Department for
Business, Energy
& Industrial Strategy

UK Measurement Strategy

The Value of Measurement: Supporting information for the UK Measurement Strategy

March 2017

Executive summary

The UK's new Measurement Strategy presents an opportunity to make strategic choices about future investment priorities in measurement-related facilities, skills and standards. Measurement underpins many sectors of the UK's economy and development of new measurement knowledge is essential for the UK to fully exploit emerging technologies, improve productivity and tackle the challenges facing the UK.

Ahead of developing the UK Measurement Strategy, we undertook a thorough review of the evidence to evaluate the impact and value of our investment in measurement. We also consulted widely among industry, regulators, academia, health professionals and government to determine the priorities for the UK Measurement Strategy. In this document, we provide a summary of the evidence for the importance of measurement and the results of our extensive consultations, both of which underpin the choices made in the UK Measurement Strategy.

This report presents evidence from economic studies and from the wide customer base of our measurement institutes that access to the best measurement capabilities and research is essential for:

- innovation – providing both new tools and techniques for research and giving investors and markets confidence to invest in and adopt novel technologies. Customers of our measurement institutes across all sectors are significantly more innovative than non-customers
- productivity – there is a strong connection between measurement technologies and labour productivity. Investment in measurement improves efficiency while reducing re-work and waste
- trade – globally comparable measurement standards are essential for exports and international supply chains. Countries invest in measurement to gain a competitive advantage by enabling the faster development of new technologies, improving productivity and leading the definition of new technical standards

The findings in this document use robust econometric methods to show clear evidence that companies that use NMS services have higher survival rates than a control group of non-customers. Additionally, the analysis shows NMS support helps to increase employment by 10%-15% within 2 to 4 years at an average cost per job of between £18k and £23k.

Reviews of the UK's measurement institutes and surveys of customers show that we have world-leading measurement capabilities, which are highly valued. Customers believe that without the support of our measurement institutes, their total annual sales of new products would decrease by at least £469 million and that about £2 billion worth of new products might be at risk without this support.

Key findings and priorities from the consultation included:

- access to world class measurement facilities, equipment, and experts is important
- improved training and practical experience for apprentices, technicians and engineers need to be developed
- areas for further focus include improving productivity, enabling industry 4.0, big data and life sciences

We have picked up these themes in the UK Measurement Strategy and will be developing a delivery plan that will set out specific objectives and targets in more detail.

Contents

1. Introduction

Measurement is part of UK life. We have set out our vision for the future of measurement in the UK Measurement Strategy 2017–2022. Here we provide the evidence to show the impact that good measurement has on trade and consumers, on production lines, in hospitals and when making policy choices in government.

Measurement has been essential since the origins of organised civilisation over 5,000 years ago. Trade in goods and construction from the earliest civilisations relied on measurement standards such as the Babylonian mina for weight, the Egyptian cubit for length and the Roman amphora for volume. Today, all modern economies are even more heavily dependent on good measurement to function effectively. Most areas of daily life are now in some way quantified, tested or evaluated through measurement to give confidence to markets, enable enforcement of regulation, or ensure adherence to a technical standard allowing goods to be traded.

The UK's enviable reputation in measurement research helps attract and retain international companies and supports UK industry to increase its global market share. Our expertise supports and enables innovation in areas where we successfully export, from advanced manufacturing, food and pharmaceuticals to personal care products. Leadership in measurement gives UK companies and products a significant competitive advantage in international markets. Surveys of UK measurement users show local access to world-leading measurement capabilities is critical to the success of their businesses.

Our historical appreciation of measurement has produced much-admired institutions that are global leaders in their fields. The measurement capabilities and standards that form the UK's core measurement infrastructure are at the leading edge of what is possible in terms of accuracy and our legal metrology expertise is highly regarded and sought after internationally. This has been achieved against a backdrop of substantial gains in efficiency over the past ten years, saving 30% in operational costs while increasing the quality of the science, range of capabilities and services, and ultimately the impact of our investment. These efficiency gains have been achieved through greater partnership with industry and other organisations, and increased leverage of the best research from the UK's academic science base.

Global leadership in measurement helps to position the UK to lead on new international technical standards which enable markets and exports. Our measurement system works closely with the British Standards Institution (BSI) and United Kingdom Accreditation Service (UKAS) to underpin the UK's quality infrastructure, supporting BSI's international position as a world leader in the development of technical and other standards. The UK's highly-respected measurement expertise and our representation on international bodies enables us to heavily influence the development of standards and regulations relating to environment, health and trade. This ensures the impact on the UK is beneficial and that UK companies can rapidly comply with any new requirements, giving them an early advantage.

We directly support measurement in the UK through investment in the UK's National Measurement System (NMS). However, this is only part of measurement in the UK, which is delivered by several routes and consists of different measurement communities, using facilities and expertise maintained by many organisations. A picture of measurement in the UK is shown in Figure 1 below, with the world-leading measurement capabilities, standards and expertise of the UK's NMS at its heart. Commercial testing and calibration laboratories, facilities developed by the Research Councils, Catapults supported by Innovate UK and the many public sector research establishments supported by government all have an important role to play in the broader delivery of measurement within the UK.

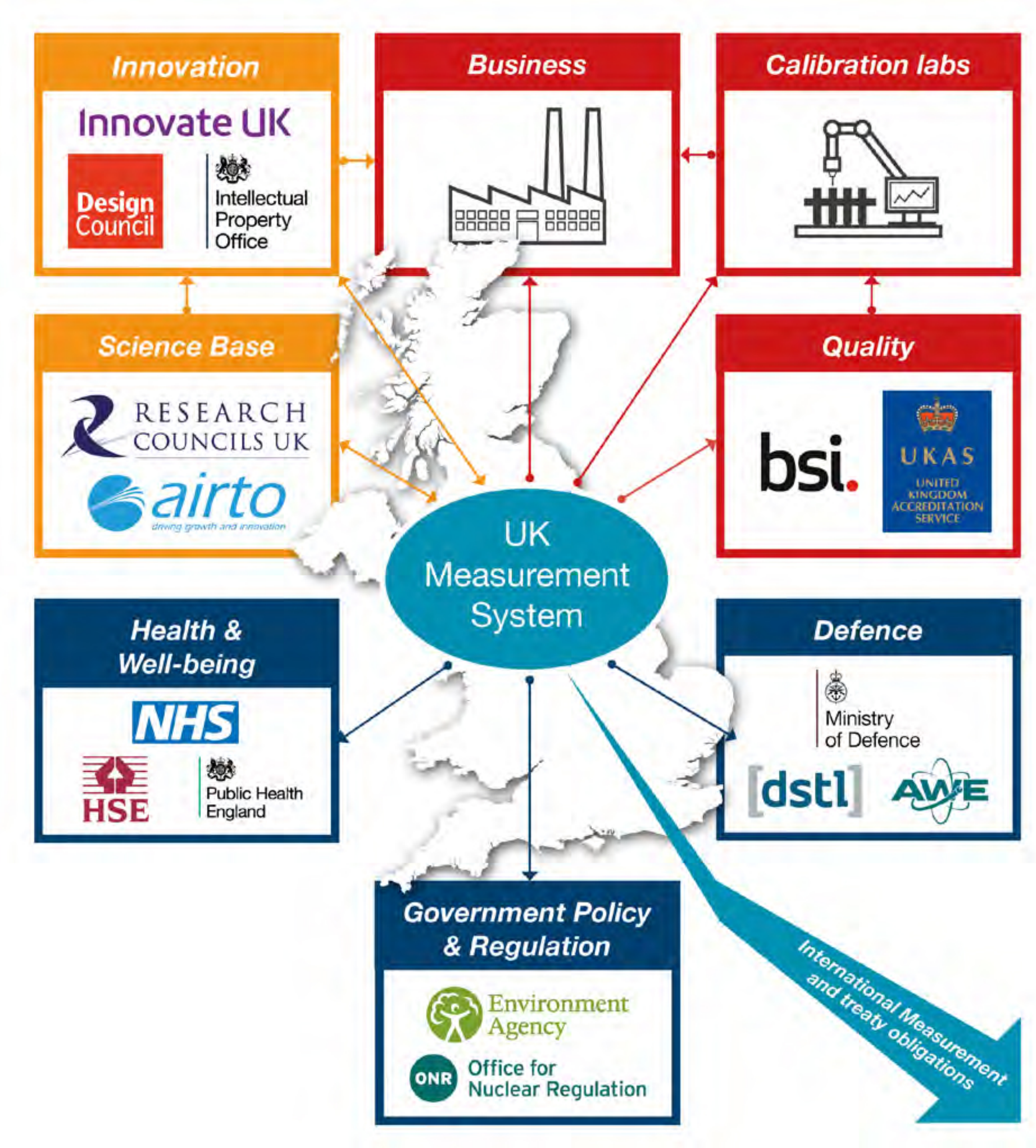

Figure 1 Measurement in the UK, underpinning and working with all parts of the economy and society.

The evidence presented in this report is presented in the following eight chapters:

- **Measurement in the UK** – Explains how measurement supports key national activities such as trade and regulation, examines the role that measurement plays in the UK, and explains how the UK's measurement infrastructure operates
- **Measurement: the economics** – We present an evaluation of the economics of measurement to provide the foundations for understanding why governments invest in measurement with a focus on establishing the value of measurement to the UK
- **The impact of public support for innovation** – A summary of a new report which shows, using robust econometric methods, the impact that the NMS has on job creation and the survival of firms
- **International comparison** – We examine the available evidence to show how the UK's NMS compares internationally. Evaluation of the evidence shows that the UK's NMS is currently amongst the global leaders
- **Survey of users** – A key performance indicator for the UK's measurement infrastructure is what the customers for measurement in the UK think of the services and capabilities that are provided. A detailed, independent survey of customers was conducted and benchmarked against a control group of non-customers. The results of this survey show users of the UK's NMS are more likely to be engaged in innovation and to develop new products than non-customers
- **Case studies** – Our NMS has developed a wide portfolio of impact case studies. A meta-analysis of these case studies has been performed to illuminate the many and varied ways in which measurement capabilities have supported the UK
- **Consultation response** – To develop the direction and objectives for the UK measurement strategy we not only reviewed the new measurement requirements coming out of the latest, top-level national priorities, industry and technology trends but also consulted widely amongst industry, regulators, health professionals and government. These consultations consisted of over one hundred interviews backed by a survey
- **Delivering the National Measurement Strategy 2011–2015** – This is a summary of our record of achievement in delivering the National Measurement Strategy 2011–2015

2. Measurement in the UK

2.1. Introduction

Measurement is pervasive – it is part of the UK's essential infrastructure but, like most core services which run well and efficiently, it goes unnoticed in daily life. Where measurement generally becomes perceived is at the frontiers of technology development, new medical diagnoses or when major national and global challenges need to be addressed. In these cases, current measurement capabilities often cannot quantify the parameters of interest with the required levels of confidence, requiring new measurement research[1] to resolve this. In this section we explore how measurement in the UK is delivered and how it underpins many key parts of the economy and supports the well-being of UK citizens.

Measurement can be regarded as an important infratechnology, essential for innovation and development of new products. Infratechnologies are defined as technical tools, in the form of knowledge-based goods, that enable the development, production and use of technologies[2,3]. As the use of these measurement tools is widespread across many economic sectors, no one company can capture all of the benefits from developing new measurement science, which results in an underinvestment by the private sector. Consequently, governments invest in measurement science to ensure more effective commercialisation of new technologies and increased social benefit within their economies.

We start this chapter by looking at the central role that measurement plays in the UK and internationally, supporting trade and regulation as well as the strong interrelationship with science and innovation.

The second part of this chapter looks at what is considered to be the measurement infrastructure for the UK, which extends beyond just the core measurement capabilities and standards maintained by the UK's measurement institutions to also consider the measurement communities which are involved in ensuring good measurement reaches the end consumer.

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[1] The science of measurement is called metrology, embracing both experimental and theoretical determinations at any level of uncertainty in any field of science and technology.

[2] G. Tassey (1982) Infratechnologies and the role of government, Technological Forecasting and Social Change, 21(2)

[3] A. Estibals (2012) Infra-technologies: The Building Blocks of innovation Based Industrial Competitiveness

Measurement supporting policy development and implementation
The National Physical Laboratory (NPL) has had a direct input into improving the European standard methods for measuring airborne particulate matter, especially PM_{10} and $PM_{2.5}$, key air quality pollutants. NPL's research significantly reduced the uncertainties of these measurements, by a factor of 2 in some cases. These improvements in particulate measurements are very important for health effects studies, enabling them to be used for more effective evidence-based policy decisions.

The ultimate impact in terms of the improvement of human health is very significant, especially in polluted urban areas[*]. The measures taken by government to reduce people's exposure to air pollution, and future changes to air quality policy, can be based on more defensible, lower uncertainty data.

[*] *Understanding the Health Impacts of Air Pollution in London*, Heather Walton, David Dajnak, Sean Beevers, Martin Williams, Paul Watkiss and Alistair Hunt, Transport for London and the Greater London Authority, July 2015

2.2. The role of measurement in the UK

Measurement – few things are as important for a modern economy. Industry, trade, navigation, communications and medicine are all critically dependent on reliable measurement to give confidence to decisions and actions. For example:

- measurement is **essential for trade**, giving confidence that the purchased goods or services meet specification. Over £622 billion[4] of goods and services are traded annually in the UK which rely on some measured quantity or specification. Authenticity and provenance of goods for statutory, quality and trade purposes relies on excellent chemical analysis based on sound measurement foundations
- measurement **increases productivity**[5] while reducing waste and cost in manufacturing through improved control of production processes and more effective verification of components and final products
- measurement helps to ensure that government **decisions on policy and funding are well informed** by relevant and reliable evidence
- in our hospitals, measurement enables **dependable medical testing, effective treatment** through improving the accuracy and reliability of diagnostic tests, and ensuring **exact dosing during therapy**
- only good measurement can deliver the **accurate physical data for climate models and validated diagnostic results in large medical data sets** without which substantial value is lost in their predictive power for policy makers and scientists
- **protection of the UK's citizens** through implementing environmental and health and safety regulations depends on new measurement capabilities when regulations are developed. Regulations also cannot be implemented without measurement to check compliance. Confidence in forensic science and for dispute resolution in court is built on good measurement to give a reliable basis on which to draw conclusions

[4] Deloitte (2009) Analysis of the economics of weights and measures legislation
[5] See the evidence chapters in this document

- accurate measurement is **critical for manufacturing** allowing many different parts sourced from complex, global supply chains to fit together
- **GPS**, essential for over 100,000 commercial flights worldwide every day, **could not function without the highly accurate measurement of time**

Good measurement supplies trusted data to deliver confidence to industry, government, regulators, the medical profession and the public. In this section we explore how measurement is important to underpin trade, regulation and innovation in the UK. We start by showing the NMS activities that support key sectors of the economy. Figure 2 shows the estimated distribution of activity by sector of the NMS research portfolio in 2015.

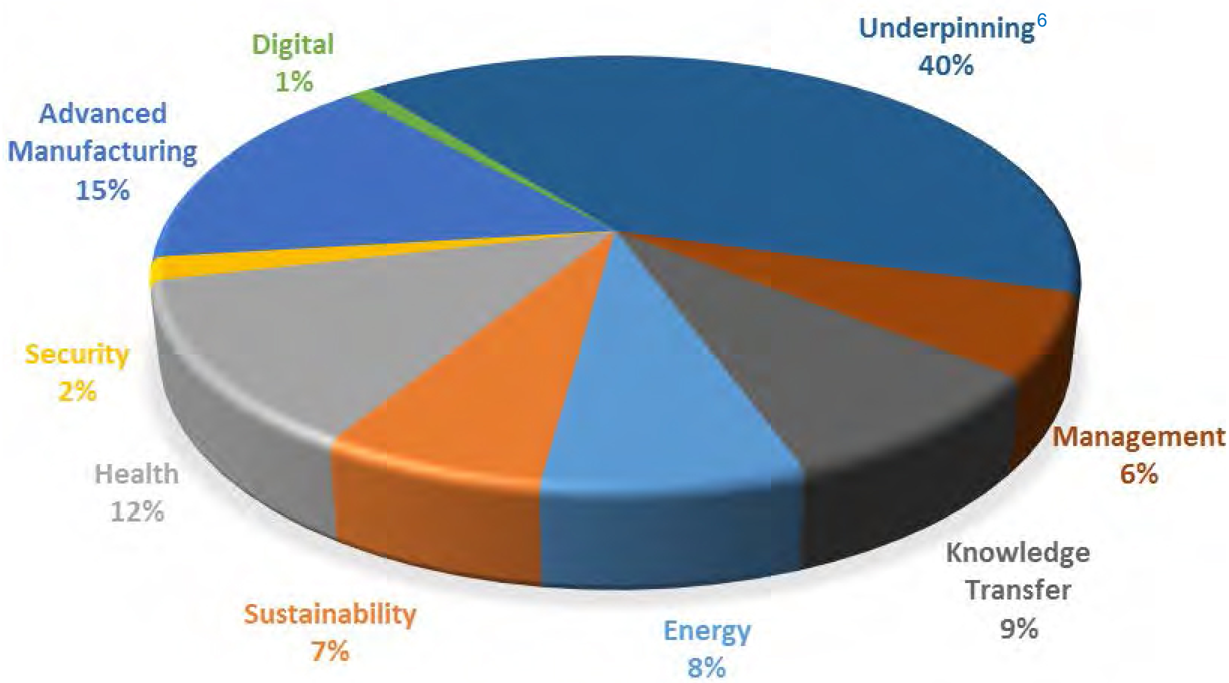

Figure 2 Estimated investment by sector of the NMS portfolio in 2015

[6] **Underpinning Measurement:** Much of the measurement infrastructure established and sustained by the NMS addresses multiple sectors and is classed as underpinning. A good example of underpinning measurement capability is the measurement of temperature, which is needed in almost every sector of the economy.

Measurement increasing productivity

Key to maximising oil and gas recovery from the UK continental shelf is technology that will allow the production from each oil or gas producing well to be measured in real-time and optimised. This is a task that presents enormous technological challenge when many of the metering locations are subsea, and are now in progressively deeper water. The maximum production depth at present is 3,000 meters, or nearly 2 miles beneath the surface of the sea.

Integration of multiphase meter technology, developed by NEL, into a single North Sea field has optimised production flow from each well and increased oil production by 17%. This equates to approximately £1.25 million per week in increased revenue at July 2015 oil prices. The indirect benefits to the UK flow from life-extension of UK Continental Shelf fields, taxation, oil and gas sector jobs and the development of knowledge and products that can be exported to other oil and gas producing areas of the world.

2.2.1. Measurement at the heart of global trade

Global trade has historically increased the prosperity and quality of life in the UK. A study conducted by Deloitte in 2009 showed that £622 billion[4] of the UK's total trade relied on measurement. Re-scaling to 2015, based on growth in the economy, the equivalent figure is estimated to be in excess of £650 billion for physical goods alone.

Removal of tariffs and trade barriers increases competition and opens markets, this has been a central feature of trade agreements led by the World Trade Organisation from the General Agreement on Tariffs and Trade (GATT) to subsequent agreements, especially the Agreement on Technical Barriers to Trade which was negotiated as part of the Uruguay Round. As covered later in section 0, the Mutual Recognition Arrangement (MRA) underpins mutual recognition of measurements carried out by signatory nations. It is one of the primary tools by which the international measurement community has responded to GATT, removing potential measurement-related, non-tariff barriers to trade which existed prior to the MRA being signed.

The removal of trade barriers has over the past two decades allowed the dramatic increase in international supply chains. A car assembled in the UK may have an engine from Japan, a transmission manufactured in China and electronics from Germany, among many other parts. Without a comprehensive, international system of measurement to ensure common measurement standards, these international supply chains would be much harder to establish. Differing measurement standards in exporting countries could well mean that parts don't match or specifications are not met. Thanks to a global system of measurement, such problems are extremely rare in the modern world.

Countries that lead the development of international standards against which goods are traded gain their industries a competitive advantage through early awareness and technical standards being influenced by the country's leading their development. Writing of technical standards is dependent on new and improved measurement methods and so, working together with BSI, the UK's measurement and quality infrastructures can achieve substantial international influence as standards for new technology emerge or new regulations are shaped.

Measurement supporting growth

Cascade Technologies produces gas sensing products based on quantum cascade lasers. They employ 48 people and will have a turnover in excess of £8 million, exporting around 90% of their products overseas. The company's founders developed an interest in laser technology for environmental measurements while working as students together at the National Physical Laboratory (NPL). NPL has since worked with Cascade Technologies at various stages of its development and growth.

Cascade Technologies recently agreed a deal with a large engineering company to supply a product that monitors the carbon monoxide and carbon dioxide emissions from domestic boilers during production. To give the boiler manufacturer confidence in the laser technology, NPL carried out an independent comparison of Cascade's technology with a competitor’s instrument. Cascade has since installed gas analysers in factories across Europe, supporting production on around 35 production lines.

"The information provided by NPL was key to commercialising the product," explains Ruth Lindley, Operations Manager at Cascade Technologies. "It helped us prove that we could supply a more accurate measurement with a faster response time giving productivity improvements for the company."

2.2.2. Measurement underpinning regulation

Regulation is important, for example, to enable trade, ensure we live and work in safe environments and to certify the pharmaceuticals and medical devices we use are fit for purpose. The UK’s measurement institutes work extensively with regulators to ensure that new or revised regulations reflect measurement best practice and their enforcement is supported by national measurement capabilities and standards.

BEIS Regulatory Delivery supports the regulatory aspects of trade by creating the right environment to enable businesses, including those with new and innovative business models, to grow and thrive and to provide better products and services at lower cost for consumers. Using regulation to ensure accurate measurement in trade underpins fair competition between businesses, and competition is a key driver for improving the productivity of UK companies.

The NMS, through BEIS Regulatory Delivery, supports a regulatory regime that delivers confidence in the market where transactions are based upon measurement. Measurement regulation (legal metrology) standardises the units of measurement for trade, requires consistent quantity information to be provided for consumers and businesses, and ensures that measuring instruments and pre-packages are accurate. Enforcement of the legislation is carried out by metrology specialists in Trading Standards who work closely with their local businesses to help them trade fairly and legally.

A consistent and proportionate regulatory regime gives confidence to businesses and enables markets, especially in areas of new technologies where potential hazards and risks exist.

