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A Summary of the Evidence for the Economic Impact from the NMS Programme

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National Physical Laboratory (NPL)

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We are the UK's National Metrology Institute (NMI), a world-leading centre of excellence that provides cutting-edge measurement science, engineering and technology that underpins prosperity and quality of life in the UK.

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Abstract

The UK's National Measurement System (NMS), delivered through its network of laboratories, provides the infrastructure required for accurate, traceable and internationally recognised measurement. This foundation underpins trade, regulation, productivity and innovation across the economy. This study consolidates the evidence on the impact of the NMS programme, structured around two economic channels: **Delivering the Measurement Infrastructure** and **Enabling Technological Change (Innovation Benefits)**.

- The Measurement Infrastructure channel highlights how primary measurement standards, calibration services, reference materials and metrology expertise reduce uncertainty, improve reliability in sectors that critically depend on precise measurement (e.g. Advanced manufacturing, Clean energy industries, Life sciences, Digital technologies etc.) and prevent costly decision-making errors across production and conformance testing. Using a macroeconomic model for the **Optimal Testing** alongside the **Fan-Out & Uptake of Traceable Calibrations** model, the report shows that the absence of NMS laboratories would imply limited or no access to precise calibrations, which would raise measurement uncertainty, increase false-rejection rates, and result in widespread productivity losses.
- The innovation benefits channel demonstrates how NMS laboratories act as a catalyst for firm-level technological progress by enhancing R&D productivity, reducing technical risk, and accelerating the journey from concept to market. The evidence is structured around four key themes: **Capability Building**, where foundational R&D and codified standards strengthen firms' technical capability; **Employment Growth & Wage Premium**, where regularly supported firms experience stronger growth and are able to offer higher wages; **Firm Survival**, with supported firms exhibiting greater survival and long-term competitiveness; and **Increased Business R&D**, where business expansion enables further investment in research and development.

Beyond these economic mechanisms, the NMS laboratories also deliver societal benefits, which are also evidenced in the report.

Integrating both channels, the Business Case Model shows that the NMS delivers substantial value for money, with strong returns on public expenditure at both the average and margin. Overall, the evidence demonstrates that the NMS is a critical national asset that strengthens productivity, accelerates innovation, supports regulation and underpins strategic national priorities in prosperity, health, environment and security. Continued investment in the NMS ensures that the UK maintains world-leading measurement capability and secures long-term economic and societal benefit.

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Executive Summary

Measurement science is a continually evolving field, shaped by ongoing scientific discoveries and technological developments. The National Measurement System through a network of specialist labs supports this technological development, trade, and regulation by providing the scientific foundation for accurate, traceable, and internationally recognised measurements. By staying aligned with international measurement standards and participating in international mutual recognition frameworks, the UK ensures its measurements are trusted and accepted worldwide.

This report consolidates the evidence developed on the role and impact of the UK's National Measurement System (NMS). It structures the analysis around two primary economic channels of impact, both of which enhance productivity growth: **delivering measurement infrastructure** in which NMS laboratories being the source provide certified reference materials and calibrations traceable to national standards, supported by a network of accredited calibration laboratories, and **enabling technological change** where NMS laboratories support firms' innovation through collaborative research and development activities and by strengthening their capabilities for effective in-house R&D. Calibration services, reference standards, and knowledge transfer form key components of the measurement infrastructure, with **traceable calibrations** delivered by NMS laboratories representing a major component. These calibrations are information goods that function as public goods, because they generate wide, indirect benefits across the economy by enabling consistent, internationally recognised measurement. In contrast, conformance testing which industries rely on to verify that products and processes remain within specification when production systems malfunction, is a private good, typically carried out in-house or outsourced to specialist testing laboratories. In regulated sectors, this may also involve conformity assessment bodies, such as inspection and certification bodies, including notified bodies for CE marking. In most respects, the effectiveness of conformance testing depends on the low-uncertainty measurements maintained by the NMS labs. *Through collaborative R&D and targeted technical support*, the NMS labs generate direct benefits for firms by accelerating innovation, reducing technical risk, and strengthening productivity. It also explains that technological change can occur through advances in the measurement sectors which underpin innovation in the non-measurement sectors. The report also touches upon the societal benefits and thematic analysis based on challenge areas.

***Delivering the Measurement infrastructure* –** Measurement underpins a vast share of the UK's economic activity and industrial capability. In 2017, **expenditure on measurement-related R&D was approximately £2 billion**, of which private sector firms carried out 87%. Around 6.3% of the workforce was employed in measurement-related roles, contributing £58.3 billion in wages. Investment in instrumentation exceeded £3.6 billion, accounting for 4.1% of investment in productive and tangible assets and 7.2% of investment in all machinery equipment[R16]. Assessments by Grand View Research, drawing on a 2024 base-year UK dataset, estimate that the **testing, inspection, and certification sector generates around £14 billion per year** highlighting the scale of the industry in the UK[R18]. Although much smaller in comparison, the **UK's calibration services market estimated to be roughly £250 million** remains critically important, as it underpins the traceability and measurement assurance on which the wider testing and certification ecosystem depends. The NMS survey for businesses 2023 reports that **businesses which work with NMS labs spend £7.7 billion annually on measurement** activities including £6.2 billion on testing and analysis, and £1.5 billion on calibration and reference materials [R23].

A central thread linking these measurement activities is the quality of the calibration that underpins them. While basic calibrations can be sourced from commercial providers, these services inherently offer only limited precision. By contrast, calibrations traceable to the National Measurement System (NMS) laboratories provide access to the highest levels of measurement accuracy available in the UK. This distinction matters because precise calibrations reduce uncertainty in measurement processes which ensures that businesses can operate with confidence.

The framework developed for quantifying the value of a measurement infrastructure implies that without the NMS labs, access to precise calibrations would either be fully eliminated or limited resulting in **uncertainty in measurements to rise by approximately 3.1%**, increasing the probability of Type I errors (incorrectly scrapping away functioning output) by around two thirds. Even partial reliance on foreign NMIs would still lead to an increase in the probability of type I error and consequently an increase in the measurement uncertainty[R30]. The Optimal Testing Model estimates that testing should be carried out approximately every **9 to 10 months**, analogous to servicing a car annually to minimise the risk of malfunction. The model identifies the **optimal testing frequency** as the point at which productivity measured as output per worker is maximised. Among the key components generated by the model is the **probability of Type I error**, which feeds into the Uptake Model to quantify how limited access to precise calibrations affects measurement uncertainty. Increase in probability of type I error implies **higher scrap rates** which reduce the efficiency of production processes and undermine the overall performance of the system[R32]. The work summarised in this chapter shows that without the NMS labs the rise in measurement uncertainties can cascade into significant economic losses, underscoring the critical role of NMS laboratories in maintaining quality and reliability.

Innovation Benefits – The NMS labs also play a role in providing the measurement expertise and infrastructure that businesses need to develop cutting-edge technologies, reduce risk, accelerate market entry and strengthen business survival. The NMS Survey shows that the 920 of the UK-based businesses that work with the NMS labs collectively **attribute £500 million in sales revenue to innovations** that wouldn't have succeeded without the NMS labs[R23]. Moreover, the evidence developed shows that firms regularly supported by NMS laboratories grow faster, adding an average of **6.3 jobs annually** and offering **wage premiums of over £4,000 per new hire** [R39]. NPL support accelerates **time-to-patent by 26%** and increases the **likelihood of patenting by 23%**[R43]. Public investment in NMS leverages private R&D, with every £100 of funding generating **£29 in additional private R&D spending**. This comes from the accelerator principle where, as supported firms expand i.e. adding jobs, improving productivity, and accelerating innovation, they also raise their internal R&D spending, creating a cycle in which growth drives further investment and further investment drives additional growth[R42]. Support from the NMS labs also plays a role in improving firm survival. Regularly supported firms show an **annual business-closure rate of around 0.6%,** compared with roughly 2% per year in a matched control group and around 5% per year in the wider UK business population[R39].

Integrated Impact – The Business Case Model indicates that the National Measurement System programme generates substantial economic value. This is captured through the NPSV–DEL ratio, which compares the Net Present Social Value (NPSV) of the programme with the Departmental Expenditure Limit (DEL) required to fund it. The programme achieves an average **NPSV–DEL ratio of 12.79 and a marginal ratio of 8.04**, indicating that each £1 of departmental expenditure is associated with £8 to £13 in net social value. These findings reflect the combined contribution of both the measurement infrastructure and innovation benefit streams [R38].

***Societal Benefits* –** Beyond economic benefits, the NMS labs play a role in delivering societal value. Its work improves healthcare outcomes and supports national environmental goals. For instance, the combined efforts of NPL and physicists in the radiotherapy community in reducing radiotherapy dose uncertainty for safer cancer treatments. It is estimated that **15 additional prostate cancer[1] patients** were treated successfully each year as a result of better dosage[R26]. In addition, the healthcare survey conducted in 2025 shows that **88%** of users across hospitals, industry and academia regard NMS labs' support beneficial and over half see it as essential. NHS organisations report the highest dependence. Roughly **one in three** users found that NMS support enabled a change new to their organisation, and around **one in seven** described the improvement as new to their industry[R20]. Moreover, the greenhouse gas monitoring services it provides enables accurate real time measurements. Between 2016 and 2020, NMS efforts equated to saving nearly **0.51 Mega tonnes of carbon dioxide equivalent gases**, worth **£67.8m**[R45].

The evidence presented in this report demonstrates that the National Measurement System and its laboratories contribute to the UK's economic and scientific infrastructure. Its impact spans productivity, innovation, trade facilitation, regulatory assurance, and societal well-being. Continued investment in measurement capabilities will ensure that UK maintains its leadership and delivers long-term value for businesses.

[1] Cancer research UK reports that prostate cancer is the 2nd most common cancer in the UK, accounting for **14% of all new cancer cases** (2017–2019).

1 Introduction

1.1 Background to the National Measurement System

The **UK National Measurement System (NMS)** is the national framework that ensures the accuracy, consistency, and international recognition of measurements across the UK. It plays a vital role in supporting trade, innovation, regulation, and public confidence by providing the infrastructure needed for reliable measurement science. Through the NMS, the UK maintains its ability to make precise and traceable measurements that are essential for scientific research, industrial processes, environmental monitoring, etc. The NMS underpins key sectors of the economy by enabling innovation in advanced manufacturing, digital technologies, life sciences, energy, and national security. It supports UK businesses through calibration services and measurement expertise, helping them meet regulatory requirements and compete globally.

Delivery of the NMS is coordinated through a network of specialised laboratories and institutions, each responsible for different areas of measurement science:

1. **National Physical Laboratory (NPL)** – The UK's National Metrology Institute, NPL maintains the country's primary standards for physical quantities such as time, length, and mass. It leads most NMS programmes and represents the UK in international metrology forums. It supports sectors such as aerospace, automotive, energy, healthcare, life sciences, manufacturing, and telecommunications etc., helping these industries improve quality, safety, innovation, and global competitiveness.

2. **National Measurement Laboratory (NML) at LGC** – Specialising in chemical and biological measurements, NML hosts the Government Chemist function, which provides independent advice and resolves measurement disputes, particularly in areas like food safety and forensic science.

3. **National Engineering Laboratory (NEL)** – Operated by TÜV SÜD, NEL focuses on flow measurement and industrial metrology. It supports sectors such as energy and water through research, calibration services, and long-term development.

4. **National Gear Metrology Laboratory (NGML)** – This laboratory specialises in precision mechanical measurements, particularly gear metrology, supporting manufacturing and engineering sectors.

5. **National Institute for Biological Standards and Control (NIBSC)** – It oversees biological reference materials and standards for vaccines, diagnostics, and other biopharmaceuticals, playing a key role in public health and international collaboration.

6. **National Institute of Airborne Acoustic Metrology (NIAAM)** – Designated as the UK's specialist institute for airborne acoustics, NIAAM provides national leadership in the measurement, characterisation, and standardisation of sound in air.

Together, these core laboratories form the backbone of the UK's measurement infrastructure, enabling scientific excellence, regulatory compliance, and economic growth through trusted and traceable measurement capabilities.

History of the NMS

Metrology is the scientific discipline concerned with measurement, encompassing both its theoretical foundations and practical applications. Globally, metrology underpins a wide range of activities from scientific research and industrial processes to international trade and regulatory compliance, by providing a shared measurement framework grounded in the International System of Units (SI).

The foundation of international metrology is rooted in the Metre Convention, signed in 1875 by seventeen nations, including the UK. This landmark treaty established a coordinated global system for measurement, ensuring consistency and comparability across borders. One of its key provisions was that each member state designates a single National Metrology Institute (NMI) to represent it in international metrological activities. This structure promotes clarity, accountability, and scientific integrity in the development and dissemination of measurement standards. Not only that, but measurement standards are also dynamic which cultivate the importance of international comparability between NMIs. For instance, standards were based on physical artefacts, such as the international prototype of the kilogram—a platinum-iridium cylinder stored in France. These artefact-based standards, while practical, were susceptible to physical degradation and limited reproducibility. Today, measurement standards are increasingly defined by fundamental physical constants, such as Planck's constant for mass and the speed of light for length.

This shift to refine SI units from tangible artefacts to universal constants and the fact that metrology has expanded into other disciplines reflects a deeper scientific understanding that measurement is not static, it evolves alongside scientific progress.

It is for this reason that, the Metre Convention created the International Bureau of Weights and Measures (BIPM), to support the global evolving measurement system. BIPM is responsible for maintaining the International System of Units (SI) and facilitating collaboration among NMIs worldwide. Its governance includes the General Conference on Weights and Measures (CGPM), which sets strategic direction and policy, and the International Committee for Weights and Measures (CIPM), which oversees scientific and technical coordination.

