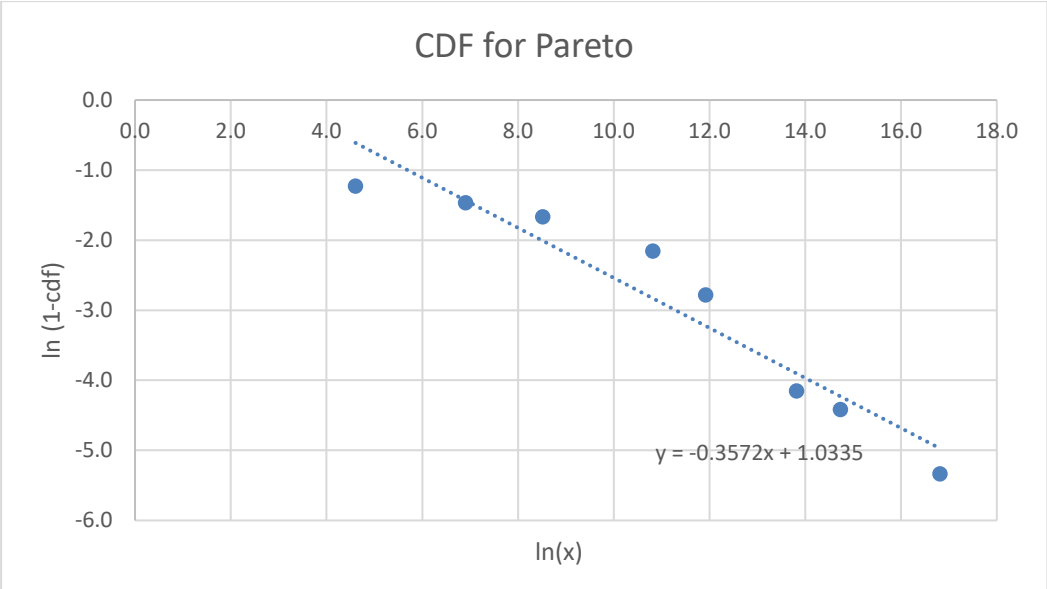


**Figure A2 Pareto CDF of revenue from new products or services**

2. The CDF for a pareto random variable which have the parameters $\alpha$ and $x_m$ can be defined as :

$$F(x) = 1 - \left(\frac{x_m}{x}\right)^{\alpha}$$

This equation can be rewritten as :

$$1 - F(x) = \left(\frac{x_m}{x}\right)^{\alpha}$$

Adding log on either sides :

$$ln\big(1 - F(x)\big) = \alpha * \ln(x_m) - \alpha * \ln(x)$$

Therefore, after rearranging the equation :

$$x_m = e^{\left(\frac{\alpha * \ln(x_m)}{\alpha}\right)}$$

From the above Figure 2, we know that :

$\alpha * \ln(x_m)$ is the intercept of the equation = 1.0335

$\alpha$ is the slope[62] of the equation = 0.3572

Substituting the values in the previous equation, we get $\boldsymbol{x_m = 18.05345}$.

[62] It should be noted that alpha should be positive in the pareto distribution.

3. Given the values of $\alpha$ and $x_m$, random samples could be generated using inverse transform sampling. When a random *U* is drawn from the uniform distribution function between (0,1), the variate *T* is :

$$T = \frac{x_m}{U^{1/\alpha}}$$

For each respondent, the values are assigned according to their segment. The missing values are replaced with *T*. For obtaining population estimates, these values were then multiplied with the respective sample weights. This would result in the revenue estimates for each individual site in the population. When these values are summed up at the end, this would provide the total revenue estimate for new products or services.

This process was repeated for 100 times and the values were placed in an ascending order such that the totals are represented as percentiles. The 50th percentile, also known as the median, is used to compute the headline number. The 25th and the 75th percentiles form the lower and upper bounds of the confidence intervals, respectively[63].

Similarly, all the above three steps have been repeated for other components 'improved product or service' and 'reaching new markets'.

4. The below table shows the final numbers for revenue impact while accounting for innovation change, real values, and attribution.