Measurement establishing new markets

Nanoparticles have unique properties which give major opportunities in industry, healthcare and environmental remediation. However, potential environmental and toxicological threats limit uptake of the emerging technology. Work within the NMS, in conjunction with European and global partners under OECD sponsorship, led to new measurement methods and reference materials which enabled reliable characterisation and quantification of nanoparticles. Without measurement research, different forms and sizes of nanoparticles could not be reliably identified. Therefore, measurement provided the essential step in knowledge that was key to enabling reliable toxicity testing and to underpin trade and industrial use of novel nanoparticles as well as effective and outcome-focussed regulation.

Regulatory frameworks need to be fit for purpose not only in the UK, but also at the international level. Internationally, the UK, through its leadership of global measurement, heavily influences the drafting of measurement standards and regulations to remove trade barriers and unnecessary burdens on businesses. Active engagement allows us to shape the measurement requirements of global markets in a way that benefits UK businesses. We achieve this through prominent roles in the OIML (International Organisation of Legal Metrology) and in WELMEC (European Cooperation in Legal Metrology). This work helps UK businesses to export their measured products and measuring instruments.

Regulation covers much more than trade. The work of the UK’s measurement institutes also supports:

- **healthcare** (prognosis, diagnosis, manufacture and delivery of therapies)
- **food (and feed)** (safety, authenticity and traceability)
- **environmental protection** (air, water and soil quality, waste, industrial and landfill emissions, noise, ionising radiations)
- **health and safety** (including product safety and performance of personal protective equipment)
- **security and defence** (including anti-counterfeiting and maintenance of mechanical, electrical, communications and other systems)
- **law enforcement** (forensic testing, breathalysers, speed guns)
- **taxation** (of trade in taxable goods such as oil, gas, alcohol)

2.2.3. Science and innovation

Outstanding measurement, science and innovation are key sources of the UK's competitive advantage. The UK has created a world-leading research and innovation structure which has propelled the UK to second in the Global Innovation Index[7], and resulted in our research institutions being ranked second in the world for quality[8] and our NMS being viewed as world leading[9]. The UK benefits from these strengths through the strong relationship between the UK's science base and NMS, which is mutually beneficial and symbiotic. Our leading edge measurement capabilities are developed in conjunction with leading academic research groups. Equally, some of the most demanding research applications, such as the Square Kilometre Array and accurate data for climate models, depend on the measurement expertise and standards developed by the UK's NMS.

> Only good measurement can deliver the accurate physical data for climate models and validated diagnostic results in large medical data sets without which substantial value is lost in their predictive power for policy makers and scientists.

The facilities that the Research Councils support and the applied science and engineering capabilities developed in the Catapults, supported by Innovate UK, are used by researchers and industry to perform some of the most leading-edge measurement in the world. We also work closely with public sector research establishments such as the Food and Environmental Research Agency, the Defence Science and Technology Laboratory (Dstl), the National Nuclear Laboratory, and many commercial and privately-funded research and technology organisations. All these organisations form part of an extended measurement community, which has strong links to the UK's core measurement capabilities and standards.

The evidence gathered later in this document shows the high value that customers of the NMS place on measurement to enable and drive innovation. All the UK's measurement institutions work to support innovation, both directly with end-users and through Innovate UK. This is manifest through the relationships developed to support strategies for innovation in key emerging technologies such as quantum and synthetic biology, and directly through support of Innovate UK funded projects involving SMEs. NPL alone has supported over 100 such projects in the past four years. Without good measurement, the value of research and development may be reduced and the resulting enabling technology innovation may not be reproducible within industry.

[7] The Global Innovation Index 2014: The Human Factor in Innovation, Cornell University, INSEAD, WIPO (2014)
[8] World Economic Forum (2014) Global Competitiveness report 2014-15
[9] NPL (2011) International Benchmarking review. See also chapter 4 of this document.

Measurement accelerating innovation

NPL scientists worked with NGF EUROPE – now the largest global manufacturer of the rubber impregnated glass cord used in automotive timing belts – to gain a fundamental understanding of how the adhesion process worked. Informed by this deep understanding, NGFE enhanced its processes and as a result the process has remained stable and problem free.

A breakthrough in materials understanding such as that made by this study can often accelerate the rate of new product introduction and market acceptance of novel products by a year or more. Since the NPL study, on average, belts were fitted on some 25 million vehicles each year giving a 1% increase in fuel efficiency. This provides a reasonable estimate of the order of magnitude achieved through the impact of the acceleration of the adoption of cam belt technology brought about by the project.

In one year 25 million vehicles travel some 500 billion kilometres. The average petrol car currently consumes one litre of fuel every 11 kilometres, so on this basis, the fuel saved by car owners in one year amounted to some 450 million litres worth around £610 million. The project also leveraged savings of 750,000 metric tonnes of CO2[*].

[*] *Belt vs. Chain – A Study on the CO2 Saving Potential of the Timing Drive*, Christof Tiemann, Jürgen Dohmen, Christoph Steffens, Stefan Wedowski, Ralf Walter, Hermann Schulte, Tomasso Di Giacomo, Aachener Kolloquium Fahrzeug- und Motorentechnik (2008)

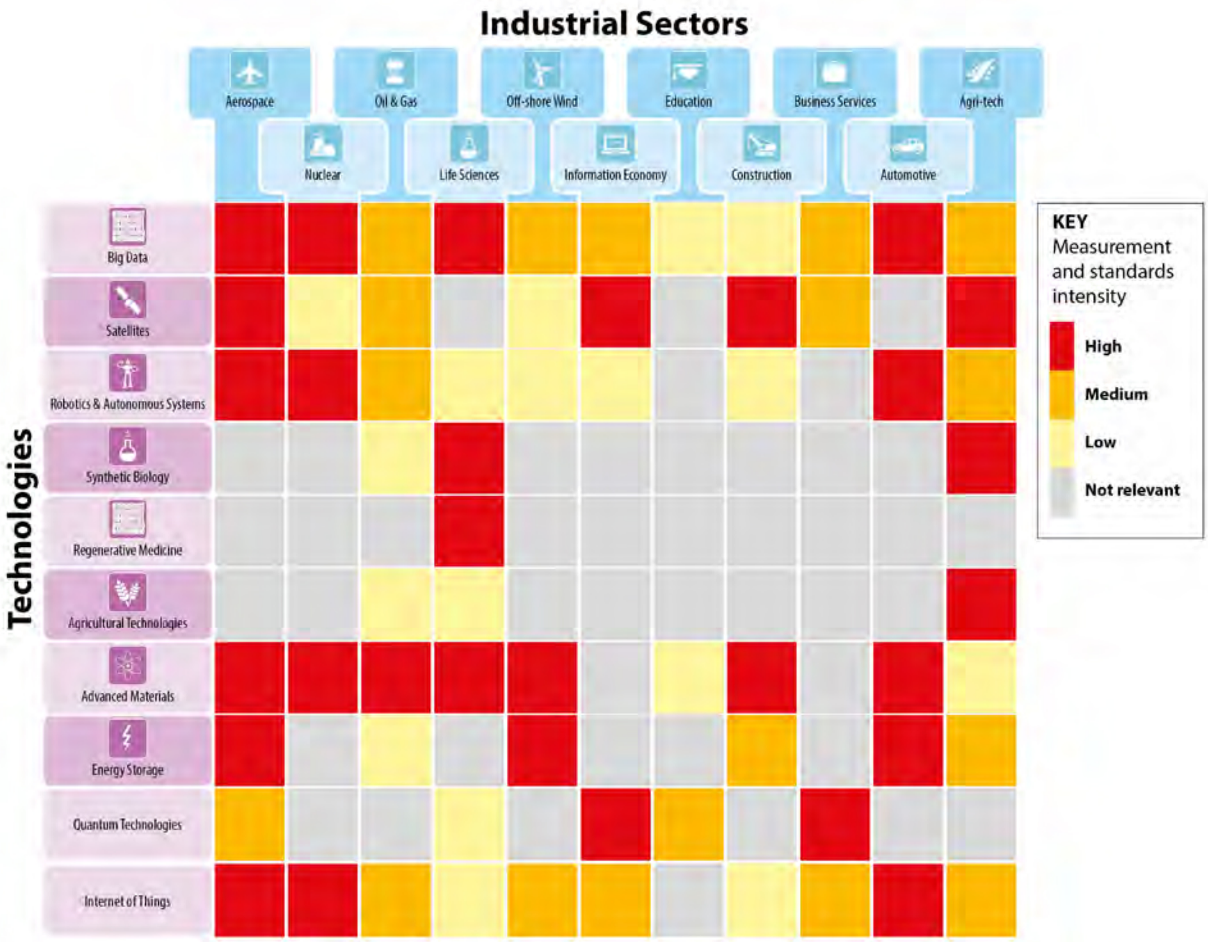

Figure 3 Heat map illustrating the measurement intensity for the eight Great Technologies and industrial strategies.

The NMS has long had an active research portfolio tackling the measurement challenges associated with the emergence of new technologies and industrial priorities. Figure 3 illustrates the relative importance of measurement to the current industrial strategy areas and the eight (plus two) Great Technologies. Through foresight activities we aim to predict trends in technologies and industry sectors in order to change and optimise the research undertaken by our measurement institutes so that the measurement infrastructure is ready to support industry and society when required.

Measurement tools, methods and standards have enabled technologies to move from the laboratory to the production line, underpinned the development of new technical standards, and supported the establishment of new markets or disruption of existing sectors. The focus today is on the eight (plus two) Great Technologies and the NMS has an extensive portfolio supporting each technology area as shown in Table 1.

Technology	NMS Response
Big data	The NMS is active in developing a variety of big data applications, including Earth observation research for climate modelling, structural health monitoring using digital image processing, marine acoustics monitoring to ensure compliance with legislation on noise pollution, new genomic technology applications and pre-clinical research in mass spectrometry applications. Future areas of research include new antimicrobial drug discovery through cognitive computing, and research into big data algorithms to certify data provenance and correct treatment of measurement uncertainties.
Robotics and autonomous systems	Research is underway to support initiatives such as Manufacturing 4.0, where highly-automated and autonomous production lines will rely on accurate sensors and in-line metrology equipment to ensure high quality, right-first-time production and the flexibility for rapid re-configuration.
Synthetic biology	Targeted genome editing using engineered nucleases has grown from a niche technology to a mainstream method used by commercial and academic life science laboratories. CRISPR/Cas9 has particularly revolutionised the ability to manipulate the genome, in situ, of numerous species and cell lines. Software is also an essential part of the genome editing tool box. LGC is currently looking at validation of CRISPR engineered cell lines with leading UK commercial companies.
Regenerative medicine	Work has been going on to develop essential metrology underpinning standards in global cells and genome therapy. LGC continues to investigate new approaches to identify and control (minimise) sources of biological measurement variability ('biological digitisation') for product comparability assessment in cell therapy manufacturing systems. NIBSC has played a key role in characterisation and preservation of stem cells, including hosting the UK stem cell bank and a taking a leading role in shaping guidance for regulation of stem cells and advanced gene therapies.
Agricultural technologies	NMS work in this area supports a variety of projects including sensing technologies for measuring the ripeness of fruit and vegetables for use in autonomous harvesting, application of new genomic technologies, high accuracy food and feed supplement measurements as well as underpinning the calibration of Earth observation satellites used for land use and crop development monitoring.
Advanced materials	NPL has a long history in materials research. Currently, NPL is leading in the development of accurate and traceable characterisation techniques for graphene, both in the R&D laboratory and also to support manufacturing of new products based on graphene. Similarly, work at NPL is providing the metrological underpinning to techniques for looking at the performance of advanced metal alloys from the sub-grain level to macroscale structures. This work is supporting many areas such as an improved understanding of the origins and development of corrosion.

Technology	NMS Response
Energy storage	NMS supported work is underpinning the advancement of fuel cell technologies by developing the measurement tools to improve the understanding of the performance and degradation mechanisms. In a related project, the tools for electrochemical measurement at the nanoscale are being developed to look at surfaces and interfaces such as catalyst and battery anodes/cathodes.
Quantum technologies	NPL is part of the £270 million National Quantum Technologies initiative, working closely with EPSRC, Innovate UK, Dstl and the university-led quantum hubs. NPL is using its long-established expertise in this area to develop platforms for the testing and evaluation of new quantum technologies as well as developing next-generation sensors and standards which offer unparalleled sensitivity and accuracy.
Internet of Things	The Internet of Things (IoT) concept promises to have an impact on how measurement systems are used to provide information about the behaviour of complex systems and to predict future events. NPL's research in this area is associated with assessing the quality of the information derived from these measurement systems, and in quantifying the integrity of the information inferred from the analysis of IoT data.

Table 1 Examples of NMS research supporting the eight Great Technologies

2.3. How measurement is delivered in the UK

2.3.1. The UK's measurement infrastructure

The UK, like all developed nations, has a national measurement infrastructure that ensures a robust system of measurement and forms an essential component of being part of a global economy. At its core, the NMS ensures that measurement in the UK is consistent with the global common system of measurement units: the International System of Units – the SI (*Système international d'unités*).

The common SI system of units underpins much of the daily use of measurement in the UK. However, there are many areas of measurement such as in chemistry, materials, biology and food science which are not currently directly linked to the SI system of units. Primary measurement underpinning these areas is established and disseminated through reference methods and/or materials. These areas are often where new measurement knowledge needs to be developed to tackle emerging needs.

Internationally, each country has one National Measurement Institute (NMI), whose role is to take the lead in international representation and to underpin delivery of a measurement infrastructure consistent with the SI system. In most countries, there are one or more Designated Institutes (DI), who support the NMI by delivering specific measurement capabilities and are recognised internationally as the lead measurement organisation for a particular physical or other quantity. In the UK, the National Physical Laboratory (NPL) is the UK's NMI and works in partnership with five designated institutes:

- LGC (formerly the Laboratory of the Government Chemist)
- NEL-TUV (formerly the National Engineering Laboratory)
- NGML (National Gear Metrology Laboratory)
- BEIS – Regulatory Delivery Directorate (Department for Business, Energy & Industrial Strategy)
- NIBSC (National Institute for Biological Standards and Control)

This network of leading measurement capabilities forms the core of the UK's measurement infrastructure which is directly supported by government through the NMS, with the exception of NIBSC, which is funded via the Medicines and Healthcare products Regulatory Agency (MHRA). Details of each institution are included at the end of this section.

The UK's measurement infrastructure is not only responsible for providing the top level measurement science and capabilities in the UK. It is also directly responsible for supporting:

- **the UK's legal metrology system**: This ensures that key legislation, such as the Weights and Measures Act 1985, is enforceable across the 207 local authorities by over a thousand trading standards officers trained in weights and measures. Reliable, robust measurement touches on every citizen in the UK through the legal metrology framework, giving trust and confidence that when every litre of fuel, pint of beer, or other goods, is sold to a consumer it is the right measure and is fit for purpose
- **Government Chemist**: A statutory function as a referee analyst under several acts of Parliament which focus on public protection, value for money and consumer choice. The government Chemist function resolves scientific disputes mainly in the food and feed sectors, gives advice to regulators and industry, and carries out research. Regulatory areas where advice may be important include the quality of food, animal feed, pesticides, medicines and chemicals

The UK's measurement institutes are:

The National Physical Laboratory

NPL is the UK's National Measurement Institute under the ownership and direction of the Department for Business, Energy & Industrial Strategy (BEIS). NPL aims to provide the measurement capability that underpins the UK's prosperity and quality of life by undertaking work in the national interest. This will deliver social and economic impact through world-class measurement science, innovation applied research and knowledge services. NPL employs over 500 scientists and is based in south-west London. The laboratory is a 36,000 square-metre purpose-built measurement building with 388 of the world's most extensive and sophisticated measurement science laboratories.

Under the NMS, NPL delivers a number of programmes, covering a broad range of science and technology areas that cover strategic and applied research as well as the maintenance of core facilities.

These include:

- acoustics and ionising radiation metrology
- engineering metrology
- materials and modelling metrology
- optical, gas and particle metrology
- quantum, electromagnetics and time metrology
- surface chemical and biophysical metrology

LGC (formerly the Laboratory of the Government Chemist)

LGC is the Designated Measurement Institute for chemical and bio-metrology within the UK's devolved NMS.

As an NMS laboratory, LGC delivers world-leading chemical and bio-measurement science to improve quality of life and promote economic growth in the UK, with particular emphasis on supporting government policy and strategy in key areas such as healthcare, food and environmental sustainability, national security and energy.

LGC is at the forefront of the development of the nascent international bio-measurement system, ensuring early implementation of standardisation tools and frameworks to accelerate the adoption of innovative and emerging technologies.

LGC's state-of-the-art measurement capabilities underpin the UK's national resilience and enable the provision of independent and impartial expert opinion that ensures trust and confidence in measurements supporting trade and consumer protection.

This is achieved through two main NMS programmes:

- chemical and biological metrology
- Government Chemist

NEL-TUV (formerly the National Engineering Laboratory)

NEL is the UK's Designated Measurement Institute for flow measurement and fluid density measurement. It provides a suite of national standards within the framework of the UK NMS. As part of TUV SUD group, NEL is based in East Kilbride but operates globally in terms of the flow measurement and fluid mechanics services offered to a broad range of industrial sectors. These services include calibration and testing, technical consultancy and longer-term applied research in all aspects of flow metrology.

The comprehensive flow measurement infrastructure provided by NEL is internationally recognised as world leading. Through standards and regulation, NEL plays a leading role in underpinning the measurement aspects of trade in liquids and gases for industrial purposes. This is a constantly evolving landscape with some exceptionally challenging circumstances for flow metrology that drive a constant focus on innovation. NEL and its partners in the Flow Measurement Institute, provide the necessary leadership and co-ordination at a UK-level to address these opportunities.

The Regulatory Delivery Directorate

BEIS Regulatory Delivery Directorate is the Designated Measurement Institute for legal metrology and static volume (delivered via the Legal Metrology programme) with a mission to simplify technical regulation for the benefit of British business. BEIS Regulatory Delivery Directorate is focussed on using the right intervention to solve problems and where regulation is necessary we ensure that it is designed and enforced in a way that supports business compliance and growth.

BEIS Regulatory Delivery Directorate’s objectives include:

- simplifying the legislative framework for weights and measures and hallmarking to support well-functioning competitive markets
- providing the assurance businesses need to understand and apply legislative requirements and giving them confidence that their investments in research and development are protected against unfair competition
- enforcing technical regulations intelligently using the Regulators’ Code to achieve better outcomes for British businesses
- providing a legal metrology infrastructure to underpin trade measurement and confidence in the market, and a range of certification services that enable businesses to export their products globally

The National Gear Metrology Laboratory

NGML is part of Design Unit within Newcastle University's School of Mechanical and Systems Engineering. Design Unit is a specialist outreach centre with expertise in design, development, consultancy and research for Mechanical Power Transmission Systems. It is part of the UK’s largest University group specialising in gearing and has a broad range of services for the international gearing industry across sectors including industrial, power generation, transport, aerospace, domestic appliances and defence.

NGML moved to Design Unit in 1987 and is the UK Designated Measurement Institute for gear measurement. The laboratory is accredited by UKAS for the measurement and calibration of gears and the calibration of gear measuring machines.

The National Institute for Biological Standards and Control

NIBSC is the Designated Measurement Institute for bio-activity metrology related to international activity units. As part of the Medicines and Healthcare products Regulatory Agency, under the Department of Health, it plays a vital role in safeguarding the quality and efficacy of biological medicines. NIBSC has over 300 staff, based at South Mimms, in Hertfordshire. The laboratory has excellent purpose-built facilities including a dedicated multi-million pound Centre for Biological Reference Materials, which is unique in its focus and capability amongst other international reference material manufacturers.

NIBSC develops, holds and distributes over 300 primary international standards (on behalf of the World Health Organization) and a further 500 CE-marked and other reference materials. In addition to its capability in reference materials development and manufacture, NIBSC also plays a vital role as the UK's Official Medicines Control Laboratory (OMCL) for testing of biological medicines under the auspices of the European Medicines Agency. NIBSC's scientific focus is arranged in core lead divisions: virology (split between vaccine and diagnostic applications), bacteriology (split between vaccines and diagnostic applications), biotherapeutics and analytical sciences. NIBSC has been home to the UK Stem Cell Bank since 2004 and through its advanced therapies division focuses expertise on new areas of gene therapy and cellular therapy.

2.3.2. Measurement – the international perspective

Measurement is not just a national enterprise. A common system of measurement with the SI units at the core is fundamental to global trade in goods and international scientific endeavours. Globally, there is an international measurement infrastructure consisting of 97 signatories and associates to the Metre Convention, an international treaty that ensures a common system of measurement worldwide under the auspices of the Bureau International des Poids et Mesures (BIPM). Similarly, for legal metrology, international coordination and harmonisation is provided by the intergovernmental International Organisation of Legal Metrology (OIML).

In 1999, a supplementary international agreement was signed, the Mutual Recognition Arrangement (MRA). The MRA meant that, for the first time, measurements that were made in one nation were recognised as equivalent to those of another where equivalence had been demonstrated through an international comparison of measurement capabilities. Prior to the MRA, mutual acceptance of measurement capability between countries relied on multiple bilateral comparisons of individual measurement capabilities being undertaken. Globally, there was a perceived lack of comparability of measurements between all nations.

Under the MRA, where measurement capabilities have been demonstrated as equivalent, they are then entered into the BIPM maintained database of Calibration and Measurement Capabilities (CMCs). The MRA provides the technical basis for international trade agreements, such as the General Agreement on Tariffs and Trade (GATT). The signing of the MRA removed a key technical barrier to trade where international exporters were often obliged to certify their products against the national measurement standards of each importing nation. Today, certification against the exporter's home measurement system is accepted internationally, reducing costs and opening markets.