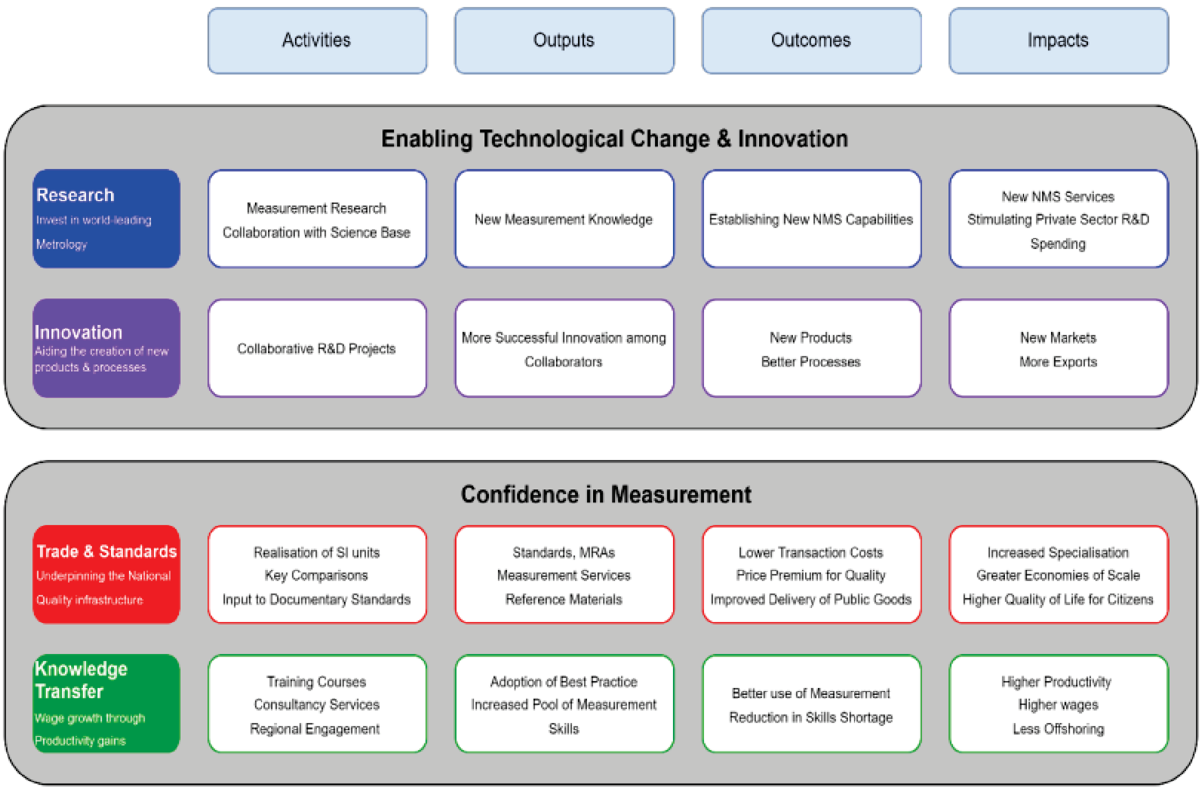
In 1999, the CIPM established the CIPM Mutual Recognition Arrangement (CIPM MRA): a globally agreed framework through which NMIs demonstrate the international equivalence of their measurement standards and the calibration and measurement certificates they issue. The CIPM MRA reinforces the principle that each member state of the Metre Convention has one designated NMI responsible for its national measurement standards. It is through international comparisons and the CIPM Mutual Recognition Arrangement (CIPM MRA) that NMIs ensure that their standards are equivalent, and their calibration certificates are globally accepted.

Since its founding in 1900, NPL has served as the UK's National Metrology Institute. It formally became the UK's NMI after signing the CIPM MRA in 1999. The National Measurement System was developed later to bring together a network of specialist institutes including NPL, LGC, and TUV-NEL under a unified framework. The system ensures that UK measurements are traceable to the International System of Units (SI) and aligned with global standards, enabling confidence in data across sectors.

1.2 Conceptual Foundations

The logic model for the National Measurement System[2] provides a stylised representation of how the activities of the NMS laboratories, along with other parts of the national quality infrastructure, lead to economic and social impacts. It is structured around four key impact mechanisms:

1. **Research and Development** – partnering with research organisations to advance fundamental metrology and the wider science of measurement.
2. **Accelerating the innovation activities** of other organisations through engaging with them in deep collaborative R&D projects.
3. **Traceability and Standards** – Underpinning the national quality infrastructure through delivering unique measurement services that provide the technical basis for trade and standards within the UK.
4. **Knowledge Transfer** – delivering training and consultancy to help organisations get closer to the technological frontier by fostering the adoption of best practice.



[2] King, M., Olakojo, S. and Gorringe, G. (2023) *NPL Report IEA 20: Evaluation Framework for the National Measurement System – A Framework for Assessing the Impact of NMS Laboratories*. National Physical Laboratory. https://eprintspublications.npl.co.uk/9853/1/IEA20.pdf

Because mechanisms 1 and 2 are closely linked, they can be grouped under a broader channel: **“Enabling Technological Change (Innovation Benefits)”.** Likewise, mechanisms 3 and 4 are interrelated and can be combined under **“Delivering the Measurement Infrastructure.”**

National Measurement System (NMS) laboratories play a dual role in the technical infrastructure framework. Their primary function is to build, maintain, and advance the UK’s measurement capability through standards, traceability, calibration, reference materials, testing and instrumentation. Existing measurement capabilities make up the measurement infrastructure. Advancing measurement capabilities constitute as innovation in the measurement sector. These advances also drive innovation in the non-measurement sectors by improving the productivity of R&D, lowering technical and commercial risks, and supporting the scaling and regulation of new technologies through standards.

Many of the services delivered by NMS laboratories under the measurement infrastructure exhibit the characteristics of **public-good-like information goods** wherein the collective social benefits exceed the private gains accruing to providers. This imbalance makes it susceptible to market failure, thereby necessitating targeted policy interventions and sustained investment. For instance, once high-quality, traceable calibrations are provided at the top of the measurement hierarchy, their benefits fan out through UKAS-accredited laboratories and specialist providers that use this traceability to support thousands of firms across the economy. These indirect benefits are largely non-excludable in practice: organisations that rely on instruments calibrated by third-party laboratories still benefit from the accuracy underpinned by national standards maintained by the NMS. Similarly, once developed, measurement standards can be freely adopted by industry, generating widespread benefits beyond the originating organisations.

By contrast, some elements of the wider measurement infrastructure, most notably conformance testing operate differently. While testing forms an integral part of the measurement and assurance landscape, it is typically delivered through bespoke, transaction-based services provided to individual firms, and its benefits are largely excludable and rival in nature, resembling a **private good**. However, the effectiveness of conformance testing depends critically on the underlying measurement infrastructure i.e. traceable standards and low-uncertainty calibrations provided by the NMS which would determine the reliability of test outcomes.

On the other hand, NMS labs provide direct support to firms through collaborative R&D, bespoke problem-solving, and development of advanced measurement and testing methodologies. These activities generate direct private benefits for users by accelerating innovation, reducing technical risks, and helping firms bring new products to market. Importantly, they also produce codified knowledge such as standards and validated methods that diffuse beyond the original user. This diffusion creates spillover effects, enabling other firms to adopt improved products and processes with lower uncertainty and thereby extending the benefits beyond the users of NMS labs[R46].

Together, the two channels reflect the mechanisms through which NMS laboratories generate impact i.e. both **direct benefits at the firm level** and **wider benefits** that extend across industry and society.

Table 1 brings together all the terms and concepts used in the report and gives a somewhat detailed explanation of each term.

	Term	**Acronym**	**Definition/ Concept**
	Institutions, Frameworks & Systems		
1	British Standards Institution	BSI	National standards body responsible for creating and maintaining technical standards.
2	CIPM Mutual Recognition Arrangement	CIPM MRA	International agreement ensuring global acceptance of calibration and measurement certificates issued by NMIs.
3	General Conference on Weights and Measures	CGPM	Governing body that sets high-level SI policy and strategic direction.
4	International Committee for Weights and Measures	CIPM	Scientific and technical coordination body of the SI.
5	Metre Convention (1875)		International treaty establishing global metrology coordination and one NMI per member state.
6	United Kingdom Accreditation Service	UKAS	UK’s national accreditation body for testing, calibration, inspection, and certification organisations.
7	UK Quality Infrastructure	UKQI	National framework integrating metrology, standardisation, accreditation, conformity assessment, and regulation.
	Measurement Science & Infrastructure		
	Calibration		Calibration is the process of comparing a measurement instrument or system against a known reference (usually a standard) to determine its accuracy. It often involves

			adjusting the instrument to align with the reference values. Institutes like NPL provide traceable calibration services, ensuring that measurements made by industry and laboratories are linked to the International System of Units (SI).
	Calibration - Basic		These can be sourced from commercial providers; these services inherently offer only limited precision.
	Calibration - Precise		These are calibrations which are directly traceable to the NMI and provide access to the highest levels of measurement accuracy available.
	Conformance Testing		Assessing whether a product or process meets required specifications.
	Detection rate		The rate at which defective output is detected, and the malfunctioning part of capital is reset.
	Metrology		Science of measurement ensuring accuracy, consistency, comparability, and reproducibility.
	Instrumentation		Refers to the tools and devices used to perform measurements. These include sensors, gauges, and complex metrology instruments designed for high precision. National metrology institutes such as NPL design, manufacture, and supply both standard and bespoke instruments, supporting calibration, validation, and compliance testing across sectors like healthcare, aerospace, and environmental monitoring.
	International System of Units	SI	Global system of measurement units ensuring international comparability.
	Random Error		Component of measurement error. Random errors are the deviations that occur due to slight changes in the conditions and can be minimised by taking repeated measurements.
	Relative Standard Deviation	RSD	It is the deviation that occurs under the hypothesis that parts of a machinery are defective. It depends on the expected uncertainty of measurement process.
	Reliability of Capital		Proportion of equipment functioning correctly in a production system.
	Reference Material		Reference Materials are substances or objects with well-characterised properties used to calibrate instruments, validate methods, or assess measurement accuracy.

	Regret rate		The rate at which good output gets scrapped erroneously.
	Standards		standards refer to the defined units of measurement or physical artifacts that embody those units (e.g., the kilogram, volt, meter). Institutes maintain national measurement standards and ensure their traceability to international standards, through participation in global comparisons.
	Standards – Primary		Maintained by national metrology institutes; highest level of accuracy.
	Standards – Secondary		Calibrated against primary standards and used in industry.
	Systematic Error		Component of measurement error. Systematic errors are biases that come with a specific instrument and can only be reduced/ eliminated with good calibrations.
	Traceability		Unbroken chain of calibrations linking a measurement to national or international standards.
	Test Accuracy Ratio	TAR	TAR is the comparison between the accuracy of a tool (Unit Under Test or UUT) and the reference standard used to calibrate it. Metrology labs aim for a minimum TAR of 4:1
	Type I Error (False Rejection)		When good output is incorrectly rejected.
	Type II Error (False Acceptance)		When defective output is incorrectly accepted.
	Economics & Models		
	Benefit to Cost Ratio	BCR	A financial metric used in cost-benefit analysis to determine the viability of a project by comparing the present value of benefits (PVB) to the present value of costs (PVC). $$\text{BCR} = \frac{\text{Present Value of Benefits (PVB)}}{\text{Present Value of Costs (PVC)}}$$
	Correlated Random Effects		An econometric panel data model (also known as the Mundlak approach) that relaxes the assumption that unobserved individual-specific effects are uncorrelated with the explanatory variables.
	Cox proportional hazards		A semi-parametric regression model used to analyse the effect of several variables (covariates) on the time-to-event.

	Difference-in-Differences	DiD	A quasi-experimental, longitudinal technique used to estimate the causal effect of an intervention or policy by comparing the changes in outcomes over time between a treatment group and a control group.
	Entropy		Entropy in information theory is defined as the expected amount of information or “surprisal” associated with uncertain outcomes.
	Heckman selection model		A two-stage econometric model designed to correct for bias arising from non-random sample selection (sample selection bias), such as when the dependent variable is only observed for a selected, non-random subsample.
	Infra-technologies		Standardised tools, methods, and protocols foundational to R&D.
	Kaplan-Meier		A non-parametric method used to estimate the survival function (probability of surviving beyond a certain time) from lifetime data.
	Log-rank		A hypothesis test used to compare the survival distributions of two or more independent groups.
	Mega tonnes CO_2e		Unit converting gases to CO_2-equivalent values based on warming potential.
	Net Present Social Value to Departmental Expenditure Limits	NPSV-DEL	This measures the net present social value (total benefits minus total costs) considering only the costs that fall within the specific departmental budget (DEL).
	Normal Tissue Complication Probability	NTCP	Risk of side effects in radiotherapy.
	Propensity Score Matching	PSM	Propensity Score Matching (PSM) is a quasi-experimental, statistical technique used in observational studies to estimate the causal effect of a treatment, policy, or intervention by reducing confounding bias.
	Regularly Supported Firms	RSFs	Regularly Supported Firms (RSFs) is defined as the firms that engage with NPL at least five times over a six-year period.
	Return on public cost		A specific type of return on investment (ROI) that measures the economic benefits generated relative to the specific portion of costs funded by the public sector.
	R&D Leverage Ratio		Additional private R&D generated per £1 of public support.

	Time-to-Patent		Time between starting innovation and filing a patent
	Total Factor Productivity	TFP	Efficiency measure linked to new technology and measurement adoption.
	Tumour Control Probability	TCP	Likelihood of tumour eradication in radiotherapy
	Scope 1, 2, 3 Emissions		Categories of direct, energy-related, and value-chain emissions.
	Wage Premium		Higher wages for workers joining NMS-supported firms.

Table 1 Glossary

1.3 Literature Review & Purpose of the report

The *Enabling Technological Change (Innovation Benefits)* channel aligns with economic theory on innovation, a well-developed area of research. In contrast, *Delivering the Measurement Infrastructure* relates to the more specialised domain of infra-technologies (such as metrology), which has received limited attention from mainstream economics. NPL economists have approached it by applying a macroeconomic model and developed a framework for delivering the measurement infrastructure, enabling the quantification of benefits.

The economic literature highlights that innovation thrives where knowledge accumulation is efficient and where uncertainty in the innovation process is minimised. Romer's (1990) knowledge-production function emphasises that new ideas build on an existing stock of knowledge. In other words, new ideas being non rival and partially excludable, are elementary for growth depicting increasing returns to knowledge: a dynamic often summarised by Newton's phrase "standing on the shoulders of giants". For knowledge creation to be productive, however, the underlying measurement infrastructure must be robust enough to support reliable experimentation, reproducible results, and the scalable application of scientific advances.

Tassey (1982) conceptualised measurement standards as a form of "infratechnology" – technical tools that enable the development and diffusion of new technologies by reducing coordination failures and supporting their widespread adoption. Building on this, Estibals (2012) argues that *both standards and measurement protocols form part of a national infratechnology* and that infratechnologies are the *building blocks of innovation based industrial competitiveness*. Since measurement and standards act as public goods, they address market failures arising from underinvestment and coordination gaps. Swann (2009) reinforced this view, showing that metrology underpins innovation by reducing uncertainty, lowering transaction costs, and enabling interoperability across markets. Furthering this argument, Tassey (2014) explains the roles of standards in the knowledge economy. He reasons that standards support the production and use of technical information within knowledge-intensive industries that drive technological change, contributing to the generation of economic benefits. Recent work by Blind further strengthens this perspective by situating standards, regulation, metrology, conformity assessment and accreditation within the broader architecture of the national quality infrastructure. Blind (2024) shows that these elements collectively shape socio-technical transformations by enabling coordination, reducing uncertainty, and influencing the direction of technological change across sectors. His wider body of research demonstrates that standards and regulatory frameworks operate both as drivers and constraints of innovation, affecting firm-level behaviour, knowledge diffusion, and the emergence of new technologies. While these contributions predominantly adopt a microeconomic and institutional perspective, they highlight the systemic role of the quality infrastructure in supporting innovation: an insight that complements the macroeconomic approach explained in this report to evaluate the value measurement brings at the economy level.