**Table A4 Total attributed revenue impact estimates**

| | Median | **Filters** *(to be multiplied with median to get headline number)* | | | Headline number | Lower bound | Upper bound |
|---|---|---|---|---|---|---|---|
| | | Non-zero values | Innovation | Attribution | | | |
| New product/service | 1872 | 0.29 | 0.79 | 0.34 | 148 | 138 | 220 |
| Improved product/service | 3246 | 0.24 | 0.81 | 0.31 | 195 | 163 | 533 |
| Reaching new markets | 2505 | 0.21 | 0.80 | 0.32 | 136 | 131 | 264 |
| **Total** | **7622** | **0.25** | **0.83** | **0.32** | **500** | **452** | **1083** |

[63] When the value of $\alpha$ is less than 1, the descriptive statistics such as arithmetic mean cease to exist and this leads to large confidence intervals. Therefore, it could be appropriate to calculate the confidence intervals for pareto distributions in the above suggested manner.

## APPENDIX C: QUESTIONS AND RESPONSE OPTIONS

1. Which of the following best describes your job role?
   - Technical (Engineer/Scientist)
   - Operational (Sales/Functions)
   - Production (Manufacturing/Delivery)
   - Other

2. In which of the following regions is your site based?
   - North East
   - North West
   - Yorkshire and the Humber
   - East Midlands
   - West Midlands
   - East of England
   - London
   - South East
   - South West
   - Wales
   - Scotland
   - Northern Ireland

3. Which of the following standard industrial classification section best describes your organisation?
   - A: Agriculture
   - B: Mining and Quarrying
   - C: Manufacturing
   - D: Electricity, Gas, and Steam
   - E: Water Supply and Waste Management Activities
   - F: Construction
   - G: Wholesale and Retail Trade; Repair of Motor Vehicles and Motorcycles
   - H: Transportation and Storage
   - I: Accommodation and Food Service Activities
   - J: Information and Communication
   - K: Financial Activities
   - L: Real Estate Activities
   - M: Professional, Scientific, and Technical Activities
   - N: Administrative and Support Service Activities
   - Z: Other

4. Currently, how many employees are present at the site that you work at?
   - Up to 1
   - 2 – 9
   - 10 – 49
   - 50 – 249
   - 250 – 499
   - 500 – 999
   - 1000 – 1999
   - Greater than or equal to 2000

- Don’t know

5. In which of the following scientific areas do you conduct the majority of your measurement activity? (Please select one option only)
   - Mass & Dimensional
   - Material Properties
   - Temperature & Humidity
   - Pressure
   - Flow
   - Electromagnetic & Electrochemical
   - Biological
   - Chemical
   - Gas & Particles
   - Optical / Radiometric Metrology
   - Quantum
   - Time & Frequency
   - Nuclear & Radiation
   - Acoustics & Ultrasound
   - Force/Torque
   - Other

6. Do you classify yourself as a commercial calibration laboratory?
   - Yes
   - No

7. Are you UKAS accredited for the following?
   - Testing and Analysis
   - Calibration and reference materials
   - None of the above

8. To understand the fanout of traceability in the economy, how many laboratories do you provide calibration services/reference materials to?

9. Of the site that you work at, what was your financial turnover/revenue in tax year ending in 2022?
   - Up to £200,000
   - More than £200,000 and up to £2,000,000
   - More than £2,000,000 and up to £10,000,000
   - More than £10,000,000 and up to £50,000,000
   - More than £50,000,000 and up to £100,000,000
   - More than £100,000,000 and up to £200,000,000
   - More than £200,000,000 and up to £400,000,000
   - More than £400,000,000
   - Site is operating at pre-revenue stage
   - Don't know

10. Does your firm’s line-of-business connect to any of the following National Challenge Areas?
    - Economic Growth through Technological Change

- Environmental Protection / Net Zero
- Healthcare / Health & Safety / Public Health
- Security / Defence
- Resilience of National Infrastructure
- Energy Security
- Climate Change Adaptation and Mitigation
- None of the above

11. Does your firm’s line-of-business connect to any of the following technologies?
    - Green Energy / Carbon Capture Technologies
    - Energy Storage Technologies (Batteries)
    - Life Sciences / Biotechnology
    - Medical Scanning, Imaging and Diagnostic Technologies
    - Digital Technologies / Future Telecommunications
    - Big Data / Artificial Intelligence / Industry 4.0
    - Quantum Technologies
    - None of the above