2.3.3. Measurement and calibration in the UK

The measurement research, calibration services and knowledge transfer supported by this government at the UK's measurement institutes are the base on which good measurement across the UK is built. However, most calibrations of measurement instruments or certification against technical standards, which are dependent on measurement, are delivered through a network of around 1,500 independent, accredited calibration and testing laboratories to industry and other end-users. This large network of calibration and testing laboratories link the calibrations they perform back to top-level national measurement standards by in turn having their principal calibration standards, instruments or other artefacts calibrated by the UK's measurement institutes. This creates an unbroken chain of measurement, linking measurements made on the shop floor in industry or in a hospital ward up to the highest-level national standards which have been compared internationally. This unbroken chain of measurement is called a traceability chain as it links primary measurement standards down to where good measurement is required to give confidence. Providing traceability is essential to unequivocally demonstrating that UK goods meet specification both nationally and when exported globally. Figure 4 illustrates how a single calibration against primary national measurement standards can lead to many thousands of measurements in industry or R&D laboratories.

Measurement supporting healthcare

LGC has enabled improvements in the accuracy and confidence of therapeutic drug monitoring for organ transplant patients so that clinical decision-making can be based on highly-accurate laboratory-based measurements of individual patients. Helping hospital labs improve their measurement methods and procedures, through robust external quality assurance schemes and compliance with standards, improves patient's clinical outcome and avoids the need for costly alternative dialysis treatment on the NHS. Successful aftercare of all donor organ patients could save the NHS £150 million each year.

2.3.4. Quality and technical standards

Technical standards define the specifications that products have to meet or the analyses that need to be done to meet a regulation. Many technical standards could not be written without the underpinning measurement methods and standards having been developed. In this sense, investment in measurement science enables technical standards for future technologies or regulation to be developed. Technical standards are developed by many bodies such as ISO, CEN, ASTM and others internationally. In the UK, the British Standards Institution (BSI) has the central responsibility to develop new technical standards, working internationally where necessary. The UK's measurement institutes provide extensive support to BSI technical committees and other international standards bodies to help define and develop future technical standards. In total, our measurement institutes support and represent the UK on over 900 measurement and technical standards committees, ensuring that measurement methods recorded in technical standards are underpinned by sound measurement practice.

Ensuring compliance to technical standards in the UK is achieved through the UK Accreditation Service (UKAS). For example, UKAS has the responsibility for ensuring the measurements that calibration and testing laboratories undertake are assessed against key measurement-related technical standards, such as ISO 17025, as part of the accreditation of their measurement capability. Measurement in the UK greatly benefits from the work of UKAS, as accreditation of calibration and testing laboratories ensures that the calibrated instruments and artefacts in use by measurement users are accurate and fit for purpose. The assurance of each stage in the transfer of measurement achieved through accreditation of calibration laboratories establishes a reliable traceability chain direct to UK national measurement standards.

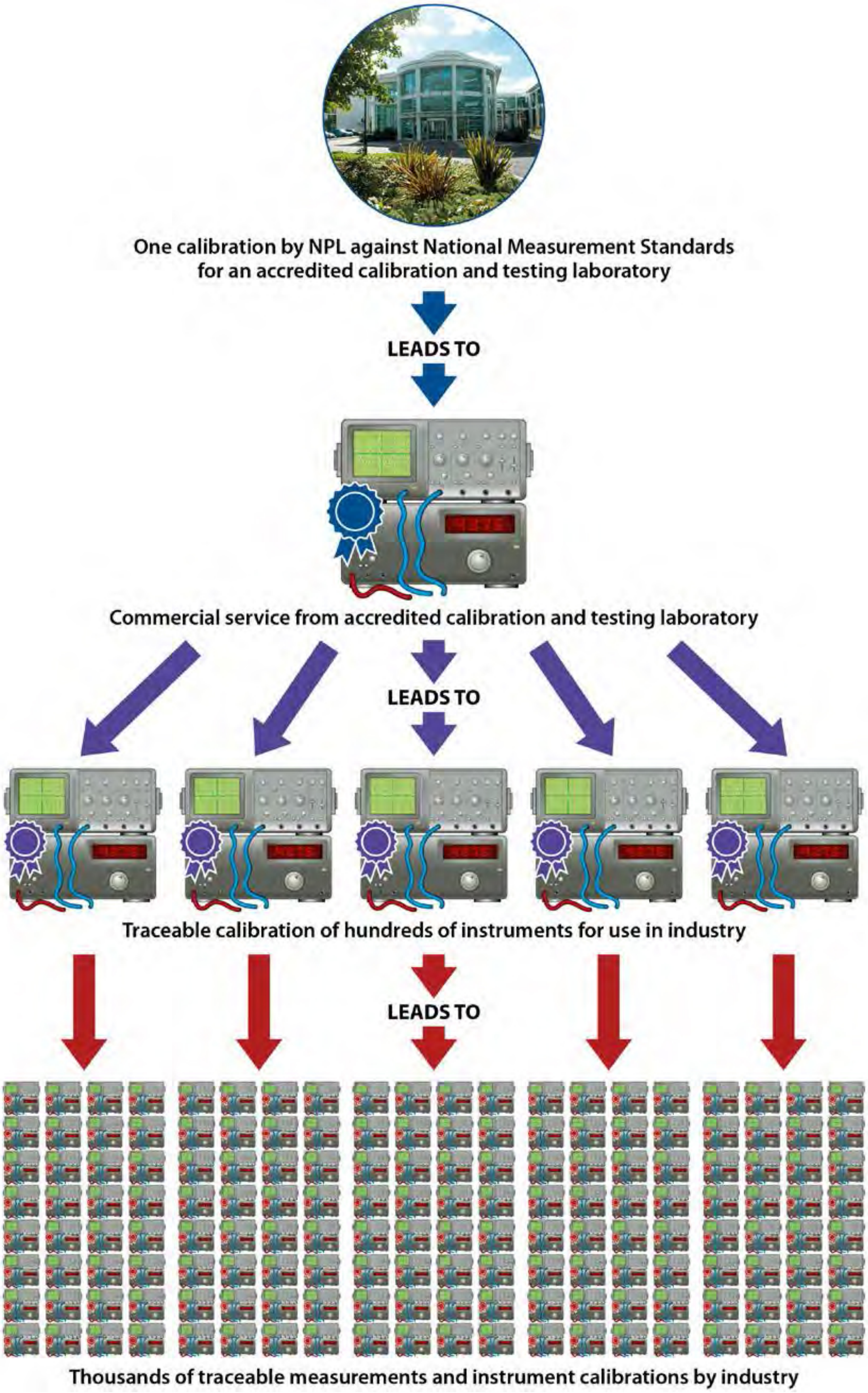

Figure 4 Schematic picture of how traceable calibration flows from one single calibration at NPL down to many thousands of measurements in industry

3. Measurement: the economics

3.1. Introduction and summary of key points

Public support for measurement science has a long history in the UK and this has resulted in many notable achievements such as the invention of the atomic clock. While these individual successes demonstrate the excellent science that underpins our measurement infrastructure, they do not provide a picture of the total benefits or the mechanisms by which those benefits are achieved. In this chapter, we review the previous studies that have attempted to establish the economic basis and value of investing in measurement. Measurement is an important part of most market and non-market sectors of the economy. However, the intensity of measurement use and the benefits obtained have enormous variation across sectors even before factoring in the cross dependency between sectors or the huge variety of different ways measurement benefits can be generated. These factors make evaluation of the economic impact of measurement both highly complex and challenging to resolve.

Past literature reviews by Peter Swann have established the mechanisms through which measurement activities generate economic benefits. Similar mechanisms are also encountered in a meta-analysis of NMS case studies detailed in a separate chapter of this review. Based on this evidence, the main benefit mechanisms are identified as:

- new measurement capabilities **increase innovation by providing new tools and techniques** for research, and provide the means of demonstrating the functionality of novel technologies
- applying good measurement practices **increases productivity by making it easier to detect errors** at an early stage of the production process, and provides the technical basis of standards and specifications that enable division of labour, specialisation and a more distributed system of production
- **enabling the market for high quality goods** by making it simple for high-end producers to show that their goods are superior to cheaper alternatives
- the system of **traceable measurements and accreditation lowers transaction costs** by promoting trust and reducing the need for repeated testing

Economic theory can been used to establish a rationale for public investment in measurement research and development of the nation's basic measurement infrastructure. **Because the knowledge generated by research spills over to firms that didn't pay for it, the level of private R&D spending will always be less than socially optimal.** Consequently, there's a need to supplement private funding with public investment in order to bring total spending closer to the optimal level. In addition to this spillover argument, there are three other reasons why public support is necessary:

- **coordination failures that affect the adoption of new standards**
- **technological uncertainty limits investment in untested technologies**
- **maintaining a single (expensive) primary standard at one measurement institute avoids duplication of standards across calibration labs**

Finally, there have been a number of attempts to quantify the benefits of investing in measurement capabilities. The headline findings from a review of previous quantitative studies are:

- **around 1% of GDP is spent on measurement, and is similar in scale to the UK's spending on R&D**
- **the benefit-to-cost ratio for investment in better measurement tools and techniques is likely to be between 3:1 and 5:1**

The quantitative studies reviewed in this chapter are based on customer surveys, case studies and stylised models. Such approaches have been widely used by government and other organisations in the past to evaluate benefits and value for money. As best practice in evaluation has evolved and the fiscal environment for government spending has tightened, there is a growing requirement for objective statistical demonstration of causal impact wherever possible. This requires a way of assessing what would have happened without public support or intervention and represents a real challenge for well-established, pervasive and underpinning infrastructures such as measurement. Tackling this evaluation challenge will involve using and developing new methods and the NMS is already working closely with universities and other agencies to develop an approach that is both practical and robust.

3.2. Changes in the evidence environment

Over the past few years, there has been a systematic drive to ensure that all government programmes are subject to robust evaluation. Sources of data should be as objective and independent as possible (e.g. balance sheets) and agencies are encouraged not to rely on customer surveys for quantification. Agencies are also encouraged to create a culture of openness and learning around evidence: datasets should be available and results should be reproducible.

Evaluations should be focussed on statistical demonstrations of causal impact, which is the difference between the observed outcome for a 'treated' individual (e.g. customer or user) and the outcome that would have occurred had they been 'untreated'. As we cannot observe what would have happened had this individual been denied support, evaluations are essentially about finding a proxy for this 'counterfactual'. In short, the challenge is to generate information about something that is fundamentally unobservable; existing guidance about how to approach such a task can be summarised as follows:

- search for sharp changes in the scope or scale of a programme and use it to perform a 'natural experiment'
- track the performance of users (and potential users) before and after they receive support
- match users to non-users based on past behaviour and characteristics, and compare changes in the performance of the treated group to change for the control group

Current expectations around the robustness of evidence are technically demanding and it will take ingenuity to develop studies of the required standard. Like many other agencies, existing evidence for the impact of the NMS is largely of the traditional customer survey variety and it will take time to assemble the datasets required for this kind of analysis.

We are already working closely with universities and other agencies to develop an approach that is both practical and robust. For example, the NMS recently participated in an econometric study by Frontier Economics that is discussed at length in chapter 4. This project combined data-linking with an econometric analysis and demonstrates a commitment to be bold in future evaluations

3.3. Rationale for government intervention

The rationale for public funding of a measurement infrastructure is widely accepted internationally. This section presents the reasons why it is necessary to maintain an appropriate level of investment in measurement science and the infrastructure of the NMS. There are essentially two types of argument: (1) the traditional argument that new knowledge and technology spills over to firms that did not contribute to its development; and (2) a series of less generic arguments that are more specific to measurement and standards.

3.3.1. Knowledge spillovers and positive externalities

The private investment in the R&D needed to generate future measurement services will always be below the socially optimal level, because the benefits this R&D generates spillover to firms who did not contribute and this creates a strong incentive to free-ride (Arrow, 1962). The problem is particularly acute in the case of the R&D that the NMS undertakes, because advances in metrology tend to have applications across many sectors. It is this wide applicability that makes the development of these new tools and techniques particularly susceptible to free-riding. Consequently, Tassey (1982) argued that measurement should really be seen as a public ‘infratechnology’: a technology that provides tools and techniques that can be widely applied across a range of sectors to enable further innovation. More recently, the claim that standards and measurement protocols constitute a national infratechnology found support in Estibals (2012).

Secondly, commercialisation is about converting research into discrete innovations that can be transferred to specific firms. In the 1990s, the conventional view of Research and Technology Organisations (RTOs) was that they commercialise the results of academic research. But there is growing recognition that such inventions are often unmarketable, despite being valuable, precisely because it’s impossible to prevent them being widely exploited.[10]

Finally, certain areas of metrology research require the setting up of large specialist laboratories. In such cases, the fixed costs could be so high that they exceed the private gains to any one company. Therefore, the facility would never be developed on the basis of individual private funds alone despite the total benefits from the capability outweighing the cost.

3.3.2. Arguments specific to measurement and standards

Variants of the argument set out in the previous subsection are well established and widely used by associated agencies and programmes. Indeed, this spillover argument is the

[10] See page 9 of K. Smith (2015) and see M. Mazzucato (2015)

traditional rationale for public interventions to support science and innovation. However, there other less generic arguments for the development of a national measurement infrastructure:

Coordination failures

Inter-comparison based on a common language is at the heart of measurement[11]. This strong association with standards means that for most users a measurement technique only becomes useful once it has been widely adopted. This can make it difficult for a technically superior technique to displace an existing technique unless users can be persuaded to switch in a coordinated fashion. This lock-in can be overcome by offering subsidised services to leading-edge users. Once these early adopters have started using the technique, network effects mean that it is progressively adopted by more marginal users until a tipping point is reached.

Technological uncertainty

Capital markets can deal with quantifiable risk but broad uncertainty is a barrier to investment because it cannot be quantified or hedged against. Investors need an independent way of validating an inventor's claims about the potential of a new technology for them to invest in developing it further. In particular, new measurement tools and techniques are often required to demonstrate an inventor's claims about novel characteristics.[12]

The Quantum Metrology Institute (see box) is an example of how the NMS responds when new measurement tools are often required to demonstrate the veracity of claims about novel product characteristics. That is, there must be a way of independently validating claims about the potential of a new technology for the market to invest in developing it further.

Measurement supporting emerging technologies

NPL's Quantum Metrology Institute aims to provide leading-edge measurements for verifying the performance of new quantum technologies.

A recent application concerns Quantum Key Distribution (QKD). Key exchange is at the heart of cryptography for secure communication. This distribution of keys using photons over an optical network can provide an extra layer of data security which is inherently future-proofed. Toshiba Research Europe, BT, ADVA Optical Networking and NPL performed the first demonstration of QKD and data encryption over a single field-installed fibre, with NPL providing traceable calibration of the QKD optical system. This showcased the technology and highlighted the importance of traceable measures for system verification.

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[11] For further details on the coordination failure see the paper of G. Swann (2009) pages 84-85 www.rohs.gov.uk/assets/nmo/docs/nms/prof-swann-report-econ-measurement-revisited-oct-09.pdf

[12] For further analysis see the model developed by Swann (2009), pages 54-57

Duplication and efficiency

The cost and difficulty of maintaining primary standards makes the structure (calibration chain) highly efficient. One expensive high-level calibration is bought by a commercial calibration laboratory from a UK measurement institute and this is then used to calibrate the instruments of a vast number of users without the need for the calibration laboratory to establish their own primary standard.

Finally, there is a question about how we maintain mature specialisms that are no longer of interest to academics because the fundamentals are well understood. The NMS maintains expertise that would be very costly to reproduce each time it was needed. That is, a specific measurement capability may not be called upon for a number of years but then become 'mission critical'.[13]

3.4. Spending on measurement

A simple way to judge the value of a service is to observe what businesses are willing to pay for it. Although, in the case of measurement tools and techniques, knowledge spillovers drive a wedge between individual private benefits and the total (social) benefit, which means that the observed willingness-to-pay necessarily underestimates the true benefit. With this in mind, four previous studies have attempted to quantify the spending on measurement activity across an economy as a percentage of its GDP to arrive at a lower bound for the value of measurement.

There are essentially two types of study, differing by methodology, economy and time period: the three early US studies were based on industrial surveys conducted by the National Bureau for Standards (NBS), which focussed on the labour input to measurement activities; the most recent study (Williams, 2002) is for the EU and was based on the turnover of NMIs and expenditure on instrumentation. The headline results for the four studies are summarised in Table 2 below.

[13] BIS Research Paper, Research and Innovation Organisations in the UK: Innovation Functions and Policy Issues, 226 (July 2015)

Source	Economy	Year	Data	Including Government	Excluding Government
Williams (2002)	EU	2000	National Accounts	-	1.0%
Huntoon (1967)	US	1967	Industrial Survey	-	2.5%
Don Vito (1984)	US	1984	Industrial Survey	-	3.5%
Paulson (1977)	US	1963	Industrial Survey	6.0%	4.2%

Table 2 Spending on measurement as a percentage of GDP[14]

As these studies are 15 to 50 years old they primarily provide insight into measurement activity in large developed nations in the late twentieth century. Their characterisation of measurement activity for this period was as follows:

- the public sector accounted for about 30% of total measurement activity
- it appears that between 1% and 5% of GDP was spent on measurement by industry within large developed nations
- each year in the UK, £342 billion worth of goods are sold on the basis of the measurement of their quantity, equating to £6.23 billion a week. In addition to this, goods worth around £280 billion per annum are weighed or measured at the business-to-business level

The age of these studies, as well as changes in the nature of developed economies, means that these results may not reflect the current level of measurement activity. Nonetheless, such studies, along with some cautious extrapolation, provide some hints. To guide this extrapolation it's helpful to reflect that in the past around 75% of measurement expenditure was attributable to labour costs. But over recent decades capital substitution (automation) will have reduced the amount of labour needed to sustain a given level of measurement activity.

3.5. Benefit mechanisms

NIST (2003) reviewed 29 case studies on the economic impact of measurement at a firm level (including semiconductors, construction, photonics, electronics, communications, manufacturing, materials, chemicals, automation industries). These mechanisms are also explored in Peter Swann's extensive review of literature (Swann, 1999) relating to the economics of measurement, as well as a meta-analysis of NMS case studies discussed in a separate chapter of this review. The main mechanisms are: supporting innovation and investment in new technology, increasing manufacturing productivity, enabling markets for

[14] See Table 1 on page 79 of Williams (2002). Details and extracts from the US studies can be found in Birch (2003)

high-quality goods, and reducing transaction cost. These mechanisms will now be explored in detail.

Outcomes	Number of citations
Increased productivity	12
Lowering transaction costs	12
Increased R&D efficiency	11
Enabling new markets	3
Increased product quality (or durability)	3
Cheaper/more efficient regulatory compliance	2
Energy cost savings/conservation	1

Table 3 Most commonly cited effects of measurement

Source: NIST, 2003

3.5.1. Innovation

Measurement protocols are required to bring structure and predictability to new phenomena in a way that echoes the role played by early cartographers in opening up previously unmapped parts of the globe for trade and development. As our understanding of physical and biological phenomena expands, this creates demand for fundamentally new (or significantly better) measurement capabilities so that we can control these phenomena well enough to use them as the physical basis of new technologies. In other words, there is an intimate connection between measurement and control. Thus, new measurement capabilities are necessary to enable and accelerate the exploitation of scientific breakthroughs.

Swann (1999) argues that innovation often takes a combinatorial form. That is, a new product offers a novel combination of product characteristics. Indeed, he uses the idea of a ‘product space’, whose dimensions are controllable physical characteristics and, as time advances, regions in this space start to fill up with established products. Hence, product innovation involves looking for unoccupied regions of this product space that have an overlay with the preferences of potential users. The development of new measurement capabilities enters the model by adding points to the scale of a particular dimension through improved accuracy and control of some characteristic. Occasionally, a fundamental advance in measurement opens up a whole new dimension of this space bringing with it a significant expansion of the space for new products.

Frenz and Lambert (2012) found a strong correlation between an industry’s use of measurement (instruments, process control equipment, calibration, testing) and its spending on R&D as a proportion of turnover. Similarly, King (2006) found a strong correlation between an industry’s use of measurement (use of NMS services) and the proportion of revenue from new and novel products. In short, there must be a way of independently validating claims about the potential of a new technology for the market to invest in developing it further. In this way, agreed standards and measurement techniques enable the formation of markets for new technologies by building confidence and encouraging investment.

Measurement supporting high technology start-ups

The NMS helped small high-technology start up Luminanz to accurately demonstrate the reliability of their LED products through specialised temperature measurement techniques. There is a direct relationship between how hot an LED gets and the LED's lifetime. If you can monitor the LED operating temperature, you can predict how it will perform during its lifetime. This information is essential to lighting manufacturers, such as Luminanz, so that their products can meet their customers' needs and expectations.

This confidence helped Luminanz to win a £5 million licensing deal and to accelerate the adoption of solid-state lighting.

3.5.2. Productivity

There are three sub-mechanisms through which measurement has an effect on productivity: early detection of errors through the adoption of best practices; enabling specialisation and division of labour through technical standards and specifications; and exposing domestic incumbents to foreign competition by reducing technical barriers to trade. Each of these sub-mechanisms will now be discussed in detail.

Early detection of errors

Kunzmann (2005) argues that 75% of all errors that occur are pre-determined in the earliest phases of production. However, 80% of these failures are not detected until later, either during the manufacturing process (including inspection) or after sales. Moreover, it is estimated that the cost of eliminating errors increases by around a factor of ten for every further phase of the product life cycle[15]. This gives some indication of the potential benefit to a particular firm that is offered by ensuring the early detection of errors through investing in enhanced measurement.

Allgair (2009) investigates how metrology influences the cost function. Advanced metrology allows tighter production processes with better control of parameters that influence the quality of a final product. Jula (2002) used the same approach to highlight the importance of selecting the right instruments and techniques in the production of semiconductors, and demonstrates how both revenue and cost are sensitive to measurement capabilities.

Standardisation and division of labour

There are a number of fundamental channels by which measurement can enhance productivity through its effect on the structure and organisation of the economy as a whole. Precision measurement has enabled a more distributed system of production in which manufacturers specialise in particular parts that are reliably assembled in the final stage to produce a functioning product. Barber noted that universal standards allow increased outsourcing of components to other specialised firms, which benefit from increased division of labour. That is, accurate measurement allows for a division of labour, in which each component is produced to a set specification and later combined to construct the finished product.

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[15] See section 3.1 of Kunzmann et al. (2005)

It has been long understood that such specialisation enables higher levels of productivity and economic development (see Adam Smith's analysis of making a pin (Smith, 1776)). Moreover, this process of specialisation and division of labour was at the heart of the American system of manufacturing and has proved highly efficient (Swann, 2009). Indeed, the fragmentation of production into ever more complex supply chains is one of the key features of globalisation.