This report synthesises and operationalises these insights by drawing together a body of empirical and analytical evidence developed by NPL economists. Building on the theoretical understanding of knowledge accumulation, infratechnologies, and standards as public goods, the report organises the evidence into two economic channels. In doing so, it moves beyond conceptual arguments and provides a coherent evidence-based account of how productivity growth is enhanced through measurement advances and innovation which itself is underpinned by the measurement infrastructure.

The two broad economic channels that capture the primary mechanisms through which NMS delivers value are:

- **Delivering Measurement Infrastructure**
  This channel focuses on the role of NMS labs in providing certified reference materials and calibration services traceable to national standards, and knowledge transfer (trainings and consultancy) in reducing uncertainty, improving reliability, and safeguarding productivity across the economy.

- **Enabling Technological Change (Innovation Benefits)**
  This channel highlights how in-house and collaborative R&D with NMS labs' support accelerate innovation, strengthen private sector capabilities, and enhance overall economic performance.

The Measurement Infrastructure stream is supported by a framework comprising multiple models that quantify the impact of the absence of a domestic National Metrology Institute (NMI). In contrast, the Innovation stream focuses on key themes where evidence has been developed and, where possible, explains the models that underpin the evidence. Certain studies are purposely discussed in greater detail as they form the backbone of the evidence base.

The summary of evidence presented in this report primarily revolves around these core economic channels, which form the foundation of our analysis. While these economic mechanisms are central, they do not encompass the full spectrum of benefits. Beyond these are broader benefits that can be viewed through different lenses. For instance, societal benefits – these include quality of life and environmental benefits. Another is the analysis of the contributions made within the theme of national challenge areas that align with priorities at a macro level. While this report touches on these thematic benefits, they will be explored in greater depth in separate, dedicated reports to ensure a comprehensive understanding of their significance.

The report is structured as follows: Section 2 introduces the two principal economic channels through which the National Measurement System (NMS) delivers impact and also discusses the drivers for innovation in both the measurement and non-measurement sectors. Section 3, the Measurement Chapter, examines the infrastructure that underpins reliable measurement, and quantitative models such as **the Fan-Out and Uptake of Traceable Calibrations Model** and the **Optimal Testing Frequency Model** that assess the economic consequences of reduced access to high-quality calibrations. Section 4, the Innovation Chapter, focuses on how support from the NMS labs accelerate technological change, supported by econometric analysis. Section 5 brings the two channels together and calculates the **value for money** they generate collectively. Section 6 broadens the lens to consider **Societal Benefits**, highlighting contributions to healthcare outcomes and environmental sustainability and explores another lens through which evidence can be examined i.e. the **National Challenge Areas**. It maps NMS labs' contributions to UK strategic priorities: Prosperity, Environment, Health, and Security & Resilience. Finally, Section 7 synthesises the findings, and identifies areas for future work.

2 Channels of Impact

As the requirements of modern measurement shift with new scientific and technological developments, there is a need for an infrastructure that can adapt and support the needs of its economy. The National Measurement System plays an important role here where it delivers impact through two economic channels. This section explains these channels in detail.

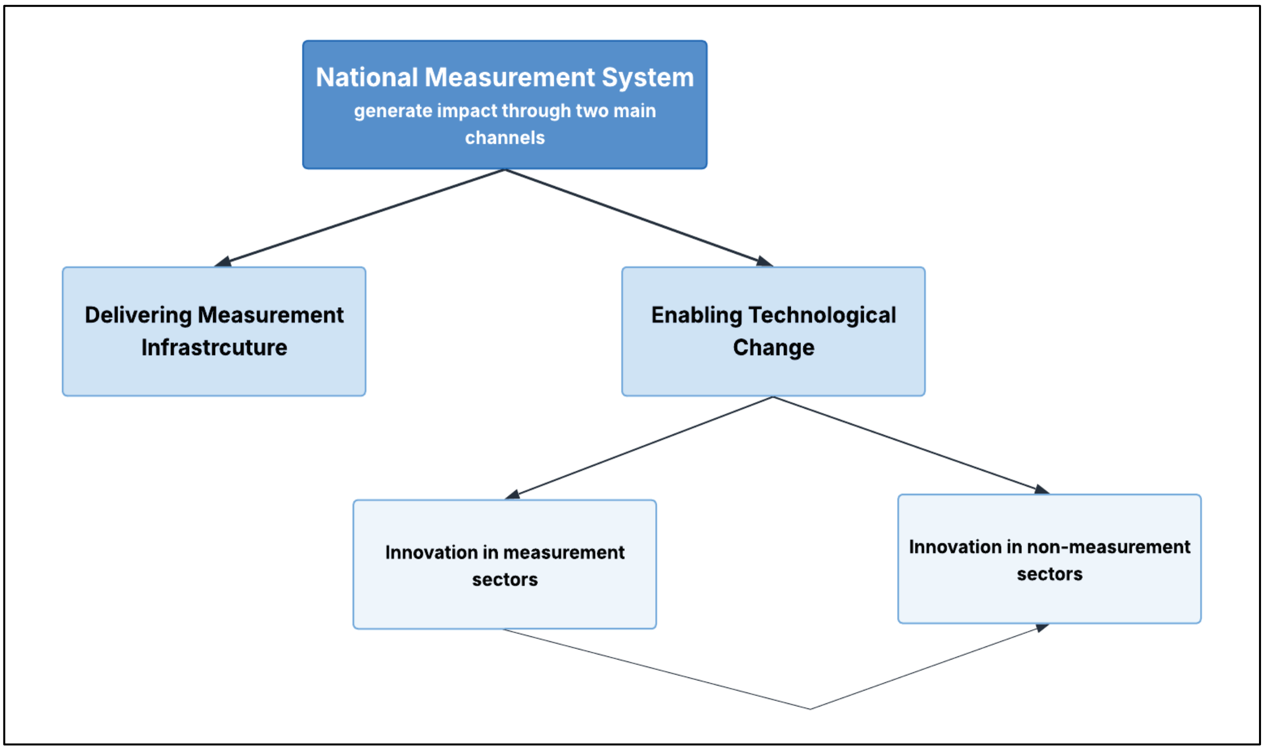


Figure 1 Channels of impact

'*Delivering measurement infrastructure'* is the system of existing primary standards, traceability chains, calibration services, reference materials, and high-quality instrumentation that ensures measurements remain accurate, comparable, and internationally recognised. These elements form the foundational architecture on which reliable production, compliance, and trade depend. The infrastructure is maintained by the National Measurement System (NMS) laboratories which is explained in detail via the models below. This ensures that firms across the economy can access low-uncertainty measurement services that anchor conformance testing, support regulatory assurance, and reduce costly errors.

'*Enabling Technological change (Innovation Benefits)'* explains the innovation that takes place both within the measurement sector and across the wider economy with the support of NMS labs. Innovation within the measurement sector includes advances in primary standards, new calibration capabilities, new and improved instruments, new reference materials, and new/ improved measurement methods. These innovations upgrade the measurement infrastructure itself. In turn, this enhanced infrastructure enables innovation in non-measurement sectors, where firms rely on precise measurement to increase the productivity of R&D, reduce technical risk, meet regulatory requirements, and scale new technologies.

2.1 Delivering the Measurement Infrastructure

NMS labs are the source that provides certified reference materials and calibrations, traceable to national standards, delivered through a network of accredited labs. The framework for the measurement infrastructure is based on assessing the impact that would arise if traceable measurements were no longer provided by a domestic national metrology institute (NMI). To assess the economic value of having a domestic National Metrology Institution (NMI), the framework uses two components. The first is the ***Fan-out and Uptake***

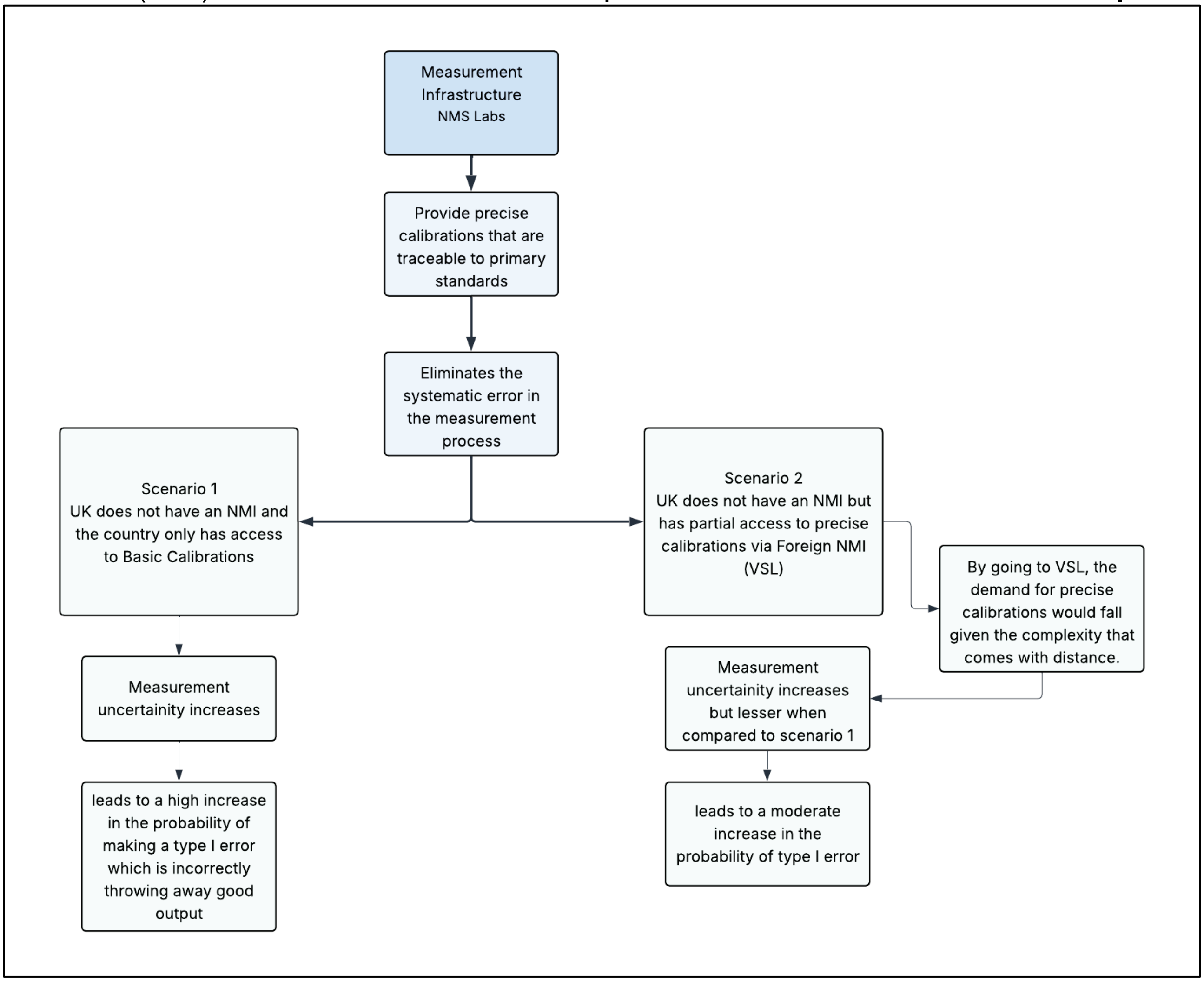


Figure 2 Framework for the measurement infrastructure

of Traceable Calibrations Model, which examines how access to high-quality calibrations influences economic outcomes. It further includes three models: an error model that measures the cost of incorrect acceptance or rejection in measurement processes (Type I and Type II errors), a distinction between basic and high-precision calibrations, and a gravity model that shows how distance affects the uptake of precise calibration services. Together, these factors highlight the role of a domestic NMI in reducing errors and ensuring widespread access to reliable measurement services. Figure 2 shows the structure of the model. Details of which can be found in section 3.4.

The second component of the framework is the ***Optimal Testing Model***, which uses a macroeconomic approach to determine the economically efficient level of conformance testing in an economy.

Drawing on principles from the Solow growth model, it balances the marginal benefits of additional testing against its costs to find the optimal testing frequency. It essentially draws out the effects of additional testing on a production process. Through the model, the probability of type I error is calculated which is then used in combination with the relative standard deviation of a measurement process to link it to the calibration uptake framework. In this way, the economic consequences of not having a domestic NMI can be estimated such as higher error rates, reduced precision, and increased spatial barriers—providing a comprehensive picture of the importance of a domestic NMI.

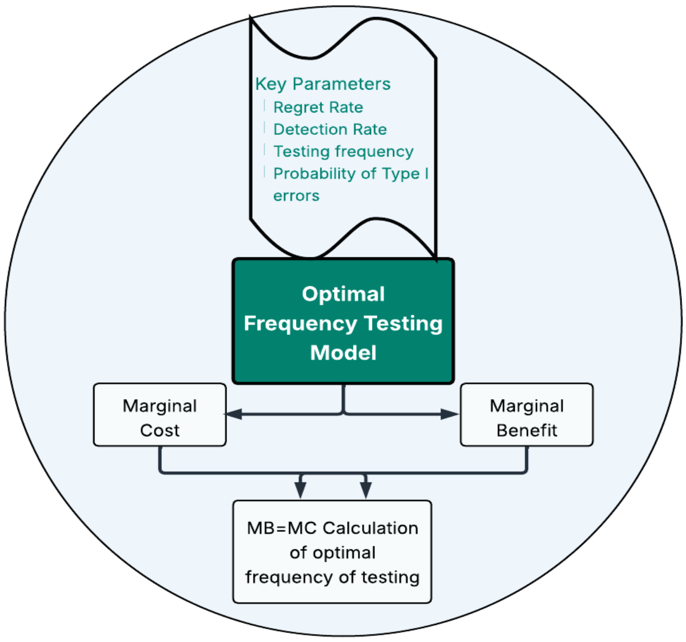


Figure 3 Optimal Testing Frequency Model

To summarise, this model is plugged into the framework shown in figure 2 which explains the role of NMS labs, and the impact within two scenarios where UK has limited/ no access to precise calibrations.

2.2 Enabling Technological Change (Innovation Benefits)

2.2.1 Drivers of Innovation in the measurement and non-measurement sectors

This section examines the key drivers of innovation both within the measurement sector and across the wider economy. It describes how improvements in measurement capability – instrumentation, standards, and validation activities underpin and catalyse innovation in non-measurement sectors.

Advancing Measurement Capability in the Measurement Sector

The primary role of National Measurement System (NMS) laboratories is to develop, maintain, and advance the UK's measurement infrastructure. This includes the provision of primary standards, traceability chains, calibration services, reference materials, and measurement expertise that underpin confidence in measurement across the economy. In short, supporting the measurement sectors of the economy.

NPL created a new type of carefully structured material that repeats in a very regular pattern at an extremely small scale, helping solve the challenge of finding reliable reference materials for tiny, microscopic measurements. As microscopes become more powerful, it's getting harder to trust their built-in scales, so researchers increasingly need reliable test materials to confirm the images they produce are correct. NPL's material provides a consistent, extremely fine pattern that microscopes can use as a reference point. This innovation is now being taken up by industry, meeting a growing need for better calibration tools in a field that has traditionally relied on much harder, inorganic materials.