12. How satisfied were you with the service NMS provided in terms of the following?
    - Timeliness of Delivery
    - Quality
    - Price

13. Overall, has working with NMS helped you to achieve any of the following? (Please tick all that apply)
    - Expand your organization's capabilities
    - Increase your users' satisfaction
    - Increase measurement confidence
    - Attract more business / customers
    - Form new partnerships and collaboration agreements
    - Improve training, qualifications, or professional development for employees
    - N/A
    - Other

14. On a scale from 1-10, where 1 is 'Not At All Likely', to 10 'Very Likely', how likely is it that you would recommend NMS to a colleague or other organization?

15. On a scale of 0 to 10, what level of innovation change was achieved by the project? (From 0, Incremental (small improvement to your organization), to 10, Disruptive (transformed the market / industry))

16. How important is measurement to your organisation for each of the following business as usual activities?
    - Calibration
    - Achieving accreditation
    - Maintaining a consistent product / service
    - Compliance with standards and regulation
    - Quality assurance of products and services to the market

17. Which of your business as usual activities has NMS assisted you with? (Please tick all that apply)
    - Calibration
    - Achieving accreditation
    - Maintaining a consistent product / service
    - Compliance with standards and regulation
    - Quality assurance of products and services to the market
    - N/A
    - Other

18. If included 'Other' in previous question. Please specify below.

19. Where do you go for testing and analysis measurement services? (Please tick all that apply)
    - We undertake it in-house
    - NMS labs
    - Commercial labs
    - Foreign NMIs
    - Don't know
    - Prefer not to say

20. If selected 'Commercial Labs' in previous question, are these commercial labs UKAS accredited?
    - Yes
    - No
    - Don't know
    - Prefer not to say

21. Where do you go for calibration / reference materials? (Please tick all that apply)

    - We undertake / have these in-house
    - NMS labs
    - Commercial labs
    - Foreign NMIs
    - Don't know
    - Prefer not to say

22. If selected 'Commercial Labs' in previous question, are these commercial labs UKAS accredited?
    - Yes
    - No
    - Don't know
    - Prefer not to say

23. For what reason/s do you perform measurements?
    - Calibration of instruments or process control equipment
    - Conformance testing (testing and analysis)
    - Process Control / Optimisation
    - Compliance with standards and regulation

- Provision of measurement services to others
- Experimental R&D/Trials
- Business information (e.g. inventory management) or for taxation purposes
- Other

24. Of your measurements that occur in house, to what extent are they made using instruments or reference materials that are externally calibrated?
    - None
    - <40%
    - 40 - 60%
    - >60%
    - All
    - Don't know
    - Prefer not to say

25. Dividing your overall financial measurement budget by 'calibration and reference materials' and 'analysis and testing', what proportion of your budget is spent on calibration/ reference materials?
    - None
    - <10%
    - 10 - 39%
    - 40 - 60%
    - >60%
    - All
    - Don't know
    - Prefer not to say

26. What proportion of your measurement in testing and analysis is for conformance testing?
    - % age
    - Don't know
    - N/A

27. Is it possible your company may have mistakenly rejected a batch that does meet specification? [False Positive (Type 1 error) is where the product is good, but it fails the test (which makes you think it’s defected), and you scrap it.]
    - Yes
    - No
    - Don't know
    - Prefer not to say

28. What is the probability of mistakenly rejecting an item or batch that does meet specification (Confidence level of the test/p-value)? Please express your answer as a percentage of likelihood.
    - % age [if not able to provide exact %, please give a bound (between x and y)]
    - Don't know
    - Prefer not to say
    - N/A

29. Is it possible your company may have mistakenly accepted a batch that does not meet specification? [False Negative (Type 2 error) is where the product is defected, but it passes the test (which makes you think it's good), and it enters the supply chain.]
    - Yes
    - No
    - Don't know
    - Prefer not to say

30. What is the probability of mistakenly accepting an item or batch that does not meet specification? Please express your answer as a percentage of likelihood.
    - % age [if not able to provide exact %, please give a bound (between x and y)]
    - Don't know
    - Prefer not to say
    - N/A