Ford Model T

In 1903 Henry Ford transformed cars from a luxury good to an affordable good. At that time, workers at the Ford factory produced just a few cars per day. Standardisation of parts allowed Ford to reorganise production and cut costs. He introduced an assembly line, where each worker had a specific task, which increased their productivity through specialisation.

Temple (2005) investigated whether there's a causal connection (a cointegrating relationship) between standardisation and labour productivity. The time series analysis performed by Paul Temple and his colleagues found that the long run elasticity of labour productivity with respect to the stock of standards is around 0.054. This means that a 1% increase in the stock of standards could be associated with 0.05% increase in labour productivity. Moreover, their accompanying statistical tests (ADF tests) showed that this elasticity is representative of a long-run equilibrium relationship between the stock of standards and labour productivity.

Since 1945 the UK economy has grown by around 2.5% per year: conventional inputs (labour and capital) together account for 1.5 percentage points, with technological change accounting for 1 percentage point. Based on these results and their elasticity estimate, Temple et al (2005) claim that standards are associated with over 25% of the change in productivity that's occurred after 1948.

However, Paul Temple and his colleagues also emphasise that this result needs to be interpreted cautiously, because, in their belief, standardisation acts in connection with a host of other factors that underpin technological growth. With this in mind it is interesting to note that Choudhary (2013) found that a large percentage of standards make detailed references to measurement and testing procedures:

- One quarter of standards include both a reference to a test procedure and measurement ('narrow' count of measurement standards)
- Two-thirds contain either or both terms (the 'broad' count of measurement standards)

Together, the implication of Temple (2005) and Choudhary (2013) is that a large fraction of long-run productivity growth is underpinned by the nation's measurement infrastructure. Based on these findings, we cautiously suggest that around 6% of long-run productivity growth is associated with the measurement infrastructure.

Exposure to international competition

International trade fosters competition and innovation. In particular, the threat of foreign firms entering the market puts pressure on domestic incumbents. This incentivises an incumbent to introduce new products or develop better the production process to remain competitive[16]. Agreed measurement standards lower barriers to entry as it's no longer necessary to have an existing reputation. In short, open standards enable new entrants to enter the market as the market rules are clear, increasing competition. This reasoning is supported by empirical studies showing that common standards and measurement practices promote international trade[17].

3.5.3. Enabling markets

Virtually every commercial transaction requires an element of trust, but buyers and sellers start with different levels of information about the quality of the goods on offer[18]. If there's a breakdown in trust, then buyers withdraw from the market. Akerlof (1970) offered the first model for what happens when you cannot be sure what you're buying. It describes the market for second hand cars that may have had their odometers tampered with before sale (otherwise known as 'lemons')[19]. Ideally, there would be two distinct markets: one market for low-mileage second hand cars and a separate market for high-mileage second hand cards. However, unless there's a reliable way to measure mileage, then the market for low-mileage second hand cards will collapse, because the buyer cannot ascertain the true mileage of the car. This situation can be avoided if there exists a way to measure the quality of the cars, where standards are brought in or where sellers are accredited. Where sellers are able to demonstrate the value of the products, the premium for higher quality can be sustained. This example was just used to make the point; in reality, the issues are around ways of detecting adulterated foods (e.g. horsemeat in beef pies) or fake cashmere sweaters.

Measurement helping to prevent counterfeits

LGC produced the first of a set of three reference materials (RMs) certified for carbon isotope ratios traceable to the SI unit of mass, the kilogram, through calibration standards of known purity. This RM is easier to replace as the certified value is independent of any particular material and current relative isotope ratio measurements. Isotopic analysis forms a part of the authentication process for confirming the origin of food and drink products with Protected Denomination of Origin (PDO) status. It can also be used to disrupt the enormous global market in counterfeit pharmaceuticals which was estimated in 2012 to be worth close to $200 billion, with over 800 counterfeit product lines in circulation worldwide.

3.5.4. Lower transaction costs

The need for buyers and sellers to verify the nature of the goods they trade has a significant cost. Product verification can represent up to 15-20% of the cost of the finished product – around £30 billion for the UK[20]. Estimates for the proportion of GDP consumed

[16] See the analysis of Aghion et al. (2009)
[17] Swann et al. (1996), Swann (2010), Blind (2001), Blind and Jungmittag (2006)
[18] See Arrow (1972)
[19] G. Akerlof (1970) The market for lemons: quality uncertainty and the market mechanism *The Quarterly Journal of Economics* 84(3)
[20] The source of this figure is National Product Verification Program (NPVP) and it refers to the large aerospace prime.

by verification activities are between 3% and 10% of GDP, although only part of this is devoted to testing. International competitive advantage can be gained from a reduction in these costs based on a system of standards and accreditation.

Accreditation promotes trust in the seller and reduces risk to the buyer. Markets function more effectively when agents are confident in the accuracy and reliability of information. In other words, once you have trust in the system you do not need to keep checking the nature of the goods you trade. This trust is at the heart of a trade in commodities (standard grades) that can be bought and sold very rapidly without any inspection.

It follows that the work of the NMS and UKAS interacts to reduce transaction costs and enable markets to function more efficiently. Ticona and Frota (2008) conducted an empirical study on the uptake of international standards and measurement techniques, which found that the 11% of growth in output from the studied industries (including steel and automotive tyres) was due to certification.

3.6. Rates of return for investment in measurement

A wide range of studies can be used to estimate returns to investing in measurement. In particular, these studies can be used to find the benefit–cost ratio (BCR), which is the quantifiable benefit of a project divided by expenditure (public funding and private costs). The UK studies are based on projects carried out by NPL and the Designated Institutes LGC and NEL, and the US studies are based on projects of programmes run by NIST (the National Institute for Science and Technology).

Main sources	Subject	Period	Number of studies	Typical cost (median)	Typical benefit (median)	Typical BCR (median)
NIST case studies (cost > $5m)**	NIST programmes	1997-2009	4 studies	$25 million	$150 million	6
Lambert and Frenz (2013)	UKAS	2012	1 study	£20 million	£220 million	10
NMS case studies*	NMS projects	2004-2012	9 studies	£0.2 million	£2 million	16
NIST case studies (cost <$5m)**	NIST projects	1998-2010	13 studies	$2.7 million	$58 million	21

Table 4 Benefit–cost ratios (BCRs) of programmes and projects

Let '*' denote quantitative NPL case studies. Details of these can be found on: pages 8 and 25 of Lambert (2010); pages 1 to 10 of Sagentia (2009); Technologia (2010); pages 41 to 44 of Technologia (2013). Let '**' denote NIST case studies. See NIST (2014) for details. Finally, see page 36 of Lambert and Franz (2013) for an assessment of UKAS (UK Accreditation Service).

The case studies divide into two types: projects that cost less than £1 million and US programmes involving a much higher level of spending. Typical estimates for projects and programmes are given in Table 4. The estimates in Table 4 show that project-based studies tend to generate higher BCRs than programme-based studies, but this may be because there's a greater tendency to underestimate the full cost of a specific intervention.

Main source	Subject	Period	Methodology	Cost	Benefit	BCR
Williams (2002)	EU NMS	2000	Calibrated Model	€80 billion	€230 billion	2.7
NPL (2015)	UK NMS	2016-2021	Calibrated Model	£1.0 billion	£3.6 billion	3.6
DATABUILD (2012)	NPL Customers	2011	Customer Survey	£70 million	£320 million	4.5 *
DATABUILD (2015)	NMS Customers	2014	Customer Survey	£100 million *	£540 million	5.4 *

Table 5 Benefit–cost ratios (BCRs) for national measurement systems

Let '*' denote our own calculations. For EU estimates see Table 1 on page 79 of Williams (2002). For the UK NMS see table on page 20 of NPL (2015) and remember that BCR = (NPV + Cost)/Cost. Also, note that although public spending occurs over 5 years, leverage occurs over 10 years, and benefits occur over 60 years. For NPL estimates see Table 1 on page 4 of DATABUILD (2012). Also, note that ONS data shows that GVA accounts for about 50% of turnover in manufacturing sectors. For NMS estimates see DATABUILD (2015). Note that the NMS budget is about £51m pa. NPL's leverage ratio (2:1) can be used to scale up the NMS budget to account for income from services.

A review of this sample of case studies found a wide variation in reported BCRs. This variation may partly reflect a genuine '80:20 rule' for the distribution of benefits, but also indicates changing attitudes about how to circumscribe the benefits and costs. In particular, a handful of the older studies found BCRs in excess of 100, which is well beyond the expected range for innovation-related interventions.

There have also been four attempts to estimate BCRs for a nation's national measurement system. These studies follow one of two methodologies: customer surveys or stylised models with parameter values chosen from the literature.

Both DATABUILD (2012) and DATABUILD (2015) were based on surveys of around 600 NMS customers and users. Firstly, customers were asked to estimate annual revenue from the sales of new products that probably would not have been developed without support from the NMS. Secondly, this additional sales revenue was re-expressed in terms of GVA (Gross Value Added) based on figures from the Office of National Statistics. This was done because GVA offers a better estimate of economic value (wages plus profits) than revenue, which includes the value of pre-existing intermediate inputs. Finally, an estimate of the BCR can be found by dividing this additional GVA by the turnover of the NMIs, which includes public funding and income from services.

	Advantages	Drawbacks
DATABUILD	Based on extensive feedback from customers with significant expertise regarding the application of measurement techniques in their industries.	The approach is not in line with the guidance regarding acceptable methodologies. Furthermore, it does not really account for customers' investment in innovation.
Williams (2002)	It's based on readily accessible data and the model is straightforward to use. Moreover, as an economy-wide study, it accounts for spillover benefits.	Provides a BCR for measurement as a whole rather than the activities of the NMIs. Moreover, it does not test the connection between measurement research and patenting.
NPL (2015)	The flow of future benefits is discounted in line with guidance from HMT's Green Book. Moreover, the model generates reasonable predictions for generic interventions to support for innovation.	The model is better suited to funding agencies rather than infrastructure and facilities. In short, the inflexibility of the model means it cannot be properly tailored to the NMIs.

Table 6 Comparison of BCR studies for the NMS

The second set of estimates come from stylised models with parameter values chosen from journal articles that used econometric techniques to estimate average returns for R&D and spending on innovation activities. Williams (2002) estimates the contribution of measurement spending to technological growth by combining the proportion of patents that are measurement related with an estimate of the proportion of GDP growth that comes from technical change (the part that cannot be explained by increases in labour and capital).[21] NPL (2015) uses a general model developed in BEIS to estimate the effect of NMS programmes over a five-year period. Once again, this model uses results from the literature to estimate leverage, returns and time lags. However, it's clear that none of these studies can be regarded as both fully robust and specific to the activities of the NMIs (see Table 6).

Nonetheless, pooling results from a wide range of studies provides tentative bounds for the likely result of any future evaluation. Table 7 shows the expected range of BCRs for each unit of analysis. This suggests that the BCR for the NMS as a whole could be around 3:1 to 5:1 but that the BCRs for successful projects may be much higher.

[21] Temple and Williams (2002) found that over 10% of patents are fundamentally measurement related

Unit of assessment	Number of studies	BCR
Projects	22 studies	5 to 25
Programmes*	5 studies	4 to 10
Measurement systems	4 studies	3 to 5

Table 7 Range of BCRs for each type of assessment

'*' denotes study of UKAS and large NIST case studies

This table shows that when individual projects are analysed, the estimated returns are often vastly higher than for programmes or institutions. This observation is accompanied by the following caveats:

- the estimated cost of small projects (or interventions) may fail to account for past research that was needed to develop a capability. In contrast, it's easier to monitor the spending on a programme or institution
- the projects chosen for use in case studies might be atypical, with returns that are higher than average. In contrast, there's less scope for selectivity when assessing all the outputs of a fairly long-running programme

3.7. Summary and conclusions

This chapter has explored the rationale for why governments support measurement and the mechanisms by which the benefits of a measurement infrastructure are realised. In summary, governments support measurement due to spillover effects: the level of private R&D spending will always be less than socially optimal. Additional factors include coordination failures, technological uncertainty and avoiding expensive duplication of measurement standards. Key benefits countries gain from a measurement infrastructure include:

- enabling and increasing innovation
- improving productivity
- underpinning of technical standards that enable markets and acceptance of new technologies
- lowering transaction costs and enabling fair markets

Evaluation of the economic benefits consistently shows a clear economic benefit for investing in measurement capabilities and research. The results show a wide range of benefit–cost ratios, with specific projects showing returns between 5:1 and 25:1, up to entire measurement systems with returns of between 3:1 and 5:1. Given the large, infrastructural nature of complete measurement systems it is unsurprising that the returns are not as high as those for more targeted research activities. While the evidence base is strong and consistent there is a need to re-examine the larger scale evaluations of economic benefit using the latest methodologies and independent datasets that form current best practice. Our intention is to continue to build our understanding of the economic and social impact of our investment in measurement and the mechanisms through which this is achieved to inform future policy choices.

4. The impact of public support for innovation on firm level outcomes

4.1. Introduction and summary of key points

A recent study by Frontier Economics analysed the impact of public support for innovation including the NMS. This is the first econometric study to provide clear evidence that NMS services have an impact on firms' survival and growth.

The Frontier Economics study[22] is one of the first attempts to make use of firm level data to assess the connection between participation in an innovation programme (or use of technical services) and future economic performance.

This study focussed on assessing the economic impact of direct support for business innovation delivered through:

- grants from Innovate UK
- paid NMS services from NPL, LGC and NEL

The study assesses the effect on survival and employment up to four years after receipt of these forms of support. It has also been possible to estimate separate effects for grants from Innovate UK and NMS services provided by the UK's measurement institutes.

There is clear evidence that companies who use NMS services have higher survival rates than a control group of non-customers. Moreover, **support from the NMS can boost employment by 10%-15% within 2 to 4 years; with an average cost to the state of £18k to £23k per job.** The results for Innovate UK are very similar but in this case there is also some evidence of turnover increasing four years after being awarded a grant.

4.2. Data sources

Frontier's analysis is based on administrative data over a 5 year period (2008 to 2012) for grants awarded by Innovate UK and income for paid NMS services. The NMS services for which invoicing records were available include:

- knowledge transfer: contract R&D; consultancy; and training
- measurement services: calibration; reference materials; and instrumentation

This administrative data on 'treatment' was matched to Business Structure Database (BSD) which includes basic annual information on most firms in the UK and can be used to monitor survival and employment.

[22] Frontier Economics, 2016. The Impact of Public Support for Innovation on Firm Outcomes, BIS Research Paper Number XX, February 2016.

The primary outcomes of interest were:

- 'survival' as proxied by remaining in the BSD
- employment growth as measured by changes in headcount
- financial success measured by growth in turnover

The BSD provides no information on a firm's previous innovation activities or whether it has used public support in the past. This problem was overcome by linking the BSD to two other datasets, namely, the BERD (Business Enterprise Research and Development) and the Business Support Database (maintained by officials at BEIS).

- appearance in the sample frame used for the BERD survey was used as a proxy for having had R&D activity in the past
- previous appearances in the Business Support Database was used to control for firms' varying propensities to make use of public support

4.3. Rubin causal model

Rubin (1973) established what has become the dominant approach to assessing causal effects in the field of programme evaluation when using observational data (rather than experimental data). Firstly, Rubin adopted the language of 'treated' and 'untreated' units, as found in medical control trials, and extended its domain so as to cover any type of intervention or programme. Secondly, Rubin argued that we should interpret causal statements as comparisons of potential outcomes: the outcome that occurs for a specific unit (e.g. firm) if it is treated versus the outcome that occurs for the same unit if it is not treated. Within this conceptual framework, the causal impact of an intervention is the difference between the observed outcome for a 'treated' unit and the outcome that would have occurred had the same unit been left 'untreated'. As we can't observe what would have happened had this unit been denied support, evaluations are essentially about finding a proxy for this 'counterfactual'.

4.4. Methodology

Frontier's analysis was based on Propensity Score Matching (PSM) and a brief methodology is outlined below:

1. Estimate the likelihood (propensity score) that a firm with a certain set of characteristics will opt into a particular treatment. That is, receive funding from Innovate UK or use NMS services.
2. Match treated firms to similar untreated firms on the basis of these propensity scores; where the matched untreated firms constitute the control group.
3. Differences between outcomes for treated firms and their matched controls are observed up to four years after treatment occurs.
    a. The survival effect t-years after treatment, is found by subtracting the probability (in percentage points) that a treated frim is still active from the probability that its matched controls are still active.

b. Frontier net off any difference in the initial number of employees (pre-treatment) between the treated firms and their matched controls. This yields a difference-in-differences estimate for the impact of treatment on employment. Hence, the counterfactual is baseline employment for treated firms plus the observed growth amongst the matched controls.
c. Frontier net off any difference in the initial turnover between the treated firms and their matched controls. As with employment, this yields a difference-in-differences estimate for the impact of treatment.

4.5. Matched samples

Frontier chose to match treated firms to untreated ones strictly within the same age group, size band, and sector. This makes the results more robust by reducing heterogeneity but also means the loss of all treated firms for which it wasn't possible to find sufficiently similar untreated firms. Indeed, for over 50% of NMS firms, it wasn't possible to find sufficiently similar untreated firms to act as controls.

- for Innovate UK it was possible to find controls for 2,665 out of the 3,703 firms for which data was provided to Frontier that received grants over a five year period [23] Hence, the analysis is assessing around 530 out of the 740 firms awarded grants each year
- for the NMS it was possible to find controls for 966 out of the 2,329 firms that paid for services over a five year period. Hence, the analysis is assessing around 190 of the 470 firms using paid NMS services each year

The tightness of the matching process created a significant difference between the treated firms that feature in the analysis and the full set of treated firms. Firstly, relative to the full set of treated firms, those assessed in this analysis are generally smaller. That is, most large companies in sectors like aerospace and electronics have been 'treated'; which makes is very difficult to find appropriate untreated companies to act as matched controls.

Secondly, as discussed above, appearance in the sample frame for the BERD was used as a proxy for past R&D activity. Based on this, the treated firms that feature in the analysis (with matched controls) appear less likely to have had R&D activity two years before selecting in treatment than is the case for the full sample of treated firms. That is, the firms assessed in this analysis appear to have less history of R&D activity than is true for full set of treated firms.

Finally, in the case of NMS firms, those for which it was possible to find controls are much less likely to have received innovation support in the past than is the case for the full set of treated firms. Indeed, for the full set of NMS firms, the majority (70%) had used innovation support in the past, whereas, only a minority (30%) of those that feature in this analysis had previous experience of innovation support.

[23] The full set of Innovate UK companies is larger than these figures suggest as it wasn't possible to provide details of all the firms the agency works with.

4.6. Assumptions

The validity of Frontier's approach rests on the following assumptions.

Firstly, on average the counterfactual outcome for the treated firms is the same as the observed outcome for the untreated firms once you control for observable pre-treatment differences between the two groups. In short, there are no unobservable elements that effect both the likelihood of being treated and potential outcomes.

Secondly, the general trend in employment - the number of new employees taken on per year - is the same for treated firms and their matched controls; which is known as the 'common trends' assumption and is really a special case of our first assumption. Finally, there is no subset of treated firms for whom opting into treatment was a total certainty. More technically, the distribution of propensity scores for treated and untreated firms fully overlap.

4.7. Main results

Survival Effects: There is compelling evidence of positive survival effects that appear to be the same for Innovate UK and the NMS. Survival effects grow from 5 percentage points one year after treatment to 11 percentage points after three years. Among the matched control firms, the survival rates are around 94% after one year and 84% after three years. Together, these results suggest that nearly all treated firms survive for at least four years. Finally, survival effects are noticeably larger for younger firms (2 to 5 years old) than for older firms.

Employment Effects: Generally, there are positive impacts on employment and these appear higher for grants from Innovate UK than for use of NMS services: by two to four years after treatment, grants from Innovate UK result in 30-40 extra employees, whereas, use of NMS services results in around 20 extra employees.[24] However, these differences reflect the fact that the (matched) NMS firms who feature in the analysis are typically smaller than those that received grants from Innovate UK. For both grants from Innovate UK and use of NMS services, the employment effects equate to an increase in employment of around 10-15% against the corresponding counterfactual outcome.

Turnover Effects: Frontier also investigated whether there are turnover effects on businesses but the results were less consistent and robust than for survival and employment.

- statistically significant turnover effects occur four years after being awarded a grant from Innovate UK. These effects are perhaps of the order of £5m to £10m, equating to a 10-20% increase relative to the counterfactual
- the turnover effects for NMS firms appear positive but aren't statistically significant. However, this isn't surprising given the small number of NMS firms that are observable four years after treatment

[24] Unsurprisingly, when expressed in terms of additional headcount, the effects are much smaller for younger firms.

It should be possible to get more robust estimates of turnover effects for NMS firms using an extended time period. For example, if we were to repeat the study in 2018, then there should be sufficient data to pick up turnover effects that are similar in magnitude to those found for Innovate UK.

4.8. Aggregated impacts

Survival Effects: The scale of the survival effects can be found by multiplying the annual number of (matched) treated firms by the average survival effect. The results suggests that:

- without support from Innovate UK, around 27 of the 530 (matched) firms awarded grants each year would have ceased operations after a year; and around 58 would have ceased operations after three years
- without support from the NMS, around 10 of the 190 (matched) firms treated each year would have ceased trading after a year; and around 21 would have ceased trading after three years

Employment Effects: The scale of the employment effects can be found by multiplying the annual number of (matched) treated firms by the typical effect on employment. The results suggests that:

- funding from Innovate UK generated around 12,000 to 16,000 additional jobs within grant holders covered by this analysis. Since Innovate UK had an annual budget of around £300m pa over this period, this equates to a cost to the Exchequer of around £19k to £25k per job created[25]
- NMS services generate around 3,000 to 4,000 additional jobs among the population of users who feature in this analysis. Since the NMS budget was around £54m pa with an additional £16m pa from grants, this equates to a cost to the Exchequer of around £18k to £23k per job created[26]

The cost per additional job appears low relative to other interventions. For example, the Homes and Communities Agency (2015) found that programmes focused on job creation have an indicative cost per additional job of nearly £30,000. Indeed, the total impact of Innovate UK and the NMS is liable to be even higher given that a significant fraction of treated firms have been dropped from the analysis. Further studies are needed to confirm the complete picture.