Another example is, Photovoltaic panels are now widely used to power homes and businesses. Organic solar cells, which rely on carbon-based materials, could lower costs and boost efficiency, but their performance still needs to improve before they can compete with traditional silicon cells. Progress in this area has highlighted how strongly a material's morphology affects device efficiency. Until recently, however, it was hard to measure how structure and electrical behaviour interact. NPL's work showed that both surface and subsurface electrical and structural information, down to around 20 nanometres, can be captured using photoconducting atomic force microscopy (pc-AFM). By using a nanoscale probe to map topography and photocurrent at the same time, the technique offers new insights that can support the development of more efficient organic solar technologies.

Instrumentation is another important driver that occupies a somewhat hybrid position within the system. On one hand, the development of advanced measurement instruments falls within the measurement sector itself, involving new sensing principles, improved accuracy, and expanded operating regimes. On the other hand, instrumentation functions as a conduit through which advances in measurement capability are transmitted into wider innovation activity. This can be illustrated by NPL development of a micro vibration platform for ESA that can detect vibrations from satellite subsystems with unprecedented accuracy. Satellites are sensitive to even tiny vibrations, which can blur images and reduce the accuracy of long-distance measurements. These vibrations come from onboard equipment such as solar array drives and rotating cryocoolers. To improve the precision of Earth-observation data, ESA needed a way to measure and correct these micro-jitters. NPL's system can be applied to small, precisely controlled forces and torques, allowing instruments to be shaken in six degrees of freedom. Its lower section isolates the platform from environmental noise such as footsteps, so the upper section can measure micronewton-scale vibrations without interference. Housed in a tent to reduce airflow disturbances and operable in vacuum, the platform enables both the characterisation of internal vibrations and the testing of satellite components under controlled vibration conditions. The resulting gains accrue not to the measurement sector itself, but to applications in climate monitoring, navigation, and environmental science that rely on high-quality observational data.

These activities are a necessary precursor to innovation in non-measurement sectors. Without sustained innovation within the measurement system itself, its ability to support R&D, standards, and regulation elsewhere would erode over time.

Enabling Innovation in Non-Measurement Sectors

There are some core drivers underpinned by measurement that enable innovation in other sectors. **Enhanced productivity of R&D** being one of them. As discussed in the literature section, measurement and standards being infra technologies[3] improve the efficiency of knowledge production. In practical terms, measurement infrastructure enables R&D teams to distinguish real performance improvements from experimental noise. Without reliable measurement, R&D effort becomes less productive: learning is slower, false technological paths may be pursued, and promising innovations may fail to translate beyond the laboratory.

This mechanism is visible in NPL's work in adapting a high-temperature particle-erosion measurement technique to create a new system that can detect micrometre-scale erosion on fast-moving wind-turbine blades. ETC carries out water-droplet erosion testing on wind-turbine blades, as erosion can reduce efficiency and cause power losses of 3–5%. They wanted a way to detect micrometre-level changes on blades moving at up to 150 m/s. NPL identified that a technique originally developed for monitoring particle erosion in high-temperature power-station environments could be modified for this purpose. With targeted adaptations and the addition of a high-speed camera and specialist software, the system could analyse data in real time. Testing showed that the instrument could accurately measure known defects down to just a few micrometres.

Measurement infrastructure also reduces technical and commercial risk by limiting reliance on trial-and-error experimentation. For instance, NPL incorporated a commercial air-forcing temperature system into its low-magnetic-field facility, creating a setup that enables accurate temperature calibration of magnetic sensors for the oil and gas industry under extreme conditions. Magnetic sensors used in sectors such as oil and gas must remain accurate in both very hot and very cold environments. For exploration and prospecting, companies need confidence that sensor readings taken during development and calibration will remain reliable once deployed in the field. Without specialist tools, large discrepancies can arise between laboratory measurements and real-world performance. NPL's experts, working within state-of-the-art magnetic measurement facilities, adapted their environment to allow sensors to be tested at a wide range of temperatures. By integrating an air-forcing

[3] Infratechnology refers to the technical knowledge, methods, and institutional capabilities that underpin R&D and production, but themselves can't constitute marketable products.

temperature system into the low-field facility, the team enabled precise temperature-dependent calibration. This has strengthened the accuracy of magnetic-field sensing and supports applications not only in oil and gas but also in space, geology, and automotive technologies.

As innovations move from research into application, **standards** offer a critical mechanism for translating R&D outputs into scalable and marketable technologies. Standards form part of the infrastructure for innovation by providing agreed methods, definitions, and performance metrics that enable comparability, interoperability, and trust. Key roles that standards play are as follows:

- NMS laboratories enable experimental results to be reliably replicated, industrialised, and scaled up by providing the measurement science and validation needed to establish credible standards in emerging or technically complex areas. Research at NPL, working with vision science laboratories across Europe, revealed how the eye's sensitivity shifts in brighter conditions and responds best to several light sources. Most road and public lighting is designed for full darkness, yet 40% of accidents occur at twilight, despite only a quarter of journeys happening then. While the eye's behaviour in bright and low light is well understood, much less was known about its performance during the transition between the two 'the mesopic region[4]'. Using its findings, NPL collaborated with international researchers through the CIE to develop a new globally accepted measurement scale that accounts for this change in visual sensitivity. This now enables the design of lighting optimised specifically for mesopic conditions.
- Standards also facilitate **certification and market access** in regulated supply chains. In the aerospace sector, NPL carried out a Nadcap-aligned Gap Analysis to help Aeromet identify weaknesses in their processes before undergoing formal accreditation. Aeromet International Ltd, a global leader in aluminium castings, was required by one of its major customers to achieve Nadcap M&I[5] accreditation. NPL's measurement specialists supported Aeromet by reviewing their procedures using the same structure as a Nadcap audit, pinpointing any areas that could lead to

[4] The mesopic region is the intermediate lighting range between photopic (daylight) and scotopic (nighttime) vision

[5] National Aerospace and Defence Contractors Accreditation Program (Nadcap), Measurement & Inspection (M&I). This accreditation demonstrates that a company's measurement and inspection systems meet the rigorous, standardised audit criteria used across the aerospace sector, helping ensure consistency, quality, and safety.

non-conformance. This enabled Aeromet to address issues in advance and strengthen their readiness for the accreditation process.

- In emerging markets, standards also help **define products and their commoditisation process**. NPL's direct support in the development of ISO standard for fibre-reinforced composites made material qualification easier and more cost-effective for the initial preliminary design and material down selection. Because there has been an increasing demand for composite materials as they are seen to be lighter, stronger, and durable in comparison to traditional materials, some industries had already adopted while others were yet to embrace it, so the standard itself received strong international support due to its relevance and need.
- Standards have a role in **developing market confidence** which reduces information asymmetries influencing commercial decisions and supply chains. For instance, the role NMS labs have played in key initiatives like the Measurement for Innovators (MFI) and Analysis for Innovators (A4I) programmes, providing subsidised consultancy support to firms (primarily SMEs) who face technical challenges in product and process development. One example is where; AgPlus Diagnostics developed a portable point-of-care diagnostic platform capable of rapidly detecting a wide range of illnesses from blood or saliva samples. During scale-up, however, high failure rates in the manufacture of screen-printed electrodes constrained further commercialisation. Under the A4I programme, NPL's Electrochemistry Group investigated the failures using spectroscopy and microscopy to link electrode structure and manufacturing parameters to electrochemical performance. This analysis identified unsuitable printing thickness as the root cause, enabling process optimisation and supporting the successful mass production of the diagnostic platform.

Moreover, Briscoe Advisory Ltd as part of the NMS qualitative assessment programme conducted qualitative standards-focused research[6] in which the respondents said:

"Compliance with international standards is vital for trade, and NPL's role in international debate and measurement exercises is highly valued."

[6] Briscoe Advisory Ltd. *NPL Standards Qualitative Assessment: Interview Findings 2023–2024*. National Physical Laboratory. *Forthcoming*

"NPL plays a vital role in helping firms understand, comply with, and develop standards—but must remain nimble as emerging technologies often outpace existing standards, leading to unvalidated claims and early-stage risk."

Reliable measurement evidence is also important for **regulatory** acceptance, removing barriers to market entry and enabling innovative technologies to be deployed with confidence. For instance, NPL validated a new instrumental method for measuring SO_2, allowing regulators to approve it as equivalent to the mandated Standard Reference Method. The Aphekom project showed a clear linear link between SO_2 pollution and mortality, probing the vitality for reliable monitoring of industrial SO_2 emissions. Although emissions are controlled under the Industrial Emissions Directive 2010/75/EU, the required Standard Reference Method is an off-line wet-chemistry technique. There are other less labour intensive i.e. more automated alternatives but can only be used once formally accepted by national regulators. To enable this, NPL led the validation work needed for regulatory acceptance, demonstrating using the CEN/TS 14793[7] equivalence procedure that the instrumental method performs to the same standard as the SRM. This resulted in formal regulatory approval and opened the way for more efficient SO_2 monitoring.

[7] CEN/TS 14793 is a European Technical Specification that defines how to validate an alternative measurement method by comparing it with a reference method for emissions from stationary sources.

2.2.2 Productivity Growth through technological change

All economic benefits that arise from the National Measurement System are a form of productivity growth. Each year, NPL's spending on R&D yields new knowledge, increasing the stock of knowledge that is relevant to metrology and measurement science. Under this channel, there are three ways through which the knowledge accrued by NPL can increase the Total Factor Productivity of its regular users:

- Firms can access new knowledge by engaging in collaborative R&D projects with NPL scientists. These collaborations are an effective way to transfer expertise that are difficult to codify
- NPL's knowhow can enhance a firm's own R&D activities more effective, increasing the likelihood of successful innovations. That is, there are increasing returns to knowledge, which economists refer to as the effect of "standing on the shoulders of giants". (The quote is attributed Isaac Newton in a letter he wrote to Robert Hook.) So, by this means, there is an increase in the amount of relevant technological knowledge produced per £1 million of a firm's own R&D spending.
- Scientific advances enable NPL to introduce new measurement services (calibration services and reference materials) and helps it to improve and update its existing measurement services. That is, the new knowledge is embodied in the new and improved measurement services that NPL provides to its customers.

How does the mechanism work?

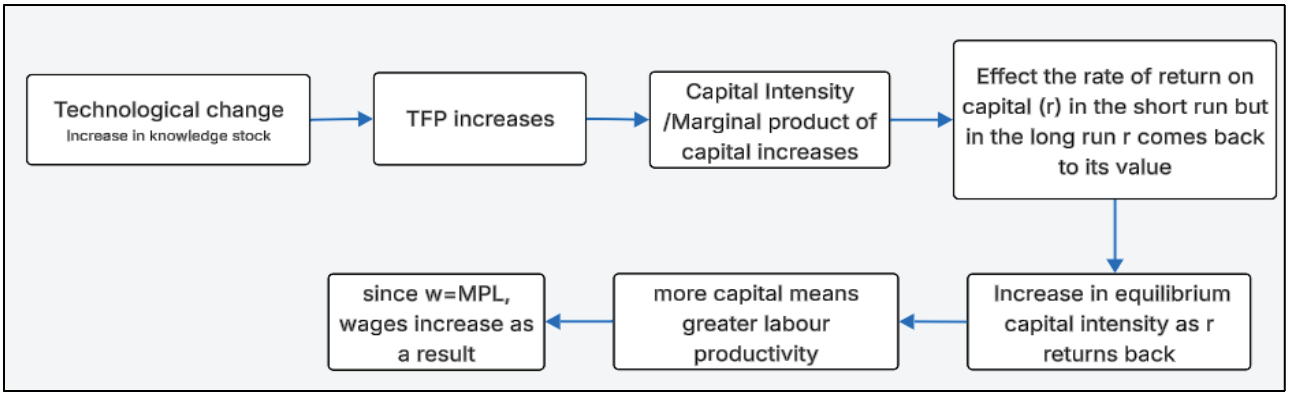


Figure 4 Productivity growth through technological change

The role that NMS laboratories play in supporting industry builds on and adds to the existing stock of technological knowledge, and this expanded knowledge base ultimately translates into higher Total Factor Productivity (TFP).This in turn raises the cost of capital. This effect, however, is only temporary, as the return on capital (r) is assumed to adjust back to its long-run equilibrium value. To restore balance in the system, the increase in TFP leads to higher capital intensity. And because wages are determined by the marginal product of labour which depends on capital intensity translates into higher wages.

Section 4 takes a deeper look at how these mechanisms play out in practice by drawing on the econometric evidence developed. It examines how firms that regularly receive support from the NMS labs experience stronger innovation performance, better growth outcomes, and improved productivity.

3 Delivering the Measurement Infrastructure Chapter

This chapter examines the UK's measurement infrastructure, which underpins confidence in data, compliance, and innovation across the economy. It begins by exploring the foundations of metrology and the International System of Units (SI), highlighting how measurement standards evolve with scientific progress rather than remaining static. The discussion then considers the UK Quality Infrastructure (UKQI), positioning the National Measurement System (NMS) under the metrology pillar within the infrastructure. Building on this, the section outlines the core functions and services delivered by the NMS laboratories, before turning to the economic significance of measurement activities and quantitative models that assess the contribution of NMS laboratories to productivity and reliability. Together, these elements demonstrate the importance of the presence of a robust measurement system.

3.1 Building and Maintaining SI

Measurement infrastructure refers to the systems, institutions, and scientific principles that ensure the reliability, consistency, and international comparability of measurements. At its core lies metrology: the science of measurement which provides the theoretical and practical foundation for accurate and reproducible data across sectors. From industrial manufacturing and healthcare diagnostics to climate science and trade, metrology enables trust in measurements that underpin decision-making, innovation, and regulation.

Historically, measurement standards were based on physical artefacts such as the international prototype of the kilogram. However, these artefacts posed challenges due to degradation and limited reproducibility. Today, standards are increasingly defined by fundamental physical constants, such as Planck's constant and the speed of light, reflecting a shift towards universality and scientific precision. Redefining the kilogram using Planck's constant eliminated drift from the old physical artefact, providing a stable and universally reproducible standard. It also enabled all national metrology institutes to realise the kilogram independently using quantum-based methods, improving global consistency[R37]. This redefinition illustrates that measurement is not static; it adapts with scientific progress.

An important pillar of measurement science is **tacit knowledge** – the kind of practical, experience-based understanding that cannot be fully codified. Research on scientific and laboratory practice shows that such knowledge develops through hands-on participation, mentorship, and immersion within expert communities, where novices gradually acquire the skills, judgement, and problem-solving abilities used by experienced practitioners. This aligns with Polanyi's classic insight that "we know more than we can tell," meaning that some aspects of scientific work cannot be articulated explicitly but are learned through practice[R3,44]. A useful analogy is that of a chef, even if a written recipe exists, the subtle techniques and instincts gained through years of experience can only be passed on by working alongside an expert. Tacit knowledge functions in the same way in specialist measurement environments, where certain behaviours, troubleshooting skills, and instrument sensitivities are best learned through direct experience and observation. Therefore, making it essential to support training and knowledge-sharing so that these specialist capabilities are sustained over time. More broadly, measurement science thrives on collaboration within institutions and globally – where shared standards and joint efforts uphold the consistency and trustworthiness of measurements worldwide.