31. In the context of conformance testing, if you do not calibrate your instruments and/or use reference materials, what is the attributable percentage increase in measurement uncertainty, in your testing and analysis?
    - % age [if not able to provide exact %, please give a bound (between x and y)]
    - Don't know
    - Prefer not to say
    - N/A

32. During the financial year 2022, can you estimate your organisations scrap rate or yield loss as a percentage of total output?
    - % age [if not able to provide exact %, please give a bound (between x and y)]
    - Don't know
    - Prefer not to say
    - N/A

33. Over the course of the financial year 2022, how likely was your production process to malfunction in a way that resulted in a defective output?
    - Never
    - 1% of the time
    - 2% of the time
    - 5% of the time
    - 10% of the time
    - More than 10% of the time
    - Don't know
    - Prefer not to say
    - N/A

34. What proportion of your product sales are returned due to defects, or failure during the warranty period?
    - Never
    - 1% of the time
    - 2% of the time
    - 5% of the time

- 10% of the time
- More than 10% of the time
- Don’t know
- Prefer not to say
- N/A

35. If you sell a defective product, how would you compensate your customer?
    - Replace the product
    - Provide a refund
    - Discount on future sales
    - Don’t know
    - Prefer not to say

36. In your industry, could there be any regulatory/compliance consequences of selling a defective product (for e.g., suspension of certification while production activities are re-certified)?
    - Yes
    - No
    - Don’t know
    - Prefer not to say

37. How important is measurement to your organisation for each of the following innovation activities?
    - Developing new products / services
    - Improving existing products / services
    - Introducing new processes
    - Improving existing processes
    - Quality assurance of research outputs
    - Compliance with standards and regulation

38. Thinking about the innovation project that you worked most closely with NMS on, which category did it belong to?
    - Developing new products / services
    - Improving products / services
    - Existing products / services reaching new markets
    - Introducing new processes
    - Improving existing processes
    - Fundamental Research (not directed at a specific product)
    - Compliance with standards and regulation
    - N/A
    - Other

39. If included 'Other' in previous question. Please specify below.

40. What level of innovation change was achieved by the project?

    From 0, Incremental (small improvement to your organization), to 10, Disruptive (transformed the market / industry)

41. Did the innovation change spill over to? (Please tick all that apply)
    - Other departments
    - Other sites
    - Third parties (e.g. other firms, partners, suppliers, customers)
    - Other industry sectors
    - Overseas
    - Don't know
    - Prefer not to say

42. How long would the innovation remain in your portfolio of products / services in its current form? Note significant improvements do not count for current form.
    - Between 1 to 3 years
    - Between 4 to 6 years
    - Between 7 to 10 years
    - Over 10 years
    - Don't know
    - Prefer not to say

43. Is this new product or improvement new to market? i.e. nothing like this has existed in the market before.
    - Yes
    - No
    - Don't know
    - Prefer not to say

44. In your industry, how long does a product last in the market? (We are asking about the wider landscape outside your company in industry e.g. before a product becomes obsolete).
    - Between 1 to 3 years
    - Between 4 to 6 years
    - Between 7 to 10 years
    - Over 10 years
    - Don't know
    - Prefer not to say

45. What is the minimum rate of return (hurdle rate) on a project/investment required by your company?
    - % age
    - Don’t know
    - Prefer not to say

46. How did NMS’ support contribute to the innovation project? (Please tick all that apply)
    - Provided strategy and direction
    - Enabled more effective improvements
    - Enabled key milestones to be reached more quickly
    - Reduced risks
    - Helped achieve a project breakthrough
    - None of the above
    - Other

47. If included 'Other' in previous question. Please specify below.

48. Which of the following best describes the scale of each organisation's input into the project in terms of strategy and direction? (For each of the following please indicate how much your organization and others contributed relative to NMS).
    - 100%
    - 75%
    - 50%
    - 25%
    - 0%
    - Don’t know
    - N/A

49. Which of the following best describes the scale of each organisation's input into the project in terms of time invested (in person hours)? (For each of the following please indicate how much your organization and others contributed relative to NMS).
    - 100%
    - 75%
    - 50%
    - 25%
    - 0%
    - Don’t know
    - N/A

50. Which of the following best describes the scale of each organisation's input into the project in terms of resources used (e.g. facilities, materials)? (For each of the following please indicate how much your organization and others contributed relative to NMS).
    - 100%
    - 75%
    - 50%
    - 25%
    - 0%
    - Don’t know
    - N/A