[25] A significant part of Innovate UK's budget is for the Catapults which have not been included in Frontier's study. Hence, funding for the Catapults should be subtracted off the total budget.

[26] The matched treated are only about half the full number of treated firms. If the employment effects were the same among the lost firms, then this would mean £7k to £9k per job created but such claims go beyond the evidence.

4.9. Testing of assumptions

Within the dataset used for the analysis there were thirty distinct combinations of age group, size-band, and sector. Separate propensity score models were estimated for each type of firm; where each model involved around thirty control variables, which gives about a thousand opportunities to compare the typical value of a control variable in the treated group with its value for matched untreated firms.

After the matching process had been completed, Frontier performed 'balancing tests' to assess the similarity of treated firms and the matched untreated firms.

- for Innovate UK, there were 595 instances (out of 1,053) where the means of the control variables are significantly different before matching
- for the NMS, there were 562 instances (out of 959) where the means of the control variables are significantly different before matching

After matching, there were two cases (for both Innovate UK and the NMS) where the means of turnover and employment remain significantly different after matching. While Frontier found no examples of significant differences in employment (or turnover) histories, they do find differences at baseline (one year before treatment). This is why they opted for differences-in-differences (DiD) estimation.

If the common trends assumption holds, then we would expect the average pre-treatment trajectory of employment to be the same for a treated group and its control group. In most cases, the change in employment between year t-3 and year t-1 (with treatment in year t) is similar for treated firms and their controls. That is, for the two years prior to treatment, the average number of employees taken on per year was about the same for the treated firms and their matched controls.[27]

4.10. Robustness and a note of caution

Selection is a problem if firms tend to drop out of the BSD as a consequence of unobservable characteristics, such as, managerial ability, that may also effect a firm's growth. Heckman (1979) showed that failing to account for this kind of selection leads to biased estimates in the same way that missing a key control variable biases results if it's correlated with opting into treatment.

The significant impact that Innovate UK and the NMS have on survival is liable to create a selection issue for the impact on employment that has not been accounted for in the current study. Hence, a degree of caution is necessary when interpreting the employment results. Although, the size of any bias would have to be extremely large for there to be no additional employment.

Finally, a further study may be able to put a bound on these survival effects. Within an age group, we know the increased likelihood of survival that comes from treatment. For

[27] The common trends assumption has been examined for all firms except those in the youngest age group where the approach isn't really viable due to data constraints.

example, suppose that the likelihood of survival increases by 10 percentage points for firms of a particular age. We can take all the treated firms in this group and rank them by performance (increased headcount after treatment). We can then remove the top 10% (or bottom 10%) of treated firms and re-compute the employment effect on the remaining firms. In this way, we could put a rough bound on likely survival effect.

5. International comparison

5.1. Introduction and summary of key points

The UK's NMS is highly valued by its large community of customers and stakeholders, as established by recent customer surveys and responses to the public consultation undertaken during the development of the UK measurement strategy. These views are important in assessing the performance of the NMS but, with no national equivalent to compare to, it is difficult to be totally objective. Overcoming this challenge requires assessing the performance against benchmark organisations and measurement infrastructures in developed economies similar to the UK's. Therefore, this chapter provides a summary of work that was undertaken to compare and evaluate the UK's measurement system and its NMI, NPL, against those in key competitor nations. Two independent investigations were undertaken, firstly to assess performance in measurement capabilities and secondly to try to give some picture of the value for money of the government investment in the UK. These investigations did not include the legal metrology aspects of national measurement systems.

Assessment of the UK's performance in measurement was undertaken by reviewing publicly-available data on measurement capabilities held by the BIPM. In broadest terms, this gives a picture of the range and scope of specific measurement capabilities and an assessment of the accuracy that can be achieved by a measurement institute. Generally, the higher the accuracy of a measurement the more advanced is the measurement capability. ***Global analysis of measurement capability and performance clearly demonstrates that on these criteria the UK's National Measurement System is a world leader.***

At the outset of considering the value for money question, it is important to recognise that how any individual country establishes and operates its measurement infrastructure is different. Any measurement system reflects the support required by the sector make-up of a country's economy, differing national priorities for health and environment as well as the organisation of national capabilities for science, innovation and quality among other factors. It is known that developing economies invest heavily in measurement when they start to develop their industry base to deliver higher added-value products to differentiate themselves from competitors purely competing on price. Equally, developed nations tend to focus more on high science and technology applications as well as building an infrastructure that underpins improved national standards in areas of well-being such as health and the quality of the environment. Thus, caution needs to be applied to interpreting the results in the assessment of value for money and more weight applied to the results for economies closest to the UK's. For the analysis of levels of support and value for money presented in this chapter it is important to note that financial and other data was only available for a country's NMI and not its whole measurement infrastructure. Hence, the comparisons are made between NMIs only.

Investment in measurement can add value to a country's economy in a variety of ways. Robust measurement standards enable businesses to trade and compete more effectively both nationally and internationally. Measurement is also known to be a key enabler of innovation, driving the development of new technology and opening markets. Measurement can be described as an infratechnology: a technology that provides techniques that can be applied to enable further innovation. Foresight Studies show that at least 10% of innovations are driven by advances in measurement[28].

UK government policy over the period of the NMS Strategy 2011–2015 has been to sustain and extend the measurement capabilities of the UK by spreading the cost of our measurement infrastructure from government to end-users and other sources. Without this additional support, the UK's measurement infrastructure would be significantly less competitive internationally and deliver less impact in the UK. The goal of broadening the support base has been successful as ***NPL has achieved one of the highest levels of leveraged income by comparison to the most equivalent competitor NMIs.***

The following sections give more detail on the approach used and the results obtained from the work undertaken on international comparisons.

5.2. NMS core capabilities and quality

In 2014, a benchmarking exercise of the quality and coverage of measurement uncertainty capabilities was carried out by NPL[29], in which Calibration and Measurement Capability (CMC) data from a number of countries (limited to ten with a reasonable coverage across the measurement areas for practical reasons) was analysed to assess the relative strengths of national measurement capabilities beyond simple counting of CMC entries by country. Entries within the database were analysed as from a country rather than institute, meaning that scores for capabilities originating from Designated Institutes, where they exist, are included.

The data were plotted as a three-dimensional set, including the following information:

- the x-axis indicates the number of services offered in a particular country expressed as a fraction relative to the total number of services assessed in the exercise. Thus a score of 100% indicates that all the services that were included in the assessment are offered by the NMI (and Designated Institutes, where applicable)
- the y-axis indicates the judgement of performance ranking, with a score of zero representing no measurements offered and 100% representing the best measurement uncertainty in the class. It is calculated as a mean value of the individual scores, including only non-zero values
- the size of the symbols is used to illustrate the depth of coverage of measurement capability, e.g. the range over which measurements can be made for each physical or other quantity

[28] Nesta (2012) Infra-Technologies: The Building Blocks of Innovation Based Industrial Competitiveness, July. Available at: http://www.nesta.org.uk/sites/default/files/infratechnologies.pdf
[29] J. Williams et al. (2014) International Benchmarking of UK Calibration and Measurement Capabilities (CMCs), NPL Report MP (RES) 028

The data from all the metrology areas were combined into one dataset and plotted as described above. The results for the five highest-scoring countries are shown in Figure 5. The overall trend shows a positive correlation between uncertainty and coverage, indicating that institutions that cover the most capability also do so with the lowest uncertainties (highest quality of measurement). At the global level, across all the metrology areas, there is not much difference in the coverage range of the CMCs, with all the plotted symbols approximately the same size.

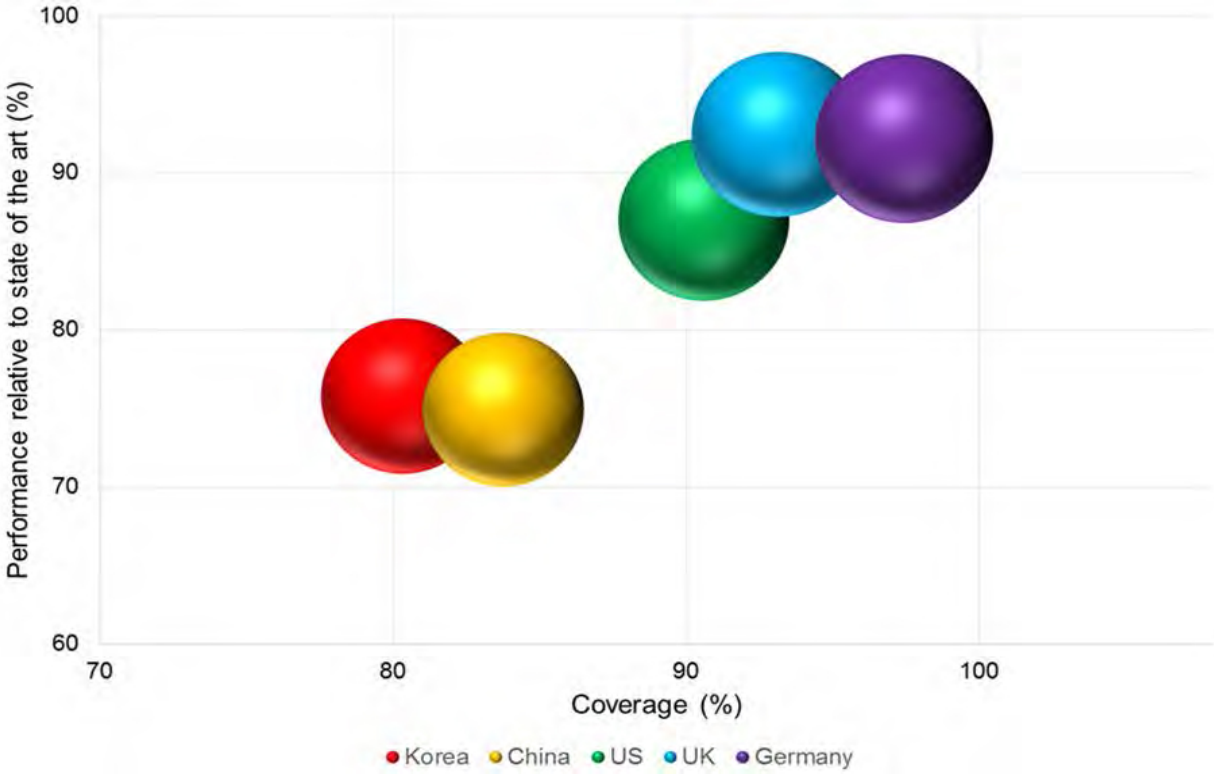

Figure 5 Measurement performance relative to state-of-the-art and coverage scores for the key CMCs at the top five countries

In ranking the average coverage range, coverage depth and uncertainty score, we find that Germany scores highest in the coverage scores, and second for the uncertainty, with the reverse being true for the UK. The US is ranked third across all three parameters.

5.3. Funding of national measurement systems

In order to make a meaningful comparison of funding for national measurement systems, data for NMIs worldwide were used as a proxy, since this data was readily available compared to the difficulty in getting reliable data for complete national measurement systems. Funding information was obtained from a variety of sources. Where possible, information was gathered from publicly-available sources, such as published annual reports and/or data presented on an NMI's website. Secondly, some financial and operational information was collected through private communications with NMIs, and these data are included in the results where permission has been granted to share this information. Using these sources, enough data for analysis were gathered for a total of twelve NMIs shown in Table 8.

5.3.1. NMI characteristics

Inferring meaning from a comparison of the different properties of NMIs is problematic. The data comprise figures from the different countries, for which we must account for the different characteristics of each entity, for example in terms of the quality of the institutions, relative sizes of the economy and relevant sectors, the structure and regulation of the markets it supports etc. All of these characteristics vary across countries and if this problem is not addressed correctly, the results of any analysis carried out will be biased. In general, these variables are difficult to observe and quantify. It is also important to recognise that national measurement capabilities are not just maintained by NMIs. In most countries there are one of more Designated Institutes which also hold and develop national measurement capabilities. The split of measurement capabilities between an NMI and one or more Designated Institutes varies by country, which further complicates the picture although the bulk of measurement capability will be the responsibility of the NMI. For this analysis, only the budget for each country's NMI could be obtained and so it excludes support for measurement at Designated Institutes.

The NMIs studied are on the whole, publicly owned and operated institutions, with the notable exceptions of DFM and VSL (Denmark and the Netherlands, respectively). The metrological functions are either provided solely by the NMI in a country, or by the NMI along with a number of Designated Measurement Institutes, as described in column three of Table 8 below.

As a first approximation in evaluating CMC activity, a simple quantification of the areas of measurement standards supported within each country, as indicated by the presence of a registered calibration and measurement capability within the 36 areas designated within the BIPM Key Comparison Database[30] demonstrates the breadth of national measurement capabilities supported.

The NMIs also vary in their science operations, from those who perform R&D purely to maintain measurement standards, to others who undertake more applied research, which in some cases is demonstrated by existing centres of excellence or joint ventures with other organisations.

Finally, the designation of legal metrology responsibilities is, on the whole, the same for all the countries studied, where the NMI (or NMI plus Designated Institutes) is responsible for developing and maintaining measurement standards, but confirmation and verification activities fall to other accredited bodies. The exception to this rule is BEV in Austria, which not only contains a division responsible for performing such metrological compliance activities, but also performs land surveying activities.

We can make a reasonable comparison for the UK against the following NMIs: NIM, KRISS, PTB, INRIM, VSL, SMU, CENAM and NIST. BEV has a different operational remit and DFM performs only a small amount of metrology functions as part of the university sector. The data for these NMIs have, however, been included in the plots below for commentary as appropriate.

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[30] http://kcdb.bipm.org/appendixC/ Accessed December 2015

NMI	Owner	Measurement infrastructure[31]	# CMC areas supported (/36)[32]	Activities beyond measurement standards
NIM (China)	Government	1 NMI with 1 DI	32 (89%)	Various applied science divisions
KRISS (Korea)	Government	Sole NMI	27 (75%)	Various applied science divisions
BEV (Austria)	Government	1 NMI with 2 DIs	19 (53%)	Yes, land surveying
PTB (Germany)	Government	1 NMI with 3 DIs	35 (97%)	QUEST Institute & various applied science divisions
DFM (Denmark)	Government through a university	1 NMI with 6 DIs	13 (36%)	No
NPL (UK)	Government	1 NMI with 5 DIs	27 (75%)	Variety of joint ventures and applied science divisions
INRIM (Italy)	Government	1 NMI with 1 DI	26 (72%)	Applied research in various areas
VSL (Netherlands)	Private	Sole NMI	18 (50%)	No
SMU (Slovakia)	Government	Sole NMI	19 (53%)	No
CENAM (Mexico)	Government	1 NMI and 2 DIs	29 (81%)	No
NIST (USA)	Government	Sole NMI	31 (86%)	Various applied science divisions

Table 8 Summary of key structural and organisational parameters for the NMIs studied

[31] Proxied through signatory list for BIPM MRA. Available at: http://www.bipm.org/en/cipm-mra/participation/signatories.html Accessed December 2015
[32] Number of CMCs by metrology area and country. Available at: http://kcdb.bipm.org/kcdb_statistics.asp Accessed December 2015

5.4. Comparison of leverage

Yearly revenue data for the NMIs were collated in local currency. The purchasing power parity method is a commonly used technique to compare the relative values of currency within different countries. Purchasing power parity compares the exchange rate of currencies based on their capacity to buy a particular basket of goods. Fluctuation in local currency values are not so visible within units of purchasing power parity so long as the economic problem being assessed considers mainly locally-traded goods (take for example the Economist's Big Mac Index[33]). However the funding and purchasing characteristics of NMIs are far more international in nature, with government spending supplemented by international research grants, and non-domestic customers paying for services. Similarly, the procurement of equipment in order to deliver the research capabilities is quite often international in nature. In light of these characteristics, the market exchange rates were chosen to make comparisons between funding levels. The currency values presented in the figures below were therefore calculated on the inflation-adjusted exchange rates using GDP deflator values.

The values of government annual funding levels for the NMIs investigated show that NIST and PTB have the largest federal funding levels. NIST, PTB and KRISS also show the largest rates of increase in support compared to the other NMIs. However, the UK's NMI has been one of the most successful in growing other sources of funding, leveraging its core capabilities to secure additional commercial and non-commercial income. Figure 6 shows a comparison of leveraged income achieved across the NMI group. Leveraged income is defined here as the ratio of non-government funding to government funding. NPL, having shown the largest rate of increase in this parameter over the reported time period is already around the top level achieved by the NMIs in 2014/2015.

Given the differences in the timespan of the available data between countries, an average value for each indicator was calculated across the range of 2004–2015, depicted as a point on Figure 6. A linear regression was performed on the same data, and where a result was found with a p-value of 10% or less, an arrow indicating the start and end of the fitted line (not the minimum and maximum of the actual data, which can be inherently noisy and therefore misleading to plot) is shown going through the data point to indicate the trend for the variable over time.

[33] http://bigmacindex.org/ Accessed December 2015

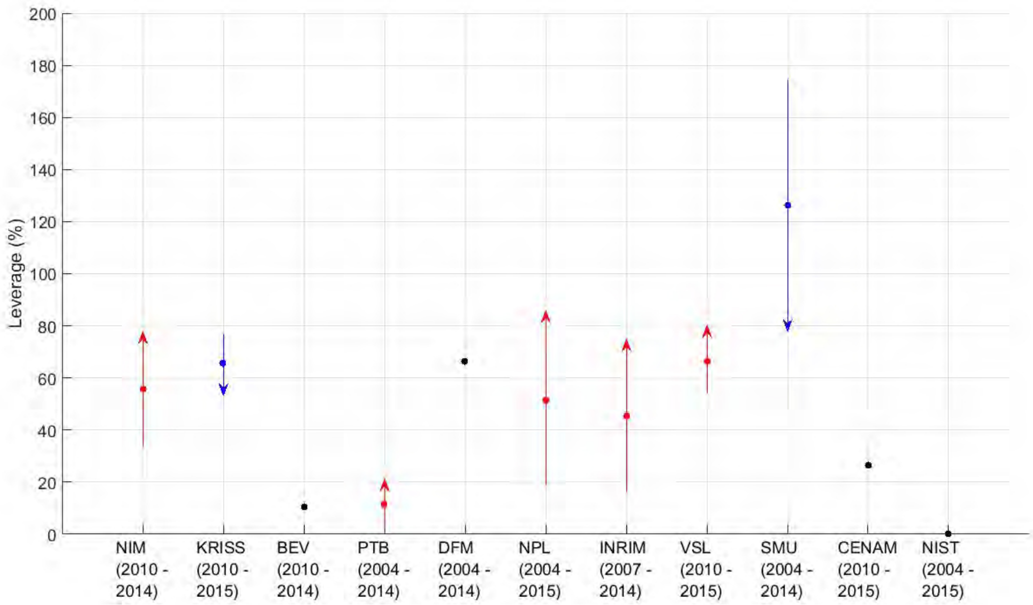

Figure 6 Leveraged income figures

5.5. Discussion

The UK has been successful in maintaining its standing as a global leader in measurement as shown in Section 5.2, through a rapid increase in leveraged funds from commercial and other sources. Thus, the evidence points to a substantial increase in efficiency and effectiveness of NPL, as the UK's NMI, over the ten years of this study. The significant differences in the levels of core government support also demonstrate that by comparison to other countries the UK gets good value for money from its investment in its NMI.

6. Survey of users

6.1. Introduction and summary of key points

Customer survey data can give an insight into how businesses use the NMS and the benefits that they accrue. This section gathers intelligence from the market and focuses on the collective experience and beliefs of current customers. According to a survey of a sample of 1000 customers and non-customers of the NMS, scaled for the total population of customers:

1. Firms receiving support from the NMS are **significantly more innovative** than a control group of highly similar non-customers. More specifically, users were found to be more than twice as likely to introduce a new product or process. Furthermore, users of the NMIs are more likely to introduce products and process that are new to their market, as opposed to just new to the company, than innovators in the control group.
2. Over 1400 users of the NMS believe that the support they received helped them make their **innovation more quickly, more effectively or reduced the risk**.
3. Users were asked about recent products that either could not have been developed without the direct help of the NMS or that required skills and capabilities that would have been very difficult to find elsewhere. **Users of the NMS believe that without the support of the NMS their total annual sales of new products would decrease by at least £469 million. Furthermore, they believe that about £2 billion worth of new products might be at risk without this support**;
4. **Over three quarters of measurement system customers use measurement throughout the production process**: during design to check goods from suppliers meet specifications, during the production process to maintain efficiency, and before despatch to ensure products meet quality standards.
5. Areas for improvement that were identified included:
    a. Engagement with small to medium sized companies is limited compared to large companies – there is scope to improve engagement mechanisms tailored to SMEs.
    b. 21% of companies thought that the products and services were at “too high a level” for their businesses, potentially indicating a need to more effectively tailor products and services to a wider range of organisations.
    c. For the 5% of customers that were less satisfied with NMS products and services two key themes for improvement emerged: Reducing prices and improving the speed of service delivery.

6.2. Methodology

A Customer and Impact Survey for all NMS programmes and activities was commissioned in 2014. The objective was to gather both qualitative data on how and why users engage with the NMS and to assess the tangible benefit they accrue in doing so.

The study was conducted through:

- 606 quantitative telephone interviews with organisations on the user databases of NPL, LGC and NEL but not including NIBSC, BEIS Regulatory Delivery Directorate, or NGML customers
- 400 quantitative telephone interviews with businesses not known to be customers of the products and services delivered by NPL, LGC and NEL that shared the same demographic profile (in terms of industry sector and business size) as organisations on the customer databases. As 'non-customers', they are used as a comparison group for NMI customers throughout the report

One contact per site (also known as an enterprise) was interviewed to prevent duplication of information. The data have been weighted to reflect the populations from which they were drawn: 6,366 organisations on the databases provided by NPL, LGC and NEL.

The section below highlights key findings from the survey.

6.3. Innovation activity

Significantly more NMS customers (80%; n=386, N=3,275) made changes to their organisation in 2012 or 2013[34] compared with non-customers (47%; n=245, N=276,021). These innovations included introducing new or developing existing products and procedures, improving measuring capability, or changing calibration. Although some innovations were specifically cited by customers, many customers were keen to point out that they were constantly innovating.