National Physical Laboratory (NPL) has long maintained a strong presence in global metrology research, consistently ranking among the leading National Metrology Institutes (NMIs) for scientific output, collaboration, and research influence. A recent bibliometric analysis (Science-Metrix, 2025) benchmarked NPL against 27 NMIs across five domains—metrology, advanced manufacturing, data & digital, life sciences & health, and energy & environment. It shows that NPL has strengthened its collaborative profile, ranking second globally for international and public-private partnerships. Its International Collaboration Rate rose from 50.8% to 62.1% since 2021, with a ten-year average of 59%, reflecting deep integration within global research networks. In metrology specifically, NPL ranked fourth worldwide for publication volume and third for scientific impact, while its Public-Private Partnership score increased from 15.0% to 22.7%, underlining its growing role in translating measurement science into industrial application. NPL also ranks among the top three NMIs for altmetric[8] performance, indicating wide reach and engagement beyond academic

[8] Altmetric performance refers to the online attention and engagement a research output receives, tracked by alternative metrics (altmetrics) that go beyond traditional citations. It is measured by monitoring mentions across various online sources like social media, news outlets, blogs, and policy documents, which are then aggregated into a single Altmetric Attention Score

communities. Collectively, these indicators demonstrate NPL's central role in converting measurement science into practical applications, supporting innovation through collaboration, and amplifying the UK's global research standing[R55]. However, bibliometric trends also show that NPL like several long-established NMIs has experienced a slight decline in its share of global metrology publications in recent years, while institutes such as China's National Institute of Metrology (NIM) have expanded rapidly as a result of sustained strategic investment. Moreover, survey insights[R23] depict that around 68% of users of the NMS labs report having access to alternative sources of support, of which around 14% are able to draw on foreign NMIs services. These responses underline the importance of ensuring that the UK's metrology capabilities continue to evolve and remain well aligned with user expectations.

To summarise, National Metrology Institutes (NMIs) are fundamental for providing economies with a robust measurement infrastructure – to not only keep pace with global scientific advancements but also to translate and disseminate updated standards, methods, and calibration capabilities nationally, ensuring traceability, consistency and comparability across all sectors within and outside the country.

3.2 UK Quality Infrastructure

The UK Quality Infrastructure (UKQI) refers to the national framework of institutions, processes, and assurance mechanisms that ensure products, services, and systems in the UK meet recognised standards of quality, safety, and reliability. It underpins domestic regulation, supports international trade, and provides confidence for consumers, businesses, and regulators. The UKQI is overseen by the Department for Business and Trade (DBT) and the Department for Science, Innovation and Technology (DSIT) and is delivered through a set of core institutions. The key components of the UKQI are:

- **Metrology** – Scientific measurement standards and traceability

  It is led by the National Physical Laboratory (NPL), the UK's National Metrology Institute and the National Measurement System Laboratory and supported by other Designated Institutes (DIs) such as NML at LGC, TÜV-NEL, and NIBSC.

- **Standardisation** – Development and maintenance of technical standards

  It is delivered by the British Standards Institution (BSI), which represents the UK in international standards bodies and develops consensus-based standards that support innovation, interoperability and global market access.

- **Accreditation** – Assurance of competence of assessment bodies

  It is overseen by the United Kingdom Accreditation Service (UKAS), which evaluates and formally recognises the competence of organisations that carry out testing, inspection, certification and calibration. Accreditation provides confidence that conformity assessment is robust, impartial and internationally accepted.

- **Conformity Assessment** – Testing, inspection and certification

  It is delivered by a wide network of accredited bodies across the UK that perform independent testing, inspection and certification to verify that products, systems and services meet specified standards or regulatory requirements. This supports trust, market access and regulatory compliance.

- **Market Surveillance & Regulatory Oversight –** Ensuring product safety and legal compliance

It is coordinated by the Office for Product Safety and Standards (OPSS) and other regulators like MHRA, Environment Agency, Ofgem, Building Safety Regulator. It has two other main components:

Legal Metrology (Trading Standards) – It is delivered by local authority Trading Standards, who enforce weights and measures legislation and check the accuracy of measurement instruments used in trade. They support fair trading and assist in local market surveillance.

Public Analysts – It is delivered by Public Analyst laboratories, which carry out statutory testing of food, consumer goods, and environmental samples to support regulatory decisions.

Within UKQI, **Measurement Infrastructure** is a subset focused on metrology and traceability. A critical part of this infrastructure is the **National Measurement System** (NMS), which has a distributed network of core labs that are designed to ensure measurement reliability and global consistency. This structure enables comparability of measurements across diverse organisations, even those not directly using top-level labs. By linking UK measurements to the International System of Units (SI), the NMS participates in international key-comparison exercises to uphold Mutual Recognition Arrangements (MRAs), which remove technical barriers to trade and support global market access[R9,47].

3.3 Core functions and services of NMS Labs

Under the measurement infrastructure, standards, calibration, reference materials and instrumentation form a hierarchical and interconnected system where each plays a critical role in ensuring reliable measurements. Standards provide the foundation by defining units and serving as reference points. Calibration builds on these standards to verify the accuracy of instruments, while reference materials validate analytical methods and support calibration, particularly in chemical and biological measurements. And instrumentation enables the practical application of these principles by providing the tools for measurement. The NMS labs have an integral role to play in this system. Below are the essential functions and services delivered by these labs [R33, 34, 35,36].

Core Functions of NMS Laboratories:

1. **Development and Maintenance of National Standards**
   NMS labs maintain the UK's primary measurement standards across physical, chemical, biological, and engineering domains, ensuring traceability and international equivalence.

2. **Realisation and Dissemination of SI Units**
   They realise and disseminate SI units (e.g., kilogram, second, metre), enabling consistent and accurate measurements across the UK.

3. **Measurement Science and Innovation**
   NMS institutes conduct world-class research to develop new measurement methods and technologies, supporting national priorities such as quantum, digital, healthcare, and net zero.

4. **Support for Regulation and Public Protection**
   They provide measurement assurance for food, water, air quality, medicines, and infrastructure, supporting regulatory bodies and statutory functions like the Government Chemist.

5. **International Comparability and Standardisation**
   NMS labs participate in global inter-laboratory comparisons and contribute to international standards, ensuring UK measurements are recognised worldwide.

6. **Knowledge Transfer and Capacity Building**
   Through training, publications, and consultancy, NMS disseminates best practices and builds national capability in measurement science.

Core Services of NMS Laboratories:

- **Calibration and Testing Services**
  NMS labs offer traceable calibration and testing services to industry, academia, and government, supporting quality assurance and compliance.

- **Reference Materials and Standards**
  NMS institutes develop and distribute certified reference materials and national standards for chemical, biological, and physical measurements.

- **Support for National Infrastructure**
  They contribute to critical infrastructure projects such as the National Timing Centre, ensuring secure and resilient timekeeping.

- **Collaborative Research and Innovation Support**
  NMS labs work with businesses and public sector organisations to co-develop new products, processes, and infrastructure aligned with strategic national goals.

- **Consultancy and Technical Advice**
  They provide expert advice on measurement challenges, regulatory compliance, and innovation support.

- **Training and Skills Development**
  They deliver training programmes to upskill professionals and support the next generation of metrologists.

The tree diagram below provides a visual representation of how the UK's National Measurement System (NMS) operates and delivers value.

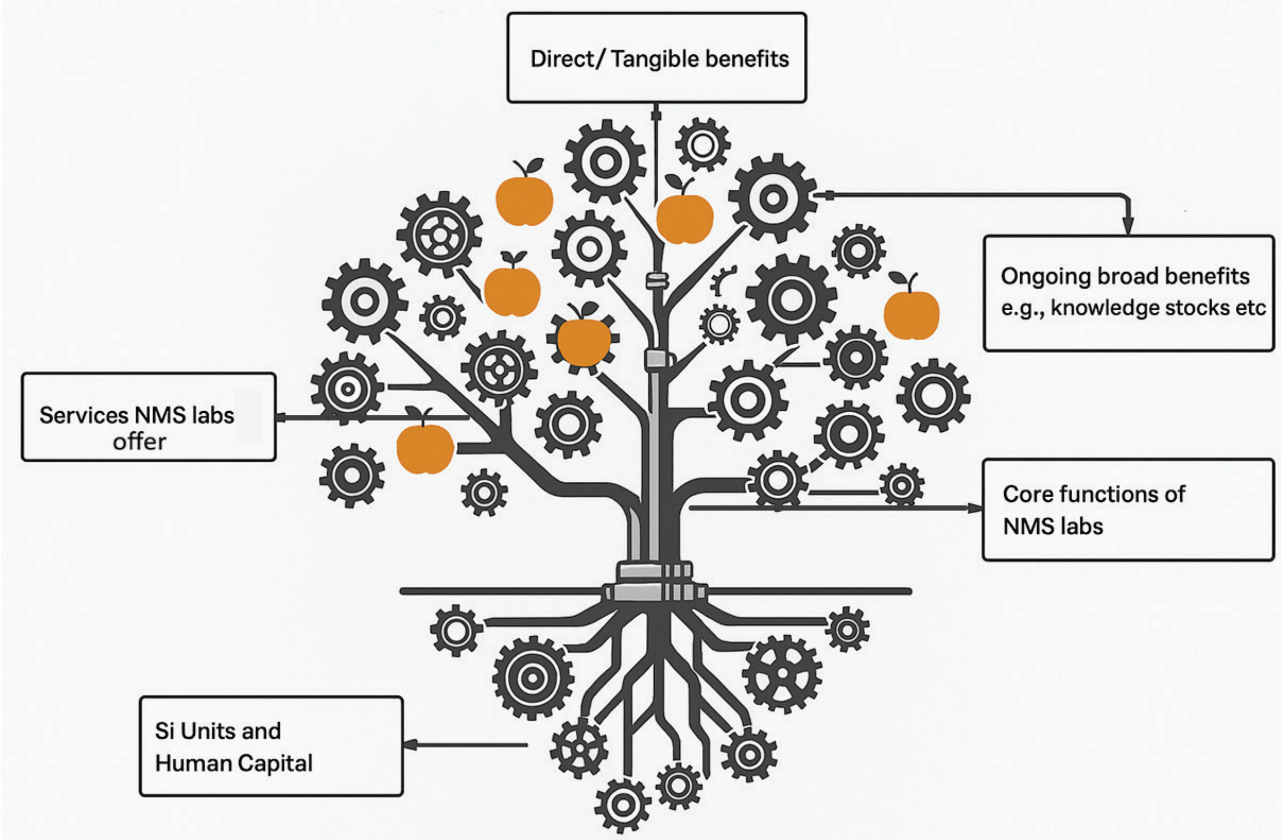


Figure 5 Tree Analogy for the core functions and services of the NMS labs

Roots – Foundational Enablers: The National Measurement System (NMS) rests on a strong foundation of resources and principles that ensure its credibility and effectiveness. These include the realisation and maintenance of SI units, a highly skilled workforce of metrologists and technical experts, advanced laboratory infrastructure, and alignment with international standards.

Trunk – Core Functions of NMS Labs: At the heart of the NMS are its core functions, which sustain the integrity of measurement science. These functions encompass the development and maintenance of national measurement standards, conducting research in metrology, ensuring traceability to SI units, and participating in international comparisons to uphold global confidence. These activities form the backbone of the UK's measurement capability.

Branches – Services NMS Labs Offer: Building on their core functions, NMS laboratories deliver a range of services to industry, government, and academia. These services include calibration and testing, technical consultancy, training and knowledge transfer, and certification to support compliance. By providing these practical applications, NMS labs enable businesses and regulators to operate with precision and confidence.

Fruit – Direct and Tangible Benefits: Fruit represents the immediate, measurable outcomes of NMS activities that directly impact businesses, regulators, and consumers. They reflect the practical value derived from accurate and traceable measurements e.g. improved product quality and reliability, compliance with national and international regulations, reduced transaction costs and disputes, and enhanced market access and trade facilitation

Leaves – Ongoing Broad Benefits: Leaves symbolise the wider, long-term advantages that extend beyond direct measurement services. These benefits are less visible but essential for sustaining innovation, competitiveness, and societal well-being e.g. accumulation of knowledge stocks and technical expertise, enabling innovation, enhancing productivity, and supporting international competitiveness and collaboration.

3.4 Measurement in the economy

Measurement constitutes a foundational element of economic systems, enabling innovation, facilitating trade, and enhancing productivity through the provision of reliable and comparable data. This section examines the economic dimensions of measurement within the United Kingdom, drawing on an extensive study conducted by NPL economists[R16]. The analysis quantifies measurement-related activities within the UK economy including labour input, capital investment, intermediate demand, and research and development. By elucidating the scale, structure, and impact of measurement across the economy, the report provides an evidence base for the importance of measurement, and the role NMS plays in its maintenance and development.

Labour Input – In terms of labour input, approximately **6.3%** of UK employment in 2017 was in measurement-related roles, equating to around **2 million people**, representing a 13% increase since 2007. Total compensation for these roles amounted to **£58.3 billion**, or 2.8% of GDP. Within this, calibration and testing services employed 162,000 individuals, earning a combined £4 billion. While employment in measurement grew faster than overall employment, real wages in the sector declined by 20% over the decade.

R&D for Measurement – Measurement-related R&D expenditure in 2017 exceeded **£2 billion**, with 87% performed by private businesses. Measurement patents accounted for **7.5%** of all UK patents, approximately 16,000 over ten years, while measurement-related academic papers represented 2.4% of UK publications (about 21,000 papers). The estimated GDP contribution from measurement R&D ranged between £3.2 billion and £4.9 billion, and the UK demonstrated a Revealed Comparative Advantage (RCA)[9]; meaning UK grants 1.04 times as many measurements related patents than its fair share[10]. The UK ranks average among peers such as Germany, France, Japan, and the United States in measurement R&D intensity. It shows RCA in business R&D, but not in academic R&D.

Instrumentation – The study shows that the annual investment in instrumentation for the UK (reported in 2017) is nearly **£3.6bn** with an intermediate demand of £9bn and so the rest

[9] A Revealed Comparative Advantage (RCA) is an index used in international economics to show whether a country is relatively more specialised in exporting a particular good or service compared with the rest of the world.

[10] Fair share factor is calculated by taking the difference of the average measurement R&D intensity in a country and the total world measurement R&D intensity.

is imported. The amount invested in instrumentation is 7.2% of the total invested in machinery and equipment. The gross capital stock for instrumentation is **£36.8bn**.

This work ensures that instruments used in industry and research can deliver reliable results. The NMS labs in particular NPL has a role to play in this sector. It designs, manufactures, and delivers highly precise metrology instruments, sensors, and artefacts, offering both standard solutions for general measurement needs and bespoke instruments tailored to complex technical challenges. In addition, NPL provides consultancy and training in instrumentation and measurement science.