51. Generally, what fraction of knowledge is acquired from other firms on a commercial basis e.g., consultancy, IP license?
    - % age
    - Don’t know
    - Prefer not to say

52. Generally, what fraction of knowledge is acquired from universities or public research institutes e.g., open source journal papers?
    - % age
    - Don’t know
    - Prefer not to say

53. Would the changes made have been possible without the support of NMS?
    - Yes
    - No
    - Don’t know
    - Prefer not to say

54. If 'yes', where could you have obtained this alternative support? (Please tick all that apply)
    - In-house resources
    - Foreign NMI
    - Another Research & Innovation Organization (RIO)
    - Don’t know
    - Prefer not to say
    - Other

55. If included 'Other' in previous question. Please specify below.

56. Have you worked on any innovation projects between 2018 - 2022 that have not succeeded and have been abandoned?
    - Yes
    - No
    - Don’t know

57. How has the number of people employed within your organization changed as an outcome of the innovation project you worked on with NMS?
    - Increased
    - Decreased
    - Stayed the same
    - Don’t know
    - Prefer not to say

58. If 'increased / decreased', what was the percentage change in terms of the organisation?
    - % age
    - Don’t know
    - Prefer not to say

59. As a result of the innovation project,  was there an increase in the basic wage of the staff at your organisation?
    - Yes
    - No
    - Don’t know
    - Prefer not to say

60. If 'yes', what is the percentage increase?
    - % age
    - Don’t know
    - Prefer not to say

61. As a result of the innovation you worked on with NMS, if 'developing new products or services' in financial year 2022, what were the annual sales of your new product or service?
    - Up to £1,000
    - More than £1,000 and up to £5,000
    - More than £5,000 and up to £50,000
    - More than £50,000 and up to £150,000
    - More than £150,000 and up to £1,000,000
    - More than £1,000,000 and up to £2,500,000
    - More than £2,500,000 and up to £20,000,000
    - More than £20,000,000 and up to £100,000,000
    - More than £100,000,000
    - Don’t know
    - Prefer not to say
    - N/A

62. As a result of the innovation you worked on with NMS, if 'existing products or services were improved' in financial year 2022, what were the annual sales of your improved product or service?
    - Up to £1,000
    - More than £1,000 and up to £5,000
    - More than £5,000 and up to £50,000
    - More than £50,000 and up to £150,000
    - More than £150,000 and up to £1,000,000
    - More than £1,000,000 and up to £2,500,000
    - More than £2,500,000 and up to £20,000,000
    - More than £20,000,000 and up to £100,000,000
    - More than £100,000,000
    - Don’t know
    - Prefer not to say
    - N/A

63. As a result of the innovation you worked on with NMS, if existing products reached new global markets in financial year 2022, what would you say the annual sales from the new markets were?
    - Up to £1,000
    - More than £1,000 and up to £5,000
    - More than £5,000 and up to £50,000
    - More than £50,000 and up to £150,000
    - More than £150,000 and up to £1,000,000
    - More than £1,000,000 and up to £2,500,000
    - More than £2,500,000 and up to £20,000,000
    - More than £20,000,000 and up to £100,000,000
    - More than £100,000,000
    - Don’t know
    - Prefer not to say
    - N/A

64. As a result of the innovation you worked on with NMS, did it have an impact on any of the following National Challenge Areas?
    - Economic Growth through Technological Change
    - Environmental Protection / Net Zero
    - Healthcare / Health & Safety / Public Health
    - Security / Defence
    - Resilience of National Infrastructure
    - Energy Security
    - Climate Change Adaptation and Mitigation
    - None of the above
    - Don’t know
    - N/A

65. As a result of the innovation you worked on with NMS, did it have an impact on any of the following technologies?
    - Green Energy / Carbon Capture Technologies
    - Energy Storage Technologies (Batteries)
    - Life Sciences / Biotechnology
    - Medical Scanning, Imaging and Diagnostic Technologies
    - Digital Technologies / Future Telecommunications
    - Big Data / Artificial Intelligence / Industry 4.0
    - Quantum Technologies
    - None of the above
    - Don’t know
    - N/A