Proportionally more NMS customers reported undertaking more innovative activities that were new to the market rather than to the firm compared with non-customers. An indication they are not only innovating more frequently than non-customers, but also being more innovative in their behaviour.

NMS customers place significant value on the support offered by the NMS. Approximately 75% of NMS customers who had made a change to their business in 2012 or 2013 either agreed or strongly agreed that the support from NPL, LGC or NEL enabled them to make improvements more effectively, more quickly and/or also reduced the risk associated with developments, see Figure 7.

[34] Any changes made throughout the calendar years, 2012 and 2013

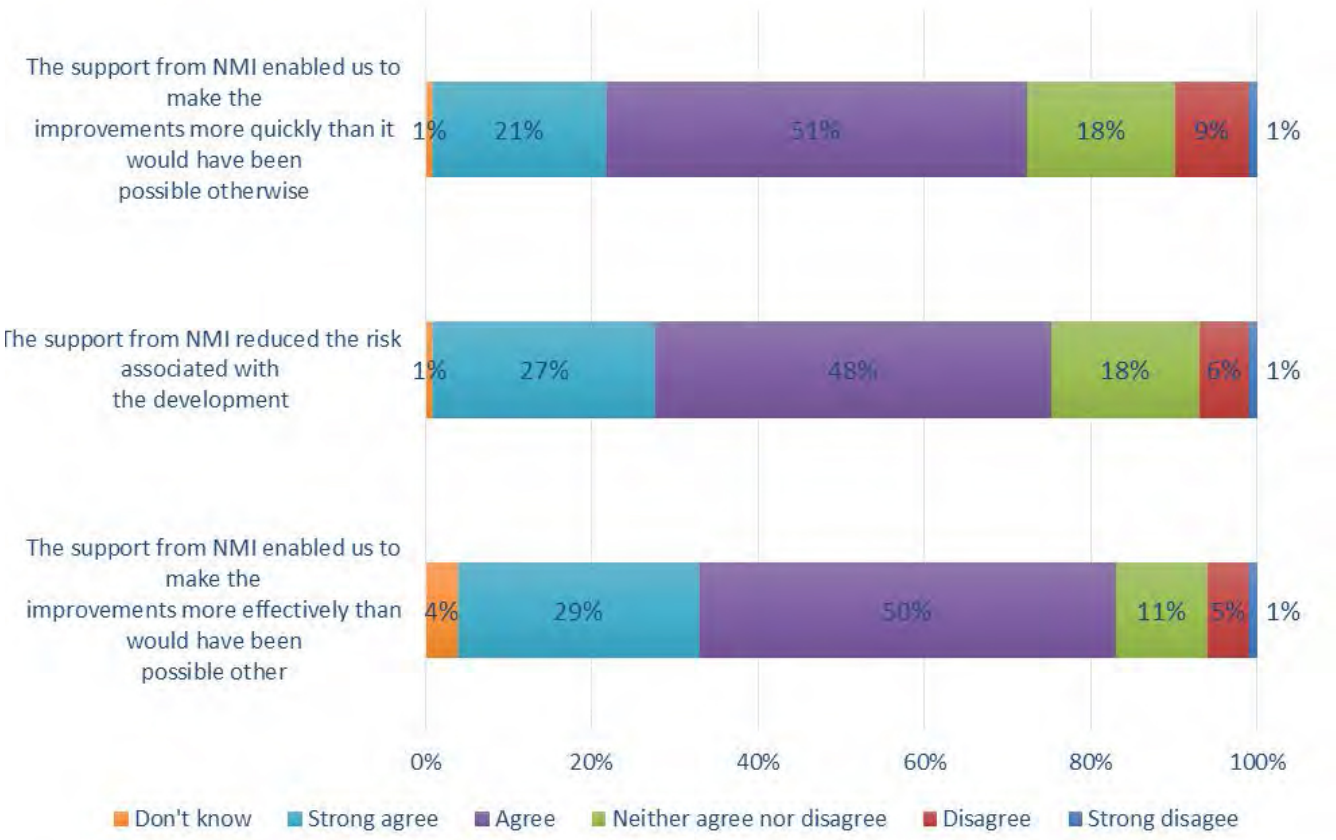

Figure 7 Customer feedback on the support they received from the NMI with regard to changes made in 2012 or 2013 [n=217, N=1,527]

6.4. Economic impact of the NMS through innovation

All customers were asked whether the NMS had supported innovations that they had made in 2012/13. They were also asked about the annual sales and profits impact of those innovations. Impacts were only attributed to the NMS if the respondents indicated that the change would not have been possible without the support of the NMS and that getting the support from elsewhere would have been either impossible or hard. In these cases, it was assumed that the impact of the support was so crucial that no change would have been possible in its absence.

Additional sales associated with products that were made possible due to changes attributed to the NMS amount to an estimated £1.3 billion. There is however uncertainty surrounding this estimate; the most conservative estimate of the sales impact of the NMS is £469 million, with an upper estimate of £2.27 billion.

Based on findings from the Annual Business Survey of 2012[35], it is possible to estimate the value added to the economy (GVA) associated with the additional sales identified through the survey. We estimate the value added to the economy to be £536 million, with a range of between £198 million and £873 million.

[35] www.ons.gov.uk/ons/rel/abs/annual-business-survey/2012-revised-results/index.html

There is significant uncertainty surrounding the amount of profit generated due to changes attributed to the NMS, however our estimate for this figure is £171 million.

		95% confidence interval[36]	
Attributed	**Total (£ m)**	**Lower bound (£ m)**	**Upper bound (£ m)**
Sales (n[37]=132, N[38]=1,007)	1,370	*469*	*2,270*
GVA (n=132, N=1,007)	536	*198*	*873*
Profits (n=64, N=991)	171	*-146*	*488*
Costs (n=46, N=652)	2.5	*0.5*	*4.5*

Table 9 Impact of the NMS attributed by users

The bounds on this data are wide in part due to the non-normal distribution of the impact data i.e. 20% of the customers get 80% of the benefit. This is to be expected for research impact.

6.5. Satisfaction with NMS services

In general, customers were very satisfied with the products and services they received from the NMS and the delivery institutes. They highly rate the professionalism of the delivery institutes, their knowledge and skills, expertise and reliability. From the small number of customers less satisfied (under one in 10 customers), two key themes for improvement emerge when asked about improvement opportunities: the speed of turnaround of product/services and the cost. 20% of customers think they will increase their use of NMS products and services in the future. As you would expect, these customers have a higher satisfaction rating than those customers unlikely to re-use NMS products or services in the future.

[36] This is the range of values into which the same estimate would fall 95 times, had the same research been replicated 100 times. It is a statistical metric that illustrates the degree of uncertainty of an estimate and largely depends on the size of the sample base of the estimate and the variation of the responses.
[37] This is the number of observations on which the estimate is based – the sample base of the estimate.
[38] This is the estimated number of customers that the sample base represents.

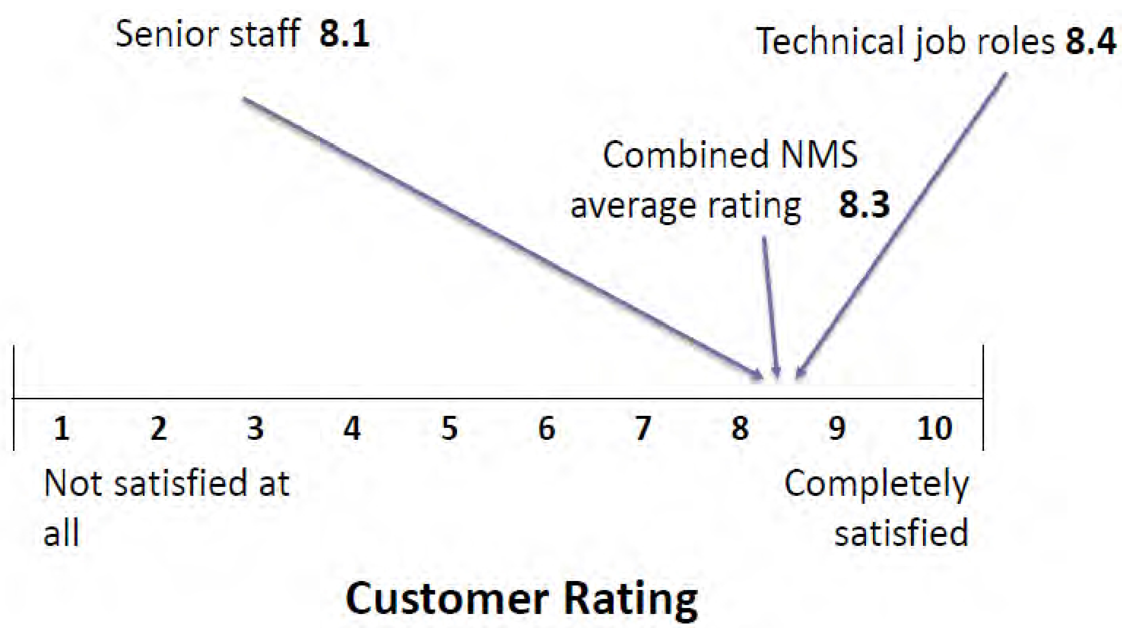

Figure 8 Customer satisfaction based on a rating of 1-10, 1 being not satisfied at all, 10 being completely satisfied

6.6. Awareness and use of NMS products and services

As might be expected, organisations on databases provided by the delivery institutes had a high level of awareness of most products and services offered by the NMS. Almost 90% were aware that the NMS offers calibration services, with around two thirds aware of the training courses, consultancy and advice at events offered. Unsurprisingly given the small amount of IP the NMS is responsible for, and the small number of companies engaged in exploiting it, licensed IP was the service with lowest awareness amongst organisations on the databases provided by the delivery institutes.

When asked if they had specifically used an NPL, LGC or NEL product, a third of respondents on the databases provided by the NMIs (n=134; N=2,281) said they had not used any of the products or services offered by the NMS. For almost half of these, this was because they had no requirement or demand for the product or service. When NMS customers are discussed in this report, these organisations have been excluded. Where NMS customers have used NMS products and services (with the exception of calibration, which some customers use as a one-off service) they were using multiple products and services for different needs.

Approximately a quarter of respondents to the non-customer survey were also aware of NMS products and services.

6.7. Profile of NMS customers

The majority of customers of the NMS were measurement users (60%; n=279, N=2,457) as opposed to providers of instrumentation and measurement services (40%; n=193, N=1,628), with the majority of measurement-using customers being manufacturing organisations.

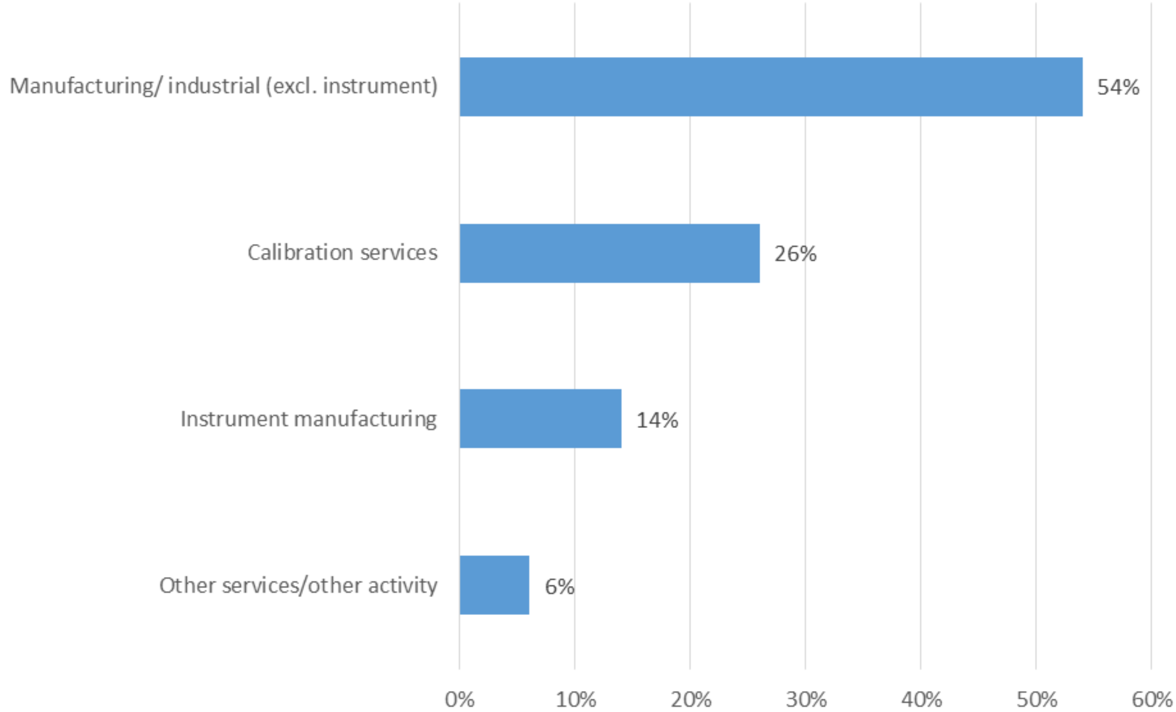

Figure 9 Analysis of NMS customer sector [n=472; N=4,085]

The NMS has a customer base from a range of organisation sizes: approximately one third are large, with one third small and one third medium-sized. Large NMS customers were more likely to be R&D intensive compared to small- and medium-sized companies. When compared to the market, the NMS has best market penetration among large-sized organisations.

Those responsible for measurement within the organisation and with most knowledge about their organisation's use of the NMS tended to perform some technical role within their organisation, either as a technician/analyst, scientist/engineer, or have a senior/supervisory role within the measurement process.

7. Case studies

7.1. Introduction and summary of key points

Case studies enrich our understanding of the way in which the benefits of measurement research and services accrue, the mechanisms by which impact occurs, and help in attempting to model the scale of the impact particularly through cost benefit analysis (see section 3.6). Analysis across a portfolio of case studies can also give insight into the breadth of impact and its intensity under certain themes.

Analysis of NMS case studies shows an **impact across a wide number of sectors** with, unsurprisingly, instrumentation being a strong area of impact as a key route to market for measurement technology. The strongest Great Technology themes from the case studies reviewed were **satellites, quantum technologies and advanced materials**. In terms of the outcomes supported by the measurement research or services of the NMS, **new and improved products**, **reduced risk and improved health** through better diagnosis and treatment were strong themes.

7.2. Background

Analysis of both case studies and case study meta-data can give an insight into the scope and mechanism of impact. However, the case studies analysed here represent a small proportion of the impacts and are unlikely to be fully representative of all impacts and their distribution. Indeed, many of the companies who are benefiting from the NMS either do not disclose the benefits that they accrue or are unaware of the fact that they are impacted as the mechanism of impact is indirect. Analysis of the text within approximately 240 case studies from NPL, LGC and NEL has been used to illustrate and give insight into the profile of benefits and their area of impact.

It should be noted that intuitively certain types of impacts are perhaps more amenable to case study treatment. For example, innovation benefits where the impact is a new or improved product or process are more likely to feature in a case study than impacts which are more diffuse such as impact on trade through standards.

7.3. Sectors

From the data in Figure 10, it is not possible to say that measurement has a greater frequency of impact on, say, oil and gas than environment, as the sample may not be representative of all impacts. However, it is clear that the NMS is impacting on a broad range of sectors, with manufacturing, instrumentation and the medical sectors being beneficiaries in more than 50 case studies.

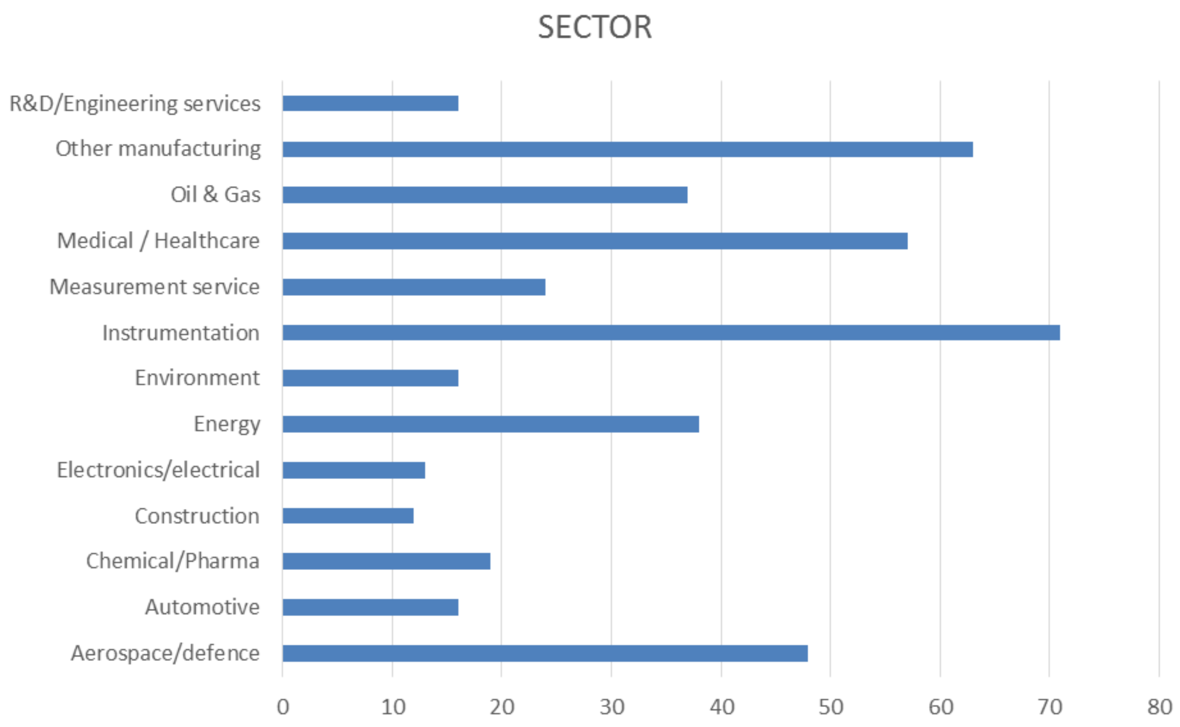

Figure 10 Sector distribution of case studies including both primary sector of influence and secondary sector

In many cases, measurement services or instrumentation companies received the primary impacts with impact cascading to other specific sectors through the sale of products and services.

7.4. Technologies

The government has decided to back eight (plus two) Great Technologies on their journey from the lab to the marketplace. These are big data, satellites, robotics, synthetic biology, regenerative medicine, agricultural technologies, advanced materials, energy storage, quantum technologies and the Internet of Things.

The case studies reflect impact in a number of the Great Technology priorities with ‘advanced materials’ and ‘nano-technology’, ‘satellites’ and ‘quantum technologies’ being the subject of a significant number of case studies (see Figure 11). Some are not represented at all: ‘agritech’, ‘synthetic biology’ and the ‘Internet of Things’. This probably reflects the fact that case studies are retrospective, looking at the impact of completed research rather than presenting a picture of current research activity and future impact.

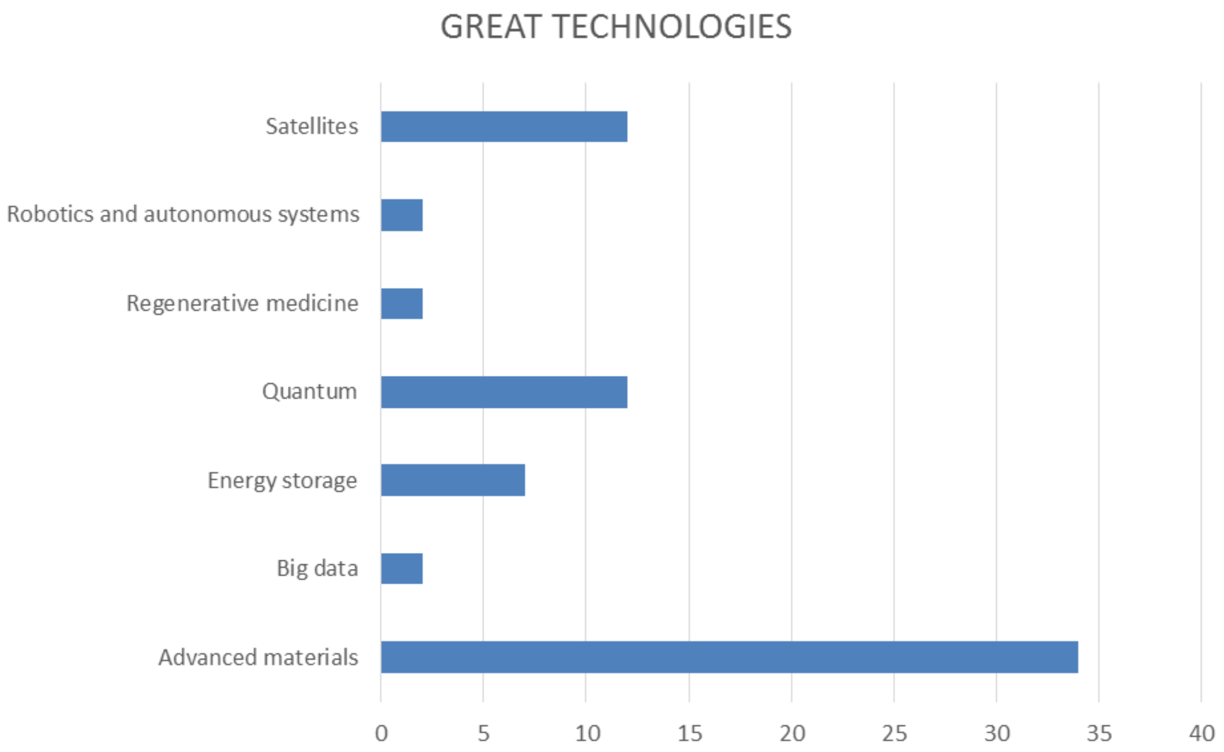

Figure 11 Great Technology distribution of case studies

7.5. Route to impact

In terms of the type of benefits received by commercial users, the most frequent benefits are new or improved products, improved health and reduced risk (see Figure 12). However, in the public sector, benefits also accrue around public policy/regulation and improved health of citizens.