Testing & Analysis – Assessments by Grand View Research[R18], based on a 2024 base-year dataset, place the value of the UK testing, inspection, and certification (TIC) sector at USD 18.0 billion in 2024. When converted using the average 2024 USD–GBP exchange, corresponds to an estimated **£14 billion** per year of which **78%** is for testing. The Grand View analysis aggregates industry revenues across testing, inspection, and certification services delivered to UK manufacturing, construction, healthcare, energy and other regulated and engineering-intensive sectors, making it one of the most comprehensive UK-specific TIC market evaluations available. This provides a robust basis for understanding the scale of economic activity underpinned by measurement, assurance and conformity assessment services within the UK economy.

Calibration – To approximate the size of the UK's calibration services market, we apply two complementary proportional-scaling methods: one based on overall economic size (GDP) and one based on the value added in the manufacturing sector for Uk and the whole of Europe. In 2023, Europe's total GDP is valued at £21.55 trillion[11], while the UK's GDP is £2.69 trillion. Dividing the UK's GDP by Europe's GDP gives a proportional share of 12.5%, reflecting the UK's weight in the broader European economy. Applying this 12.5% economic share to the European calibration market valued at £2.2 billion[12] yields an estimated **£275 million for the UK's market for calibration services**.

The second method uses manufacturing value-added, which more closely represents sectors where calibration demand is concentrated. Europe's value-added for the

[11] The GDP values are taken from the report published by World Bank. Please see details of the calculation in the annex
[12] Reported as $2.7bn in the report. Using the rate 1$ = £0.8042, the value has been converted to £2.2bn.

manufacturing sector totals £2.1 trillion, while the UK's value added for the sector is £224 billion, implying that the UK accounts for roughly 10% of Europe's manufacturing base[13]. Applying this proportion to the same £2.2 billion European calibration market gives an estimate of **£220 million**. The true value is probably above because high-precision industries such as aerospace, defence, pharmaceuticals, and advanced engineering require more calibration per unit of output than general manufacturing.

Additionally, the survey results for the private businesses report that the annual spent on measurement of NMS users is **£7.7bn** which is 5% of total turnover. Out of this nearly a **fifth is spent on calibration and reference materials**, the rest goes in testing and analysis which is approximately **£6.2bn** of which nearly **£4.8bn** is for conformance testing. 50% of all measurements rely on externally calibrated instruments which is nearly **£3.85bn**[R23].

Calibration Chain and Traceability provided by the NMS labs

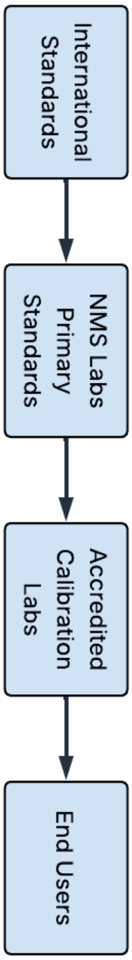
The UK's National Measurement System (NMS) through its designated institutes deliver world-class calibration and metrology services, ensuring traceability to national and international standards and because NMS labs' standards are linked to the International System of Units (SI) through the International Bureau of Weights and Measures (BIPM), this connection guarantees that measurements calibrated at NPL are recognised globally. The laboratories provide top-level calibrations across a wide range of domains:

- **National Physical Laboratory (NPL):** Offers primary standards and calibrations in time, frequency, temperature, pressure, electrical quantities, and dimensional metrology, supporting sectors such as aerospace, automotive, energy, healthcare, life sciences, manufacturing, telecommunications, etc.
- **National Measurement Laboratory (NML) at LGC**: Specialises in chemical and biological measurements, providing reference materials, calibration services, and analytical method validation for sectors like food safety, healthcare, and pharmaceuticals.
- **TÜV SÜD National Engineering Laboratory (NEL):** The UK's Designated Institute for flow measurement, NEL performs high-accuracy calibrations for single-phase and

[13] Europe's manufacturing sector value-added (source) = €2.5 trillion (£2.1 trillion with a rate of 0.86)
UK's manufacturing sector value-added (source) = £224 billion
UK's manufacturing sector value-added proportion to Europe's ~ 10%

multiphase flows, including oil, gas, water, and hydrogen, under varied pressure and temperature conditions.

The National Measurement System (NMS) laboratories sit at the top of the UK calibration hierarchy, ensuring that every measurement made in the UK can be traced back to internationally agreed definitions under the SI system. This traceability chain begins with the SI units, which provide the global foundation for measurement standards. NMS laboratories maintain these UK's primary standards and provide it to accredited calibration laboratories, such as those recognised by UKAS. These labs extend this assurance by providing it to the rest of the industry. In other words, traceable calibrations provided by the NMS cascade through the tiers of the industry. This is because, beyond direct users, **primary calibrations** behave like **information goods**: the accuracy embedded in first hand NMS calibrations is re used and resold down the traceability chain, creating large indirect benefits without additional income to the originator. Finally, end users rely on these calibrated instruments for trade, quality assurance, and regulatory compliance. The survey also reports that NMS labs work with 35% of all UKAS accredited Calibration labs. The NMS labs indirectly supported **75,500 organisations in the UK through the "fanout" of calibration services**. King and Nayak (2023) estimate that high-quality primary calibrations provided by the NMS labs significantly reduce systematic errors and



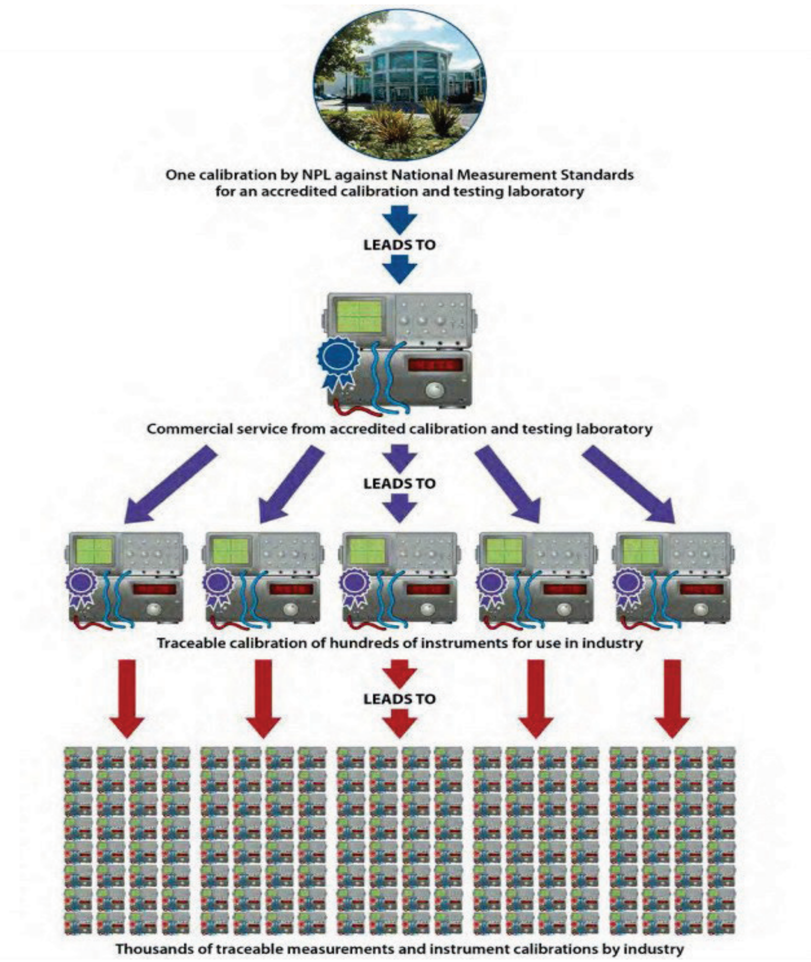
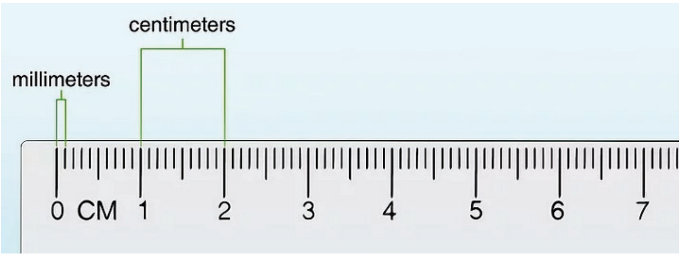


Figure 6 Traceability chain

measurement uncertainty, lowering costs in conformance testing. This improvement safeguards gross value added for manufacturing firms that use the NMS labs[R31].

Valuing information gained from measurement

To be able to quantify the value measurement brings, Qureshi and King (2025) use an approach that comes from entropy in information theory. Shannon (1948) introduced the concept of entropy as a way of quantifying uncertainty within any piece of information. New information is defined as "surprisal" and **entropy** is defined as the expected amount of "surprisal". In the context of measurement, entropy provides a natural framework for describing how better measurement means more information and thus lower uncertainty. Before a measurement is taken, a quantity is only known to lie within a broad interval. A more accurate measurement narrows this interval and therefore lowers entropy.



A simple example is that of a ruler: A ruler with just centimetres can be thought of as a basic version. A better version is one that also gives millimetres i.e. gives more information through more divisions.

Using this framework, advances in metrology can be interpreted as processes that reduce entropy and therefore generate additional information for decision-makers. Better measurement reduces the likelihood of Type I and Type II errors, lowers production and verification costs, and enables firms to operate with tighter tolerances and less waste. The model applied in the study links the informational gain (expressed in bits) to its monetary benefit by comparing the value of information to the cost of achieving improved accuracy. Through this economic model for agents maximising the net-benefit generated from better measurement information, it finds that for **£1 spent on improved measurement, the return on measurement is £1.30**. This approach provides a baseline for valuing better measurements[R46].

3.5 Quantitative Assessment of NMS labs' Contribution to Measurements

This section introduces the main study[R30] which provides the first rigorous attempt to quantify the economic contribution of a measurement infrastructure tied to the National Measurement System. King and Nayak (2025) adapt a standard growth model to reflect real-world conditions where production processes can fail and require corrective action. It highlights how measurement activities particularly those supported by NMS laboratories affect reliability in production and, ultimately, economic performance. The models link reliability and capital intensity to productivity, showing that accurate measurements and effective conformance testing reduce errors and waste. These improvements depend on the infra-technology maintained by NMS labs, which underpins calibration services and ensures consistency across the economy. Using UK data, the study estimates how changes in measurement capability influence output, and it explores scenarios where reduced access to high-quality calibrations would lead to measurable economic losses.

The following sections explain the two main components of the framework used i.e. **Fanout and Uptake of traceable calibrations model** and the **Optimal Testing model** and highlight the key methodology and findings.

3.5.1 Fanout and Uptake of Traceable Calibrations Model

This model analyses the importance of the presence of a domestic NMI in providing high quality calibrations. This component consists of **three** sub-elements: the **Type I and Type II error model**, which quantifies the economic impact of incorrect acceptance or rejection in measurement processes; the distinction between **basic and precise calibrations**, which differentiates between standard calibrations and those requiring higher precision; and a **gravity model** that captures how the uptake of precise calibrations is effected by an increase in the distance, reflecting spatial frictions in accessing high-precision measurement services.

Type I and Type II error model

The standard deviation of measurement results

Measurements come with unknown errors, but these errors will follow a known distribution. There is a trade-off between Type I error and II errors, and the trade-off depends on the standard deviation of measurement errors. To explain this, consider the following example of a piston.

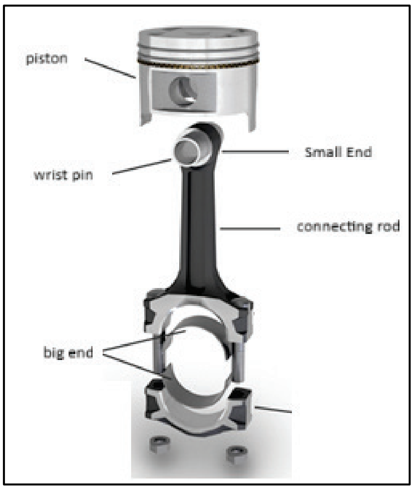


Figure 7 Piston

The piston and the connecting rod will only work if the small end is of a specific diameter. Let's say that if the measurement is off by 1mm, the small end will not fit. The deviation from the true value can be denoted as D. Here the assumption is that the production process either produces the part that conforms to $\mathbb{E}[D] = 0$ or produces a defective product $\mathbb{E}[D] = 1$.

The measured value comes with an unknown error which can be positive or negative.

$$\text{measured value} = \mathbb{E}[D] + \text{error}, \text{where error} \sim \mathcal{N}(0, \sigma^2)$$

The interpretation of σ is that it is the deviation that occurs under the hypothesis that parts are defective, known as relative standard deviation (RSD). The standard deviation depends on the expected uncertainty of measurement process. The uncertainty of measurement process incorporates random and systematic errors. Random errors are the deviations that occur due to slight changes in the conditions and can be minimised by taking repeated measurements. Systematic errors are biases that come with a specific instrument and can only be reduced/ eliminated with good calibrations.

Deriving the relationship between p, q and σ, we find that from $q = \Pr(\mathrm{T} > \Phi^{-1}(1-p) \mid \mathrm{H}_1 \text{is true})$

$$\boxed{\sigma = \frac{1}{\Phi^{-1}(1-p) - \Phi^{-1}(1-q)}}$$

With $p = 0.3\%$ and $q = 99.9\%$, relative standard deviation (RSD) is calculated to be 17.1%[14]. In the model, the power of the test is treated as non-negotiable that is, the probability of a Type II error (q) must remain constant. This reflects the assumption that buyers would not accept less rigorous testing procedures that allow more defective products to reach the market. Given this constraint, any increase in the relative standard deviation, regardless of its cause, would affect the probability of a Type I error (p). Because q is held constant, and there is a trade-off between the probability of Type I and Type II errors, this would imply that the variations in the test precision must be absorbed in p.

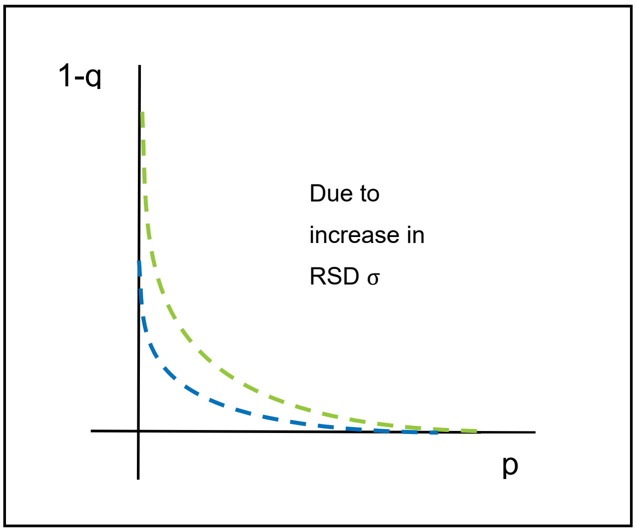


Figure 8 Relationship between probability of type I error, Power of the test and the RSD

Therefore, through derivation, an expression can be found for the change in p due to a change in the RSD.

$$\frac{\Delta p}{\Delta \sigma} \approx \frac{1}{\sigma^2} \Phi'\left(\Phi^{-1}(1-p)\right)$$

Impact of Basic and Precise Calibrations on relative standard deviation

For this part let's imagine a set of 1m rulers. Each ruler may be slightly smaller or larger but none exactly 1m. These deviations from 1m are called systematic errors. There is a term that explains the minimum threshold that metrology laboratories aim for: **Test Accuracy Ratio (TAR)**[15].