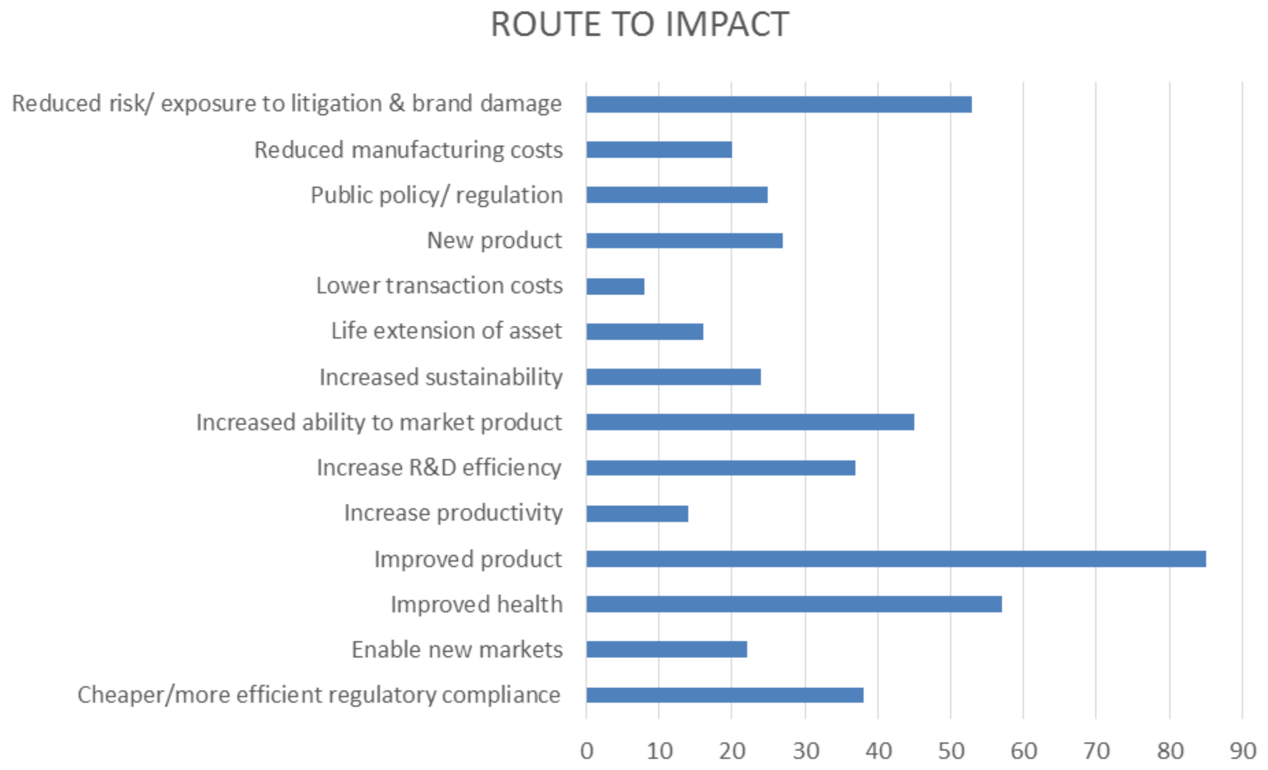

Figure 12 Benefit type distribution of case studies

8. Consultation response

8.1. Introduction and summary of key points

Overall, 450 end-users and stakeholders of the NMS were consulted as part of the strategy development. The consultation consisted of both an online consultation and over 100 structured interviews. Some stakeholders represented the views of members or groups of organisations. These resulted in significant endorsement of the approach to the strategy, rich information on sector and technology priorities, views on how to balance the portfolio of work within a restricted budget and specific opportunities for collaboration. The comments and feedback have been taken into account when developing the UK measurement strategy and they will also shape the more detailed delivery plan.

Key messages collected across both the online and structured interview process include:

- new technologies have **increased complexity** and have an increasing need for measurement
- there is an opportunity for stronger leadership and the development of **a more joined-up system**
- big data and the Internet of Things require a **better understanding of data quality and uncertainty**
- the **instrumentation and equipment sector** are key to and strongly interlocked with the NMS
- how the measurement system works and its importance needs to be **more effectively communicated and access needs to be improved**
- There is considerable **unease around devolving traceability** and safeguards would need to be in place to manage risks and ensure UK expertise is maintained if any measure were to be devolved
- **access to world-class facilities, equipment, and experts is critical**
- **more hands-on training and practical experience** is required for apprentices, technicians and engineers
- the **importance of measurement in raising productivity and enabling Industry 4.0** was identified
- a stronger case needs to be made for regulation and trading standards to **ensure consumer protection**
- **key areas for investment include manufacturing, big data and life sciences**

8.2. Online survey

8.2.1. Background to respondents

A total of 330 online responses to the consultation were received over a period of eight weeks. The respondents consisted of a mix of both private and public organisations in industry, academia and government. The majority of respondents finished the questionnaire with many responses to both the open-ended and closed questions.

Sector	Response percent
Mining, extraction and utilities	1.2%
Food and drink	2.8%
Materials	2.5%
Chemicals and pharmaceuticals	4.9%
Metals	0.6%
Electronic and optical equipment	5.8%
Medical equipment manufacture	1.8%
Instrument manufacture	11.1%
Transport equipment and aerospace	4.6%
Manufacturing not elsewhere covered	4.9%
R&D services	11.1%
Testing labs	4.3%
Calibration labs	7.1%
Engineering services	3.1%
Computing and software development	3.1%
Health	1.5%
University	7.1%
Local government and regulation	10.5%
Nuclear	1.2%
Other	31.1%

Table 10 Sector breakdown of respondents

The breakdown by sector reflects the underlying user base of measurement in the UK consisting of both the public sector and the private sector with a predominance of advanced manufacturing and engineering companies.

The range of roles responding to the questionnaire was fairly evenly distributed across director, manager and technical roles, all of which offer valuable insight into the strategy.

With regard to their familiarity with the NMS, around half collaborate with the national measurement infrastructure with less than one fifth of respondents having no involvement.

Answer options	Response percent
Planned programme of collaboration	24.1%
Occasional collaborations	45.1%
Use commercial services	31.5%
Use information from the National Measurement Institute	26.2%
No involvement	19.4%

Table 11 Engagement of respondents

8.2.2. Key technology trends

The following key technology trends were identified by a number of respondents to the online consultation:

- **industry 4.0** where the Internet of Things is applied to deliver the strong customization of products under the conditions of highly-flexible mass production
- **new manufacturing technologies** including rapid prototyping, additive and subtractive manufacturing
- **automation and integration** of measurement systems with references to modular, wireless, miniaturised and ruggedised systems
- the need for **real-time**, in-process measurement data
- challenges of **big data** including data analytics, simulation and software development
- improved **measurement technology** including cheaper, better, faster sensor systems
- development of **weighing** equipment
- support for the development of **energy storage** technologies
- **security,** including cyber-security and quantum-based technologies
- improvement in **oil and gas** measurement technology during production and at the forecourt, and the development of the infrastructure for and quality control of renewables
- improved measurement for **healthcare** including improved diagnostics and production of pharmaceuticals
- use and fabrication of **advanced materials** including nanomaterials and graphene
- **emissions** measurement, particularly air quality

65% of respondents believed that measurement is essential to developing the key technology trends within their sectors. Only 1% of respondents believed that measurement has no role in supporting their key technologies.

Respondents were also asked to prioritise which of the eight (plus two) Great Technologies would most benefit from measurement activity to overcome technical challenges and accelerate commercialisation. The results show a fair level of support for the potential impact of measurement within all the technology challenges (see Figure 13 below).

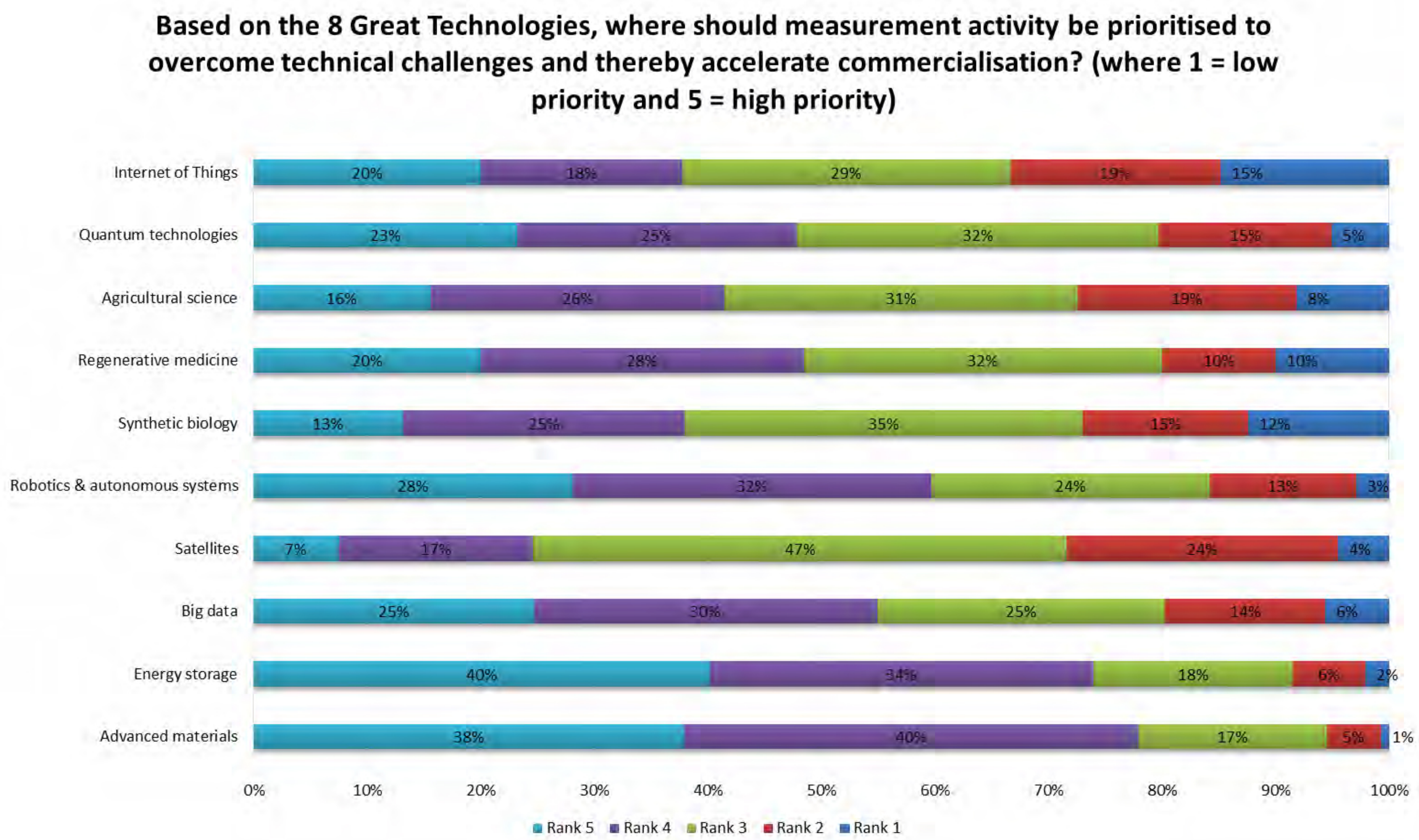

Figure 13 Based on the eight (plus two) Great Technologies, where should measurement activity be prioritised to overcome technical challenges and thereby accelerate commercialisation? (where 1 = low priority and 5 = high priority)

8.2.3. Measurement investment for productivity

Productivity is one of the biggest challenges facing the UK. High productivity is closely associated with greater economic competitiveness and higher standards of living[39].

Respondents believed that measurement related to manufacturing and process control should be a priority for improving productivity. Specifically, support was articulated for the development of automated, in-line, in-situ measurements with the potential to be integrated within a Industry 4.0 environment. It was noted that productivity would be enhanced by remote distributed sensors and actuators generating data that can be used in real-time. Access to investment and the capacity and skills to implement measurement technology were seen as a requirement for businesses to successfully increase productivity through the adoption of measurement technology.

It was also noted by many that measurement, for example diagnosis and treatment of poor health and control of harmful emissions, ultimately increases productivity through reduced hours lost through ill health and reduced resources committed to dealing with the health issues that result.

8.2.4. Best practice and standards

In the consultation, companies were asked to rank their level of adoption of measurement best practice.

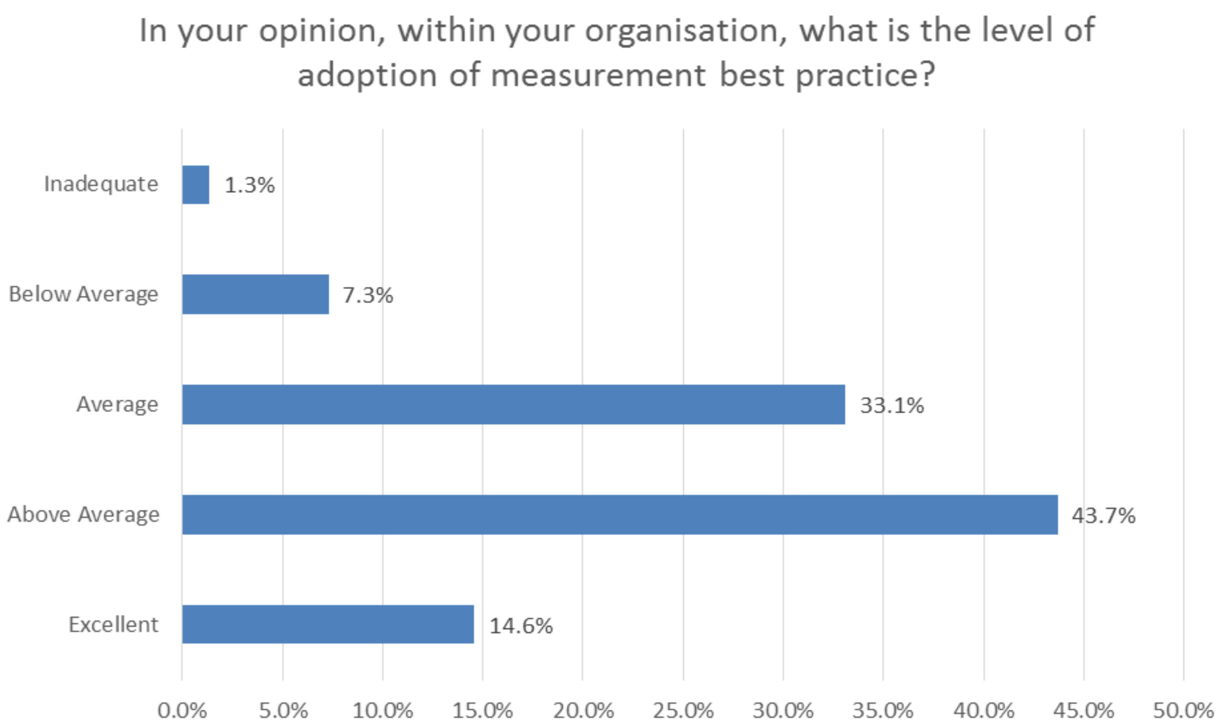

Figure 14 Adoption of best practice

[39] HM Treasury, Fixing the foundations: Creating a more prosperous nation (July 2015)

Perhaps unsurprisingly for contacts of the NMS, the majority of companies rank their knowledge of best practice as average or better.

The areas which were identified for further training covered many specific measurements, but also included many subjects in common such as:

- measurement for manufacturing and production including product verification, particularly focussing on early-stage career development such as apprenticeships and technicians
- PhD and undergraduate training was perceived to be weak with regard to measurement, especially within engineering departments and for biology courses particularly around interfacial disciplines and advanced genomics
- uncertainty calculation is still seen as a continuing need
- designers were identified as a group who would benefit from a greater understanding of measurement, particularly from a manufacturing/tolerance stand point
- management appreciation of the importance of measurement good practice was also identified as important
- several respondents identified specific training for Trading Standards Officers – these were largely respondents from the trading standards community itself

Respondents were also asked about their preferred methods of receiving training. It is clear that there is little agreement on the preferred method, with support for all modes of learning.

Figure 15 Preferred forms of training

Respondents were asked which regulations or 'red tape' could be eliminated by the introduction of measurement best practice and standards. A number of respondents believed that much of the regulation in the area of measurement was necessary and in fact needed to be strengthened, acting to drive up consumer protection and fair trade.

Specifically, a number of respondents mentioned areas where standards could be improved, including standards for Industry 4.0 where interfaces between measurement equipment and production are an issue. Related topics, including laboratory informatics, robotics and automation, were also identified as areas where further progress was needed. Standardisation requirements around big data were also identified, particularly validation and the incorporation of uncertainty. The Measurement Instruments Directive was also mentioned by several respondents, particularly the harmonisation of the laws of member states. Non-contact measurement techniques were also identified by more than one respondent, with standards and guidance on technique selection being a feature.

In the commentary, respondents were divided between those who prioritised the importance of having a local access point and those who believed an authoritative UK voice was the prime importance and that location was a secondary issue. When questioned about local delivery, it is evident that there is no one preferred mechanism (see Figure 16).

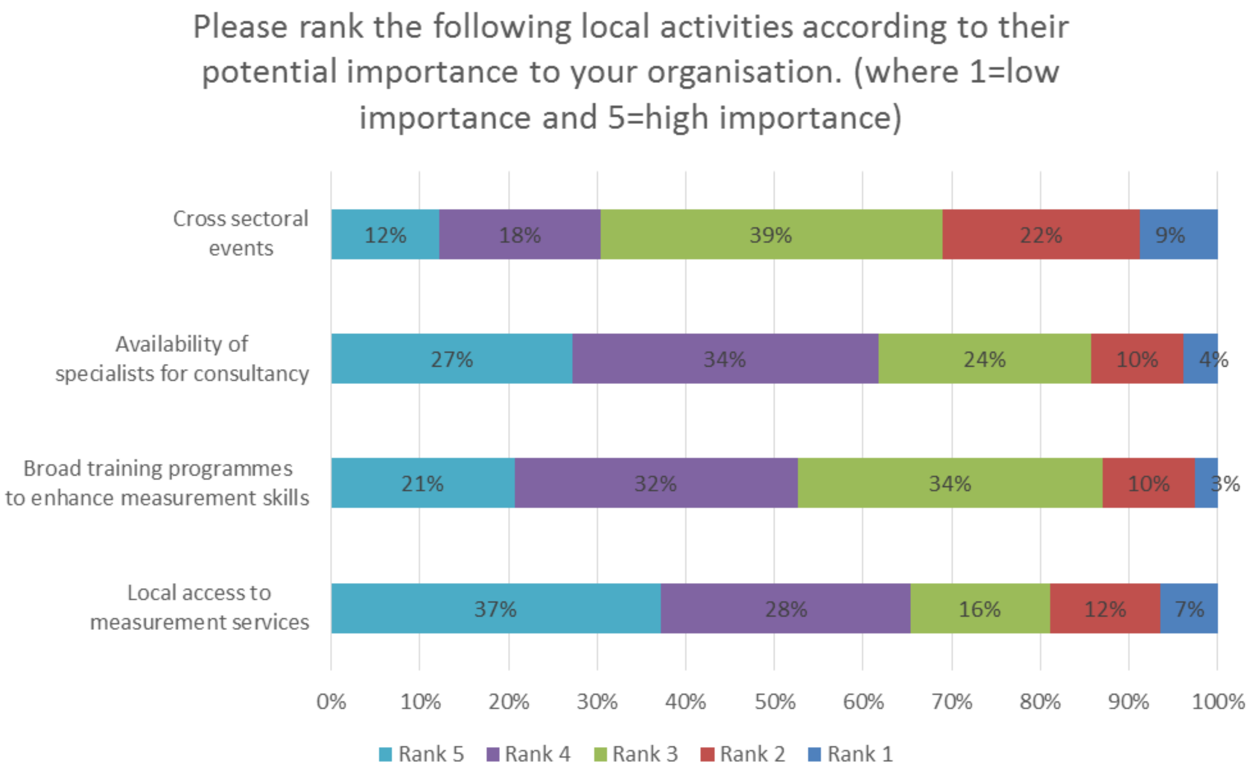

Figure 16 Relative importance of various local access activities

8.2.5. Making choices

The remainder of the questions in the online survey focussed on how to prioritise activities within a limited budget.

Measurement capabilities essential for the UK to maintain

A sizeable proportion of respondents believe that no national measurement capabilities should be lost and that we should not rely on foreign NMIs for traceability. Reasons cited for this view vary, but include loss of reputation internationally, a belief that overseas NMIs give second-rate access to their services and disadvantage British businesses, and the loss of underlying expertise in the UK.

A large variety of measurement types were cited by other individuals as important for the UK to retain. However, a number of underlying topics were seen as important principles for retention of specific capabilities:

- difficulties with logistical issues, for example complications with shipping radioactive isotopes which have short half-lives
- national security/defence requirements
- it would make more sense for others to rely on the UK in an area where we are world leading rather than dropping UK capability and becoming reliant on overseas suppliers

A smaller group of organisations were open to sourcing traceability from overseas if there was security of supply e.g. a number of alternative providers and the service was open, transparent and would allow for scrutiny.

Issues or benefits from receiving traceability from foreign NMIs

Some respondents identified benefits from devolving traceability to overseas NMIs. These included benefits to companies operating in international markets, where the support of an overseas NMI may be helpful, and also the prospect that the increasing specialisation of NMIs may lead both to a concentration of expertise, improving the technical capability, and possibly price reductions because of the increased economies of scale.