[14] Optimal Frequency Testing model is used to calculate the probability of type I error (p)
[15] An acceptable Test Accuracy Ratio (TAR) is 4:1. Useful references for this are:
Mitutoyo Institute of Metrology (n.d.) *Decision Rules, TAR, and TUR*. Mitutoyo America Corporation.
https://www.mitutoyo.com/webfoo/wp-content/uploads/15005A.pdf
https://www.duncanaviation.aero/intelligence/2019/January/aircraft-tool-calibration-what-is-test-accuracy-ratio

"TAR is the comparison between the accuracy of a tool (Unit Under Test or UUT) and the reference standard used to calibrate it. Metrology labs aim for a minimum TAR of 4:1, meaning the standard should be four times more accurate than the tool."

For the purposes of the model, we assume two grades of calibration

- **Basic calibrations:** These can reduce calibration related uncertainty. Here we suppose that the calibration related uncertainty can be as much as 25% of total uncertainty.
- **Precise calibration:** These can almost eliminate the calibration related uncertainty.

Precise calibrations are only offered by accredited calibration labs whose calibrations are traceable to the primary standards maintained by the NMS Labs. In this part the aim is to find the impact on UK businesses if they were no longer able to access precise calibrations in which case they will revert to basic calibrations.

The methodology to estimate the impact is via considering the effect on type I errors and its subsequent effect on the measurement uncertainty (RSD). The study sets up a stylised model[16] for the cost of measurement errors. the approach is to value calibration services in terms of the extent to which precise calibrations help reduce mistakes that come with measurements. We find that the relative standard deviation has two components; one which is not affected by calibrations ($\sigma_0{}^2$) and the other which can be removed using precise calibrations (u^2)

[16] Assumptions for the model are: First assumption is without a network of calibration labs, which offer services traceable to national standards, many businesses would lose access to high-quality calibrations. Second assumption is that without access to high quality calibrations, businesses would revert to tests based on this minimum TAR of 4:1. (Whereas, of courses, with access to high quality calibrations, these businesses can eliminate the systematic errors associated with calibration). Third assumption is that if the NMS labs ceased to be an anchor for chain of calibrations, then a work-around would be found, which at least preserved a basic kind of calibration. By combining these assumptions, we can estimate the proportional increase in σ that would occur if there wasn't a network of top-tier calibration labs taking traceability from national standards.

$$\sigma(u) \approx \sigma_0 + \frac{u^2}{2\sigma_0}$$

In essence, if you use basic calibrations $\sigma(u) > \sigma_0$ otherwise with precise calibrations, this becomes $\sigma(u) = \sigma_0$. The extra uncertainty introduced through less accurate calibrations could be as much as 25% of the baseline uncertainty, implies $\frac{u}{\sigma_0} = 25\%$.

The study finds that the change in the relative standard deviation that would occur should businesses lose access to high quality calibrations is given by:

$$\Delta\sigma = \sigma(u) - \sigma_0 \approx \frac{u^2}{2\sigma_0}$$

The proportional increase in RSD can be written as

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

Without access to precise calibrations, businesses default to using a TAR of 4:1 which means

$$\boxed{\frac{\Delta\sigma}{\sigma_0} \approx \frac{1}{2}\left(\frac{1}{4}\right)^2 = 3.1\%}$$

Hence, this analysis implies that without a network of calibration labs taking traceability from national standards, **σ would increase by 3.1%.** Furthermore, this increase in the relative standard deviation of the measurement process would then lead to more mistakes in conformance testing.

Gravity model

The effect of taking traceability from a foreign NMI

NPL is the first vital link to the chain of calibrations through which the benefits then fanout across the economy. Evidence suggests that if some proportion of NPL's services ceased to exist, the whole chain would be weakened, i.e. the use of precise calibrations would decrease. This would imply that the users (UK based) of NPL's services can be expected to go to the next best alternative which based on distance and role would be the National Metrology Institute in Netherlands, VSL. By analysing a counterfactual, an estimate of how much the use of precise calibrations would decrease without the NMS labs, can be calculated. An econometric analysis (Renedo and King, 2020) finds that there is a strong negative relationship between distance and uptake of services. That is, the elasticity of invoices with respect to distance is -0.48 which means if the distance between the UK and another country was somehow to double, then demand for NPL's services would drop by 48%. The study shows that if the separation of "NPL" and its userbase is increased by 65%, this would cause **the demand to decrease by 31%**. Furthermore, because, NPL currently covers a higher proportion of the CMCs than VSL, prospective customers may encounter some drop in capability if NPL ceased providing its services. Hence, this decline in demand may be even larger.

The effect - if NMS labs didn't exist anymore

This part of the analysis covers two scenarios

1. UK loses access to all precise calibrations and now all the UKAS labs can only provide basic calibrations. In this scenario, the proportional increase in the RSD is calculated as 3.1% (shown above) and since the rigour of the test cannot change, this would imply the probability of type I errors going up. The study shows that due to the increase in RSD, the probability of type I errors increases by 0.2%. **This is a proportional increase of 67% for the probability of type I errors**.

$$\Delta p = 0.2\% \rightarrow \frac{\Delta p}{p} = \frac{0.2\%}{0.3\%} = 67\%$$

2. UK retains partial access to precise calibrations by going to a foreign NMI.
   We know that the proportional increase in RSD is 3.1% if UK lost access to all precise calibrations, in which case the labs can only provide basic calibrations, and the use of precise calibration would drop by 31% if UK could retain access to VSL. Using these calculations, we can estimate the proportional change in RSD given partial access to precise calibrations can be retained.

$$\frac{\Delta\sigma}{\sigma} = 31\% \times 3.1\% = 1\%$$

   In this scenario, the proportional increase in RSD of 1% leads to an increase in probability of type I errors by 0.05%. the **proportional increase in the probability of type I errors is 16.7%.**

$$\Delta p = 0.05\% \rightarrow \frac{\Delta p}{p} = \frac{0.05\%}{0.3\%} = 16.7\%$$

Closing Analysis

The analysis highlights that the relative standard deviation (RSD) of measurements plays a critical role in balancing Type I and Type II errors in conformance testing. When precise calibrations are unavailable and businesses revert to basic calibrations, RSD increases by approximately 3.1%, which raises the probability of Type I errors by about two thirds. If partial access to precise calibrations is retained through foreign NMIs, the RSD increase is limited to 1%, causing a smaller proportional rise in the probability of Type I error probability by approximately one third. Survey evidence reinforces the model's findings where businesses report an average 3% scrap rate, matching the model's estimate, with one-third caused by avoidable Type I errors. The survey also shows that calibration removes around 20% of total measurement uncertainty, meaning firms that forego precise calibrations can face about a 2% rise in RSD and a 0.1-percentage-point increase in costly mistakes during conformance testing[R23].

These findings highlight the importance of the NMS labs for giving access to high-quality, traceable calibration services, as even modest increases in measurement uncertainty can significantly amplify error rates and associated costs.

3.5.2 Optimal Frequency of Testing Model

This model is based on a macroeconomic framework that characterises an economy where production processes occasionally malfunction. It adapts the Solow model and estimates the level of testing where marginal benefit equals marginal cost. Testing reduces the probability of production failures, improving reliability and economic efficiency. By equating the marginal benefit of additional testing with its marginal cost, the model derives the optimal testing intensity that maximise welfare and estimates key variables. One of these is the probability of Type I error, which is then integrated into the fan-out and uptake model to compute the value for the presence of a domestic NMI.

Model setup

Production processes sometimes fail, reducing output. Regular testing detects faults and restores reliability, but additional testing comes with costs. The goal is to find the **optimal frequency of testing** where the **marginal benefit of an additional round of testing equals the marginal cost**.

The model is based on the **Cobb-Douglas production function** with constant returns to scale:

$$Y = AL^{\alpha}K^{\beta}, \alpha + \beta = 1$$

Here, A is the Total Factor Productivity (TFP), L is labour, and K is capital.

When production reliability is imperfect, output adjusts as:

$$Y = A(1 - \theta)vL^{\alpha}K^{\beta}$$

where:

v: reliability of capital (proportion functioning correctly)

θ: regret rate (Type I error – good capital scrapped)

Expressed in per worker terms as:

$$y = A(1 - \theta)vk^{\beta}$$

This shows output per worker depends on reliability of capital and testing effectiveness which determines the likelihood of decision mistakes (Type I and II errors).

The table below describes the probabilities of passing or failing a conformance test for two types of capital: functioning (good) and defective (bad).

	Functioning Capital (Good)	**Defective Capital (Bad)**
Pass	$\Pr(\text{pass} \mid \text{good}) = 1 - p$	$\Pr(\text{pass} \mid \text{bad}) = 1 - q$
Fail	$\Pr(\text{faill} \mid \text{good}) = p$	$\Pr(\text{fail} \mid \text{bad}) = q$

Table 2 Contingency Table for conditional probabilities

p measures the probability of how often good capital is wrongly scrapped (regret rate) and q measures the probability of how effective the test is at catching bad capital (detection rate).

The testing is performed by Conformance Testing engineers (CT engineers). These belong to the non-output producing sector, so their wages are paid through the share of output produced by output-producing labour force. From here a concept called ‘reliability tax’ is derived. This is not a tax in the traditional sense but like an overhead to fund the wages of the CT engineers. An example here is: Human Resources (HR) play a vital role in managing an organisation, even though it doesn't directly contribute to the production of output. The salaries of HR staff are typically covered through the organisation’s overhead costs. The 'reliability tax' (τ) is considered to be proportional to the capital. The more capital there is, the more testing is required, and hence greater share of output goes to funding the wages of CT engineers.

The framework uses a type of **Markov model for the reliability of capital** to explain the flows inside and outside of the functioning and malfunctioning capital, when the system is in equilibrium. Initially all capital is functioning and falls into the first bucket. There are inflows coming from the gross investment and then there are two types of outflows: one is in the form of depreciated capital and capital reductions due to growth in workforce; and the second one is functioning capital that flips to defected capital due to entropy in production processes[17]. From the defective capital, the inflow is simply the functioning capital that flips as defected, and the two outflows are: depreciation; and the defective capital that gets **detected** and reset, so flows into the functioning capital bucket. In equilibrium these inflows and outflows from each bucket must be equal.

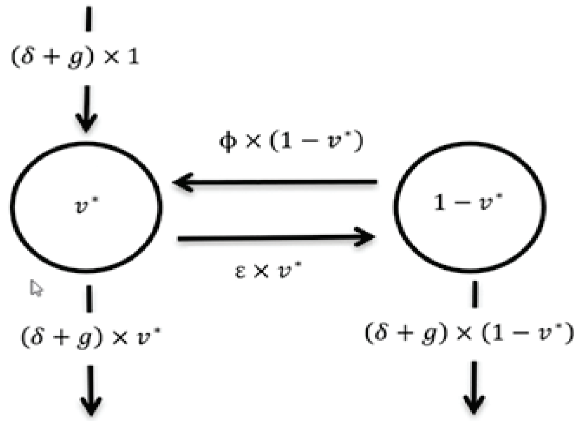


Figure 9 Flows of probability in and out of $\boldsymbol{v}^*$ and $\mathbf{1} - \boldsymbol{v}^*$

Therefore, a key parameter in the model is the detection rate which is expressed as follows:

$$\frac{d\phi}{d\text{n}} = q(1 - \phi)$$

More formally, the detection rate (ϕ) is defined the rate at which capital is detected as bad and then reset to become good. $(1 - \phi)$ is what previously couldn't be detected as bad and so could not be reset. With each round of testing, a fraction of bad undetected capital is correctly detected and reset[18].

[17] All systems naturally wear down, drift, degrade, or move toward disorder unless energy is put in to maintaining them.
[18] Details can be found in R32. King, M., Qureshi, Z. & Katanguru, D., (2026). Optimal Testing in the Economy. Forthcoming.

Another important component is the **elasticity** which is a measure of how sensitive the reliability of capital is to changes in the frequency of testing.

How the model works

The output depends on labour, capital, and productivity, but when reliability of capital falls due to malfunctioning in production processes, output declines. Testing improves reliability of capital by detecting defective output and resetting the capital that malfunctions. However, testing also introduces costs in the form of wages for the testing engineers. The model adapts a concept shown by Solow where a specific savings rate **maximises steady-state consumption per worker** known as the **Golden Rule savings rate**. It essentially balances the trade-off between current and future consumption. Similarly, the **optimal testing rule** identifies the frequency of testing that maximises welfare. The optimal testing frequency occurs precisely where the next round of testing would no longer increase productivity.

The elegance of the model lies in its ability to simplify complexity. It begins with a wide set of interdependent components some known, others unknown. Through systematic algebraic reformulation, the model reduces this complexity to just two key unknowns. Solving the two main equations simultaneously allows us to calculate the two key components, regret and detection rate. Once these are estimated, all the other unknowns are calculated.

Below are the key results obtained from the model:

- **Frequency of testing**: $n \approx 1.18$ rounds/year (≈ every 9–10 months)
- **Detection rate**: $\phi \approx 69.24\%$
- **Regret rate**: $\theta \approx 0.34\%$
- **Probability of type I error:** $p \approx 0.29\%$
- **Elasticity**: $\mathcal{E}(v, n) \approx 2.34\%$

Finally, the model demonstrates that testing every 9–10 months maximises productivity while balancing costs. If testing is too infrequent, the reliability of production processes declines, resulting in more defective output and reduced productivity. Conversely, if testing is carried out too often, the associated costs can outweigh the benefits, diminishing net output. Moreover, the Golden rule optimality says:

$$\underbrace{2.00\%}_{\substack{\text{Spend on testing} \\ \text{as a} \\ \text{percent of output}}} = \underbrace{2.34\%}_{\substack{\text{Elasticity of reliability} \\ \text{with respect to} \\ \text{frequency of testing}}} - \underbrace{0.34\%}_{\substack{\text{Losses from} \\ \text{false positives} \\ \text{(type 1 errors)}}}$$

where spend on testing comes from Fennelly (2021). The “golden rule” is based on equating the marginal cost and marginal benefit of the extra information from another round of testing. Doubling the frequency doubles the cost (2% of output again). Doubling the frequency increases the reliability of production processes (the elasticity is 2.34%) but adds to the loss from false positives in the testing process (a further loss of 0.34%). Overall, it yields a net-benefit of about £5.50 for each £1:00 of public funding.

Additionally, the optimal testing model and its calculator allows us to conduct comparative statics to see the impact on the system if a basic parameter, for instance, probability of type I error shifts, and also conduct sensitivity analysis in the future to see how small variations in basic parameters can affect the other components.