The majority of respondents identified concerns or disadvantages, many of which were cited many times:

- difficulties and additional costs associated with logistics, especially transporting sensitive materials or instrumentation across international boundaries
- increased timescales for delivery of a calibration due both to shipping times and potentially slower turnaround time from overseas NMIs
- loss of contact with local experts compounded by language barriers and differences in time zone
- increased risk that service will not be maintained and that items will be damaged in transit
- issues with national security

- commercial disadvantages compared to domestic companies in terms of service provision
- conflicting standards compared to the UK

Balancing priorities

Within a limited resource, consideration has to be given to balancing the portfolio in order to best meet requirements and maximise impact. Respondents were equally supportive of the following priorities:

- maintaining a broad range of traceability in the UK
- underpinning future technologies through research
- improving measurement best practice

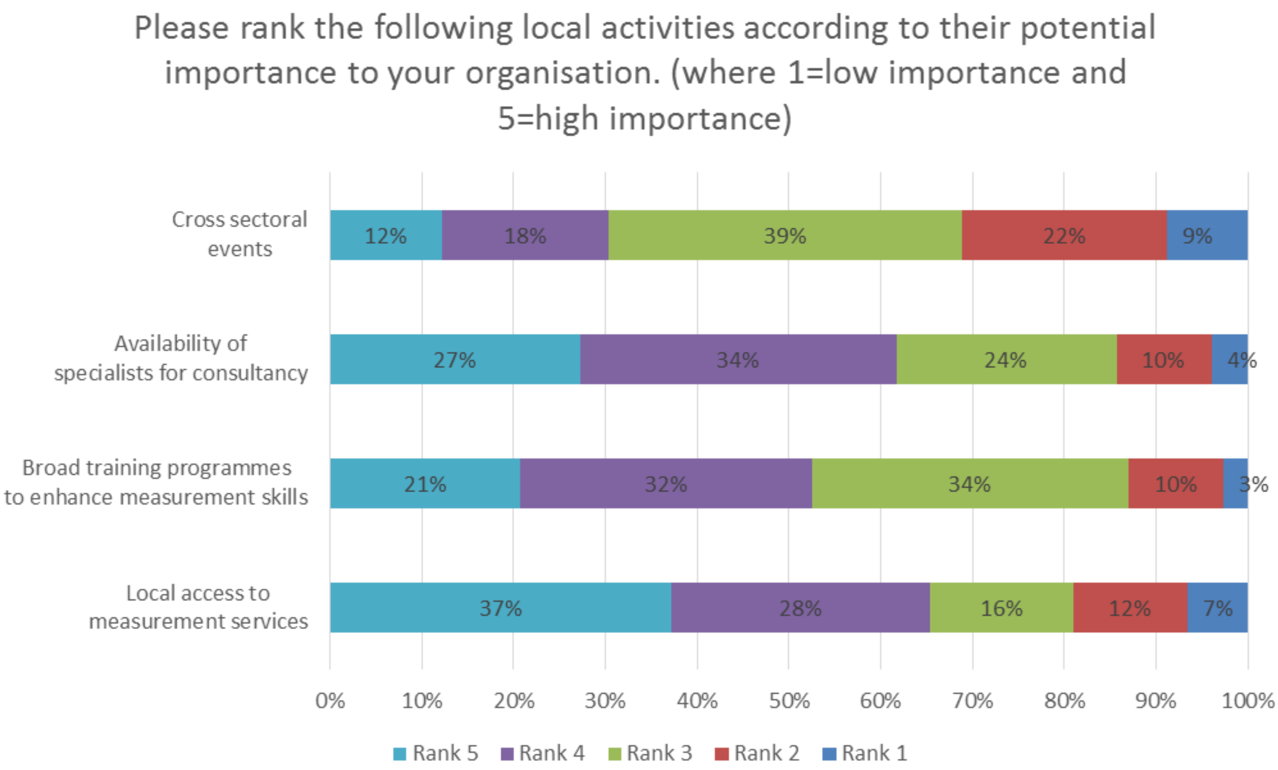

Figure 17 Ranking of priorities for the national system

Opportunities for collaboration

Over 100 of the organisations consulted were interested in working together with the NMS and many put forward specific ideas on how this could be taken forward. The openness and interest in collaboration stimulated at least in part by the consultation suggests that there is more scope to integrate activities and for delivering in partnership.

8.3. Structured interviews

8.3.1. Individual consultations

In order to gather a rich input to the strategy, individual consultations were held with a number of key stakeholders. Semi-structured interviews with over 100 organisations, including business, academia, public and professional bodies, have been key in shaping the strategy. A draft summary strategy was circulated in advance of the interview; most respondents were supportive of the key themes and direction of travel of the emerging strategy. The main themes addressed in the interviews were: identifying the current and future needs of science, business and government; shaping the method of delivery of the NMS to increase effectiveness; joining up the science, innovation and quality infrastructures on measurement; and themes for future investment.

All interviews have been reviewed to identify those issues which were highlighted across many stakeholders particularly those which were common to different sectors. These are discussed in sections 8.3.2 to 8.3.5.

In addition, many sector or company-specific needs were identified and noted. These will be reviewed to see if there is sufficient need to address these with specific projects or programmes.

8.3.2. Leadership of an integrated system

A number of stakeholders believed that NPL should be more ambitious in its leadership role and set a clearer framework and mechanism for further joining up the system. Furthermore, it was anticipated that better coordination and connectivity would lead to simplification and efficiency.

A number of specific points were made:

1. The vision and key messages for the measurement system need to be stronger and better communicated.
2. Measurement needs to be linked to other science and innovation activities. Specifically, greater involvement with the Catapults was mentioned by many respondents, as was stronger collaboration and alignment with universities and other government departments, especially in emerging technologies. The requirement for the DIs and the NMI to work more closely with each other was also noted so that effectiveness is maximised.
3. Respondents also believed that the role of measurement in delivering other government objectives, such as in underpinning the eight (plus two) Great Technologies or in supporting effective and efficient nuclear decommissioning, was key.
4. There is more scope to join up the standards, regulation and accreditation aspects of the quality system. Many respondents were particularly supportive of the involvement of NMI and DI experts in standards committees. This was seen as an activity of high importance and supportive of UK exporters.

5. A strong international presence was seen as good for the UK with better international coordination of metrology capabilities and international collaborations seen as effective in dealing with global challenges.
6. The role of the NMI amongst some respondents was seen as needing a greater focus on coordination and quality assurance of delivery of all organisations delivering within the system.

8.3.3. Access

Many respondents took the time to recognise the support they receive from the NMS. They particularly value access to measurement experts. The personal contact with and advice from experts of international standing was seen as crucial to some organisations. However, despite these strong and valued relationships, engagement with the NMS was generally seen as something that could be improved with the following specific points made:

1. The communication of the role, capabilities, offerings and tangible benefits of measurement needs improvement. Many organisations believe that the profile of measurement is too low and awareness of products and services needs to be improved.
2. Ease of access by SMEs needs to be improved in order to support innovation.
3. Academics need to understand the mechanisms for collaboration with the NMS so that the measurement system works more closely with the academic community and research programmes are aligned.
4. Regional delivery is important for smaller companies and elements of the public sector, such as the NHS, where costs of access can be a significant barrier. For others, accessing the national/international expert was seen as more important than regional delivery. Regional delivery was seen as an activity which it is important to coordinate with existing regional organisations and also which requires a more agile NMS so that regional opportunities can be capitalised on in a more timely way.
5. For all potential partners and stakeholders, the offering, model and entry point need to be defined. This then needs to be communicated clearly.

8.3.4. Skills

An absence of measurement skills was the most frequently identified issue during the consultation. Many organisations acknowledged that they were finding it difficult to recruit individuals with the right level of knowledge and skills in measurement and this was seen as likely to persist for at least the next five years. A pressing need was identified to create the next generation of engineers and scientists with metrology skills across many disciplines.

1. The measurement skills gap was identified at many levels:
    - among postdoctoral researchers, where training in quantitative methods was seen as weak
    - among graduates more generally, where the absence of a core module on measurement was noted in most technical degrees and a lack of awareness of the measurement basics was identified

- among apprentices and early-career stage individuals, where specific measurement training is required

2. The measurement skills gap seemed to be prevalent across many sectors, being identified within manufacturing, oil and gas, engineering, space, life sciences, energy and nuclear. It was recommended that the NMS take the lead in proactively identifying skills gaps.

8.3.5. Investment

There was support for investment in new capabilities to stay at the forefront of new technologies. Specifically, it was noted that there will be more need for metrology into the future as functionality, speed, and complexity increases. Measurement will have a key role in delivering better yields, lower costs and higher productivity.

Many areas for investment were identified including quantum, materials, graphene and nanotechnology. However, three future technology requirements were mentioned by many stakeholders as key areas where the NMS should expand its role.

1. **Manufacturing and productivity**
   Many respondents emphasised the need for more real-time, in-line measurement of manufacturing processes to allow process control, delivering right-first-time production and increased productivity, such as sensors on machine tools. Furthermore, it is foreseen that the Internet of Things will impact strongly on manufacturing, with a growing importance of autonomous systems with machines making more complex decisions. Industry 4.0 will enable reliable, adaptable production processes without operator intervention capable of real-time product customisation. This will require the joining up of processes at the systems level with the inherent need to ensure interoperability of measurement technology across a wide range of applications (plug and play) and for the output to be understandable by autonomous systems. In general, it is thought that the NMS needs to consider its role in supporting an Industry 4.0 environment.

2. **Big data, models and sensor networks**
   Many stakeholders believe that changes being driven by both Industry 4.0 and increased modelling of systems will lead to both more simulation and the collection of greater volumes of measurement data. Specifically, it was identified that faster communications coupled with increased data storage capacities have created the concept of meta instruments from a static or evolving network of sensors. The complexity of the scenarios and volume of data require new trusted visualisation and simulation tools as part of a modern measurement test and design protocol.

   In addition, users need to be able to fully understand what the data represents and to check the veracity of inputs, outputs and data processing algorithms. A greater trust in data and an understanding of the provenance of data will support the development of the digital economy. Understanding how to handle, analyse and extract data for autonomous decision making will be a key skill for delivering future smart process design.

It is perceived that big data may have a strong impact on the life sciences where systems are complex and the consequences for poor decision-making serious, for example, if automated decision-making were to lead to misdiagnosis.

3. **Life sciences**

Many gaps were identified in life sciences by a range of stakeholders even through there are many hundreds of primary reference materials in this area. Overall, it was judged that this is an area where measurement is less mature compared to the physical sciences and is also more complex. During manufacture, there is a need for simplified on-line, real-time measurements capable of supporting compliance with quality assurance and quality control measures. In addition, there is a move towards continuous as well as batch production processes to support smaller, more personalised therapies. This will place additional demands on the analytics required to support both product development and manufacture. Analytical skills in the biological sciences were seen as lacking and it was thought that new standardised tools and methodologies were needed to support product development and the increased importance of QA/QC in clinical measurement and genomic technologies. In particular, it was identified that many biological systems are not fully controllable, involving for example many components or contamination which influence the final analytical measurement produced, and an understanding of how to mitigate this is needed. These require multivariate analysis and the creation of new mathematical/computational models to predict outcomes.

9. Our record of achievement – the National Measurement Strategy 2011–2015

9.1. Introduction

The first National Measurement System Strategy 2011–2015 was developed during the period 2010–2011. This strategy set out a vision for the UK's core NMS-funded measurement infrastructure. The key objective was to pave the way for the continued development of the UK's world-leading measurement infrastructure, giving UK businesses confidence in the quality of measurement standards and stimulating innovation in new measurement techniques.

The central vision for the strategy had three key themes: leadership in measurement, supporting a national measurement infrastructure, and responding to national challenges. Delivery of these three core themes was designed around working with key partners to achieve impact while addressing key national challenges concerning:

- growth
- energy
- sustainability
- health
- digital
- security

Recognising the complex nature of the challenges facing the UK and the multifaceted nature of the UK economy, a challenging set of 122 objectives was set to ensure that the vision for the strategy was achieved. Release of the strategy came at a challenging time as the economic downturn was biting hard and financial support for the NMS was declining while demands for new services and capabilities were rising.

9.2. Delivery of the 2011 NMS Strategy

As part of evaluating the performance of the UK's NMS, delivery of the 2011–2015 NMS Strategy was reviewed. In summary, the strategy successfully delivered or exceeded all but a couple of the 122 objectives set. The two objectives where the NMS did not deliver the original strategies were about:

- carbon trading: The assumption at the initiation of the NMS strategy was that regulators would base their market model on measurement of carbon emissions. Instead the market and regulator adopted measurement of the carbon based fuel inputs combined with modelling rather than measurement of emissions from

combustion. Hence this significantly reduced the need for new measurement capabilities
- health: The original target for supporting the health sector was to maintain the level at a static17% of the NMS portfolio. However, the proportion of the portfolio reduced to 12% by 2015. This was due to a number of factors such as increasing support for other sectors, higher spending on knowledge transfer activities to drive impact across the NMS and efficiency gains in health related infrastructure costs

Notable accomplishments delivered during the period of the 2011–2015 NMS Strategy included:

- The Centre for Carbon Measurement was established at the National Physical Laboratory (NPL) in March 2012 with key activities around climate data, carbon markets and low carbon technologies. Strong relationships have been built across a network of stakeholders including government, academia and industrial bodies to raise awareness and increase the impact of the NMS low-carbon and climate science portfolio. The work of the Centre for Carbon Measurement has been recognised in the national press and parliament. For example, NPL provided evidence on the environmental risks of fracking at the Environmental Audit Committee in January 2015. The Centre for Carbon Measurement has helped to secure an additional £2 million non-NMS funding per annum, and increased leverage on NMS funding while the portfolio of low carbon work has been estimated to enable the delivery of reductions in gaseous emissions equivalent to 2% of the UK's annual CO2 emissions[40]
- working together with leading stakeholders, LGC has made substantial improvements to health-related measurement including: reference methodologies and reference materials to support therapeutic drug monitoring for immunosuppressant drugs given to organ transplant patients, the UK's first SI traceable methodology for the quantification of a clinical protein biomarker, accurate methods to understand and improve chemotherapy dosimetry, and novel laser ablation mass spectrometry imaging technology to support disease diagnostics. This work enables new drugs, diagnostics and therapies that will improve the lives and treatment of patients across the UK and beyond
- launch of a Flow Measurement Institute in 2014. NEL in partnership with Coventry University launched the Flow Measurement Institute which has created an EngD programme, PhD programme, and major investment at Coventry University in an entirely new faculty for flow measurement research
- establishment of the National Centre of Excellence for Mass Spectrometry Imaging (NiCE-MSI) in partnership with the University of Nottingham and the pharmaceutical industry. The goal of the centre is to drive the development of the next generation of instruments to give researchers unprecedented information on the locations and activities of key drugs and other molecules in biological samples. The unique world-leading facilities are designed to give UK researchers in industry and academia a clear competitive advantage in science and for accelerating innovation

[40] See 2014 Technologia report on the impact of the centre for carbon measurement. Available at: www.npl.co.uk/upload/pdf/ccm-impact-report.pdf

- opening of the Quantum Metrology Institute in partnership with EPSRC, Dstl and Innovate UK as part of the £270 million national initiative on quantum technologies. The centre will drive innovation through providing the facilities that enable verification of performance, giving confidence to investors and opening markets
- UK borders are more secure and travellers safer as a result of LGC work to improve the detection of drugs and explosives using ion mobility mass spectrometry
- tripling the number of scientists, engineers and other professionals working with and connected to the NMS to 15,364 in 2014/15. This includes increasing the number of learners receiving measurement training annually to over 2,000 in 2014/15 – an increase of 122% since the launch of the NMS Strategy
- increasing the external financial contribution to supporting the core measurement infrastructure from 46% of the government investment in 2011/12 to 62% in 2014/15

9.3. The changing shape of the NMS portfolio

In 2010/11 the NMS portfolio of research programmes was analysed to determine both the spread of investment by key economic sector and also by the type of activity being undertaken. This work was undertaken to understand how the NMS was responding to its core mission and national areas of importance. Analysis of the results helped enable strategic choices to be made about where future investment should be focussed to increase the impact of the NMS and where there were opportunities to increase efficiency. Important challenges were set around increasing the investment in challenge-led R&D areas such as energy and sustainability while reducing the costs of sustaining core infrastructure and services. Targets were set in the 2011–2015 NMS Strategy based on the desired outcomes of the strategic choices made.

Ahead of the development of the current UK Measurement Strategy, the shape and activities supported by the NMS portfolio of research programmes in 2015 were analysed to map the changes to the portfolio over the five-year period of the NMS Strategy. To ensure consistency, the methodology employed for the 2015 analysis, including the definitions of sectors and activities, was the same as that used for the previous study.

The **top level results are positive with a significant increase of activity on challenge-led R&D achieved through efficiency gains in delivering the core infrastructure** and related national and international obligations. **The goal of increasing investment in the energy and sustainability sectors has also been achieved** as shown earlier in Figure 2. The breakdown of the NMS portfolio by activity is shown in Figure 18 below.

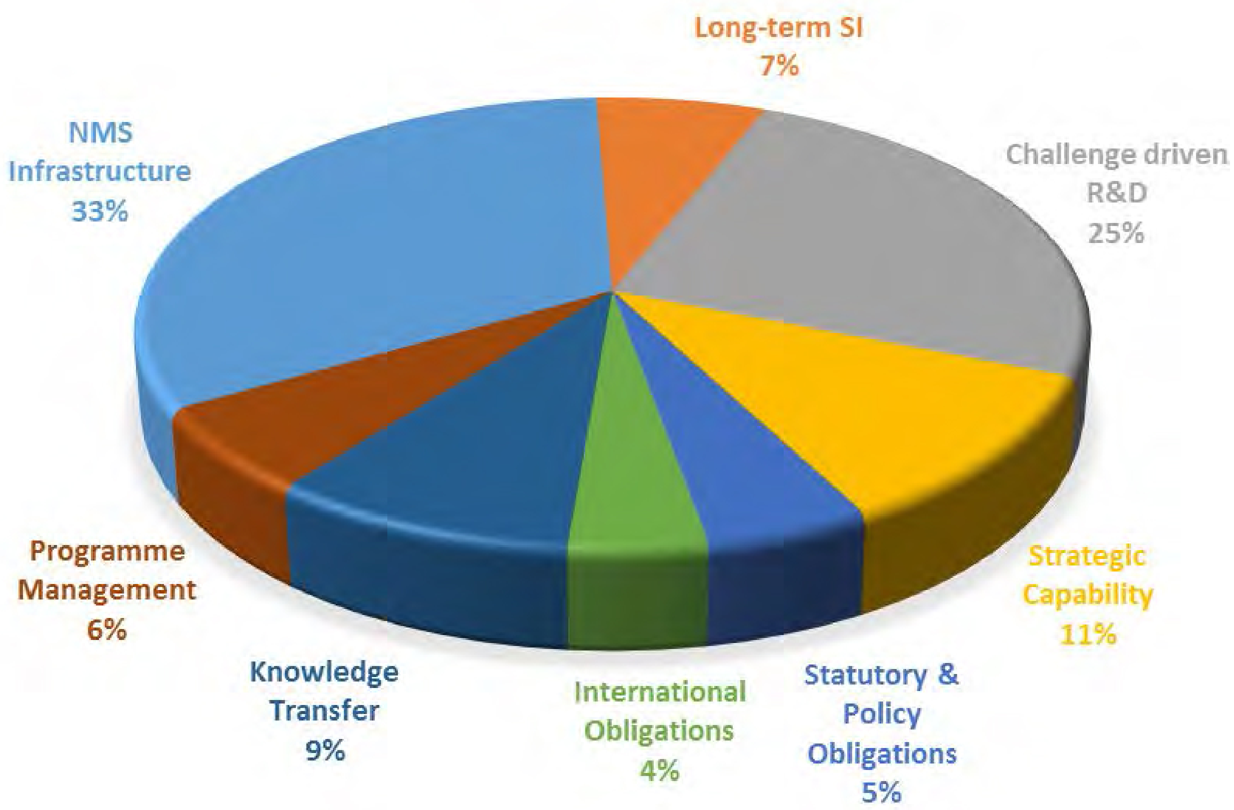

Figure 18 Estimated investment by activity of the NMS portfolio in 2015

Annex A – References

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Annex B – Abbreviations

BCR	Benefit–cost ratio
BEV	Bundesamt für Eich- und Vermessungswesen (Federal Office of Metrology and Surveying, Austria)
BIPM	Bureau International des Poids et Mesures (International Bureau of Weights and Measures)
BEIS	Department for Business, Energy & Industrial Strategy
BSI	British Standards Institution
CENAM	Centro Nacional De Metrología (National Measurement Institute of Mexico)
CIPM	Comité international des poids et mesures (International Committee for Weights and Measures)
CIPM MRA	CIPM Mutual Recognition Agreement
CMC	Calibrations and Measurement Capabilities
DFM	Danish Fundamental Metrology (National Measurement Institute of Denmark)
DI	Designated Institute
Dstl	Defence Science and Technology Laboratory
EU	European Union
FP7	Seventh Framework Programme for Research and Technological Development
FTE	Full Time Equivalent
GATT	General Agreement on Tariffs and Trade
GDP	Gross Domestic Product
GVA	Gross Value Added
HMT	Her Majesty's Treasury
INRIM	Istituto Nazionale di Ricerca Metrologica (National Measurement Institute of Italy)
IoT	Internet of Things
IP	Intellectual Property
KRISS	Korean Research Institute of Standards and Science
LGC	LGC Ltd (formally the Laboratory of the Government Chemist)
MID	Measurement Instruments Directive
NBS	National Bureau for Standards
NEL	National Engineering Laboratory
NGML	National Gear Metrology Laboratory
NIBSC	National Institute for Biological Standards and Control
NIM	National Institute of Metrology (National Measurement Institute of China)

NIST	National Institute for Science and Technology (National Measurement Institute of USA)
NMI	National Measurement Institute
NMS	National Measurement System
NNL	National Nuclear Laboratory
NPL	National Physical Laboratory
NPV	Net Present Value
NPVP	National Product Verification Programme
OECD	Organisation for Economic Co-operation and Development
OIML	International Organisation of Legal Metrology
ONS	Office of National Statistics
PDO	Protected Denomination of Origin
PTB	Physikalisch-Technische Bundesanstalt (National Measurement Institute of Germany)
PVP	Product Verification Programme
QKD	Quantum Key Distribution
R&D	Research and Development
RIO	Research and Innovation Organisation
RMO	Regional Metrology Organisations
RTO	Research and Technology Organisations
SI	Système International d'Unités (International System of Units)
SMU	Slovenský metrologický ústav (Slovak Institute of Metrology)
SP	Sveriges Provnings (Technical Research Institute of Sweden)
UKAS	UK Accreditation Service
UKCS	UK Continental Shelf
USD	United States Dollars
VSL	Van Swinden Laboratorium (National Measurement Institute of the Netherlands)
WELMEC	European Cooperation in Legal Metrology

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Department for Business, Energy & Industrial Strategy
1 Victoria Street
London SW1H 0ET
Tel: 020 7215 5000
Email: enquiries@beis.gov.uk