Evidence used:

R55. Yildiran, C. & King, M. (2025) A summary of Science-Metrix’s bibliometric assessment of the National Physical Laboratory’s metrology research outputs (2013–2023). NPL Report IEA 26. National Physical Laboratory: https://doi.org/10.47120/npl.IEA26.

R16. Fennelly, C. (2021) Quantifying measurement activity in the UK. NPL Report IEA 7. Teddington: National Physical Laboratory. https://eprintspublications.npl.co.uk/9064/1/IEA7.pdf

R30. King, M. & Nayak, S. (2025) A macroeconomic model with imperfect production processes and conformance testing. NPL Report IEA 27. Teddington: National Physical Laboratory. Available at: https://eprintspublications.npl.co.uk/10127/

R31. King, M. & Nayak, S. (2023) An economic model for the value attributable to high-quality calibrations by reducing mistakes in conformance testing. NPL Report IEA 19. Teddington: National Physical Laboratory. Available at: https://eprintspublications.npl.co.uk/9816/

R32. King, M., Qureshi, Z. & Katanguru, D., (2026). Optimal Testing in the Economy. Forthcoming.

4 Innovation Benefits Chapter

4.1 Introduction

Measurement science is a continually evolving field, shaped by ongoing scientific discoveries and technological developments. This progression requires a strong and adaptable infrastructure that can respond effectively to emerging needs.

Within this context, the economic benefits delivered by the NMS laboratories arise through several mechanisms. Through foundational research and development, the labs build broad measurement capabilities that underpin firms' ability to innovate and improve their products and processes. By helping businesses overcome technical barriers and reduce uncertainty, this support enables firms to grow, bring forward new or improved offerings, and strengthen their competitiveness. Growth in turn contributes to employment creation and increases firms' appetite to invest further in R&D as new opportunities and challenges emerge. Reliable measurement and robust standards also enhance firms' ability to operate efficiently, improving their chances of long-term survival in the industry.

Figure 10 NMS labs contribution to Innovation and Growth

The following sub sections will look at evidence connected to each theme and where possible discuss the underlying framework/ model.

4.2 Capability Building through R&D & codification of knowledge

NMS laboratories build capability in firms by both generating new measurement knowledge through direct R&D and by codifying existing expertise into standards and validated methods. Through collaborative R&D, firms gain access to advanced measurement capability that strengthens their absorptive capacity, reduces uncertainty in development, and helps them overcome technical barriers that would otherwise slow innovation. Ultimately enhancing productivity growth.

This is supported by the evidence developed by NPL's economists. Starting with a study that positions NMS as an enabler of innovation-led growth. The report argues that the UK's ambition to raise R&D investment to 2.4% of GDP by 2027 cannot be achieved solely through traditional funding mechanisms like university grants and business subsidies. Instead, it calls for a shift towards improving the productivity of R&D itself by investing in **infra-technologies**: the tools, standards, and protocols that underpin reliable and reproducible measurement in research. The study highlights the growing challenges of declining R&D efficiency and diminishing returns from subsidies, underscoring the need for more enablers of innovation. Central to this is the role of metrology which enhances the effectiveness of R&D by reducing costs, increasing benefits, and improving the allocation of resources. Public investment in infra-technologies such as **calibration services and reference standards** is shown to unlock private R&D potential, making more projects commercially viable. Measurement activities already account for approximately 14.3%[19] of total R&D effort (reported in 2020), positioning them as a major lever for improving productivity. Institutions within the UK's National Measurement System (NMS), including NPL, LGC, and NEL, provide the technical infrastructure essential for supporting emerging fields such as life sciences, quantum technologies, climate science, and digital innovation. It shows that by strengthening the NMS and its labs, the UK can make more R&D projects privately profitable, thereby mobilising private sector investment and helping to meet the 2.4% GDP target[R27].

[19] King and Renedo (2020) estimate this from an analysis of roles among employees working in the scientific research and development industry.

Add-on to this is a study that shows that public investment in NPL directly translates into increased support for UK businesses: The study uses data that encompasses annual information on the level of funding received, the number of scientists and engineers in the workforce, and the number of UK-based firms supported from 2010 to 2017 for each of the 17 scientific groups[20] of NPL. The report finds that an additional **£1 million per annum of NMS resource funding enables NPL to support approximately 9 more UK companies**, either through commercial services or collaborative R&D projects. This equates to an average cost of £110,000 per supported company, which compares favourably to Innovate UK's average cost of £155,000 per incidence of support. NPL's services help firms develop new products and processes, enhancing their market power and productivity[R28].

The evidence also includes a study that connects to unlocking private sector R&D through targeted and bespoke support given to businesses. It evaluates the impact of the Measurement for Innovators (MFI) programme, a key initiative under the UK's National Measurement System (NMS), which ran from 2004 to 2010. Led by the National Physical Laboratory (NPL) and delivered in collaboration with LGC, NEL, and OPSS, the programme aimed to provide subsidised consultancy support to firms, primarily SMEs, facing technical challenges in product and process development. Using a robust empirical framework, including difference-in-differences and propensity score matching[21], the study compares outcomes for firms that received support with those that did not. The study finds that subsidised consultancy support (offering expert measurement advice to firms lacking in-house capabilities) from NMS laboratories significantly boosted innovation among participating firms, particularly SMEs. As a result of this programme, there was an **11% increase in patenting activity in the year of support**. Firms also experienced **sustained asset growth, with treated companies growing 5% faster annually than their peers**, even eight years post-treatment. The results also showed that the firms that received measurement support were better equipped to assimilate and exploit knowledge, leading to

[20] The National Physical Laboratory (NPL) is structured into several scientific groups, each dedicated to a specific area of measurement science and expertise.

[21] The DiD approach is a research design for estimating causal effects of treatment which is based on the potential outcome approach developed by Rubin17. This is a common technique used to estimate the difference between the outcomes of two groups – the treated group and the treated group had it not received the treatment (counterfactual) – before and after receiving support. Propensity score matching (PSM) calculates the probability (p) of treatment assignment conditional on observed baseline characteristics and finds a comparison group made up of members who are not exposed to the treatment but, given their observable characteristics, had the same probability of receiving treatment as the individuals who were treated.

a cycle of innovation and expansion. The estimated benefit-cost ratio of **£5: £2** which implies that for every £1,000 spent on an MFI consultancy by the NMS the supported firm received a value of £2,500 (lower bound estimate) [R40]. These outcomes highlight the importance of the NMS in enhancing R&D effectiveness, its contribution to unlocking private sector innovation, and supporting long-term productivity. By providing expert measurement advice and technical infrastructure through programmes like MFI and its successor Analysis for Innovators – A4I, the NMS plays a vital role in helping the UK move towards its 2.4% R&D intensity target.

Moreover, a further in-depth econometric study is underway which examines the impacts of these National Measurement System's innovation programmes: **Analysis for Innovators (A4I)**, **Measurement for Quantum (M4Q)** and **Measurement for Recovery (M4R)** where NPL provides independent measurement services to businesses. The work extends earlier econometric studies to assess employment and turnover outcomes following public innovation support. This report will be key to providing a deeper and programme-specific assessment of how targeted measurement support contributes to innovation-led growth across UK businesses.

Standardisation which can be defined as codified knowledge provides a primary channel through which spillovers diffuse across the economy. By translating specialist expertise into codified forms such as standards, good-practice guides, and validated methods, knowledge becomes accessible, repeatable, and easy for industry to adopt. A study developing a framework for classifying and explaining these spillover channels for the NMS labs, demonstrate that standardisation is the mechanism that gives rise to product diffusion and process diffusion, enabling codified knowledge to flow beyond direct users and generate wider spillover benefits. Product diffusion occurs when pre-defined standards enable innovations to be more easily adopted, replicated, and commercialised by other firms, while process diffusion arises from the revision of standards and the use of best-practice guidance that embed standardised routines and methods across industry. Using the survey for businesses data, the study estimates that new products remain within the originating firm for **7 years** and within the wider industry for **13 years**, implying that **45% of total benefits arise indirectly** as these innovations are taken up, improved upon, and scaled by others. These findings reinforce that standardisation is a key driver of technological diffusion, and once this knowledge is codified, it naturally becomes part of the measurement infrastructure as it is taken up as best practice across industry[R46].

There is also evidence showing an ‘invention consequence of support’, illustrating how the two pathways, direct R&D engagement and standardisation help firms move a step closer to innovation. A dedicated study examined whether regular support from the National Physical Laboratory (NPL) accelerates the innovation process among UK firms, specifically by reducing the time it takes to develop and file new patents. Grounded in the Resource-Based Theory of the Firm, the study uses survival analysis techniques including probit modelling, propensity score matching, Kaplan–Meier log-rank tests, and Cox proportional-hazard models[22] on a panel of 6,793 firms over 19 years (2002-2017). The findings reveal that firms regularly supported by NPL experience a **26% shorter time-to-patent and a 23% higher propensity to patent compared to occasionally supported firms**, although the statistical significance is modest[R43]. These results indicate that NPL’s technical and measurement support meaningfully enhances firms’ innovation capability, helping them convert ideas into patentable outputs more rapidly and strengthen their competitive position.

Moreover, the survey for businesses conducted shows that without this support given by the NMS labs annual sales of new products would decrease by at least **£500 million**, with £1.5 billion worth of new products potentially at risk[R23]. These figures underline the substantial commercial significance of the NMS labs and the role they play in sustaining innovation-led growth.

[22] Kaplan–Meier estimator: A non-parametric method for estimating the survival function from time-to-event data.
Log-rank test: A statistical test used to compare the survival distributions of two or more groups.
Cox proportional-hazards model: A semi-parametric regression model that assesses the effect of covariates on the hazard rate, assuming proportional hazards over time.

Evidence used:

R23. Katanguru, D.R., Qureshi, Z. and King, M. (2025) A survey of UK-based businesses using laboratories funded through the National Measurement System (2023). NPL Report IEA 28. National Physical Laboratory. http://eprintspublications.npl.co.uk/10151.

R28. King, M. and Renedo, E. (2020a) The impact of the National Measurement System funding on the uptake of NPL's service.http://eprintspublications.npl.co.uk/8810

R27. King, M. and Renedo, E. (2020) Achieving the 2.4% GDP target: The role of measurement in increasing investment in R&D and Innovation.http://eprintspublications.npl.co.uk/8653

R40. Nwaigbo, N., 2022. Evaluating the Impact of the NMS Innovation Projects on Supported Firms. NPL Report IEA 10. National Physical Laboratory. http://eprintspublications.npl.co.uk/9407/

R43. Olakojo, S., Renedo, E. and King, M., 2023. Time-to-Patent: Does NPL Support Accelerate Innovation? NPL Report IEA 18. National Physical Laboratory. https://doi.org/10.47120/npl.IEA18

R46. Qureshi, Z. and King, M. (2025) A framework for assessing the economic significance of NPL's spillovers. NPL Report IEA 25. National Physical Laboratory: https://doi.org/10.47120/npl.IEA25

4.3 Employment Growth & Wage premium

Innovation has long been a driving force behind economic transformation, and its impact on employment is both profound and multifaceted. As new technologies emerge and industries evolve, innovation reshapes labour markets, creating new opportunities and redefining existing roles. In the short term, innovation may lead to disruption, automating routine tasks and displacing certain jobs. However, over the medium to long term, it acts as a powerful engine for employment growth.

Employment growth can be considered an outcome of increased productivity. Employment growth has the underlying premise that in an economy operating near full employment, labour tends to flow toward firms offering higher wages. Firms that have enhanced their operational capacity, enabled by increased investment resulting from support provided by National Measurement System (NMS) laboratories, are better positioned to offer premium wages. The following sub sections provide a model and evidence that illustrates this process.

Model & Framework

Nayak, Olakojo, and King (2023)[23] provide an economic explanation of how support from the National Measurement System (NMS) translates into improved business outcomes. At its core, the model assumes that each firm operates as a temporary monopolist in its product market and produces output using a Cobb-Douglas production function:

$$Q_{i,t} = A_{i,t} K_{i,t}^{\alpha} L_{i,t}^{1-\alpha}, 0 < \alpha < 1$$

Here, output depends on physical capital (K), labour (L), and Total Factor Productivity (A), which captures efficiency gains from technology and innovation. NMS support raises A by providing access to advanced measurement capabilities and technical expertise, enabling firms to reduce production costs and improve reliability. This increase in productivity enhances the marginal product of labour, which in turn affects wages and employment.

To see this mechanism, consider the firm's behaviour. Profit-maximising firms hire labour up to the point where the marginal revenue product of labour equals the wage. Using the production function, the marginal product of labour can be expressed as:

$$MP_L = (1 - \alpha) A_{i,t} (\frac{K_{i,t}}{L_{i,t}})^{\alpha}$$

Thus, when NMS support raises A, the marginal product of labour increases, encouraging firms to hire more workers and pay higher wages. This creates a positive feedback loop: better technology improves productivity, which drives employment growth and wage premiums.

The model also incorporates a simple Hotelling framework to explain labour mobility. The framework assumes that there is a 'linear' city where labour is uniformly distributed and firms i and j are located at each end. Workers choose between firms based on wages and commuting costs. In equilibrium all workers to the left of l_t^* are employed by firm i and all those to the right are employed by firm j. l_t^* denotes the location of the worker who is indifferent between travelling to either firm.

[23] R39: Annex 2 of the report discusses the model in detail.

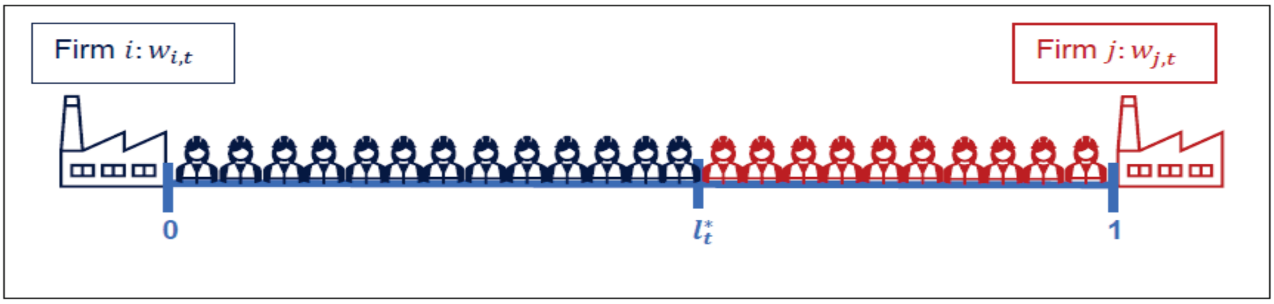


Figure 11 Hotelling model at baseline time (t)

If firm i receives regular support from the NMS labs, its total factor productivity increases, and it is able to offer higher wages. As a result, it can attract more workers and so the point of indifference shifts to the right. The workers who switch to firm i are represented by the light blue colour, and the wage premium earned by these switchers is simply the difference in the wage offered by firm i after experiencing productivity gains and the wage firm j offered.

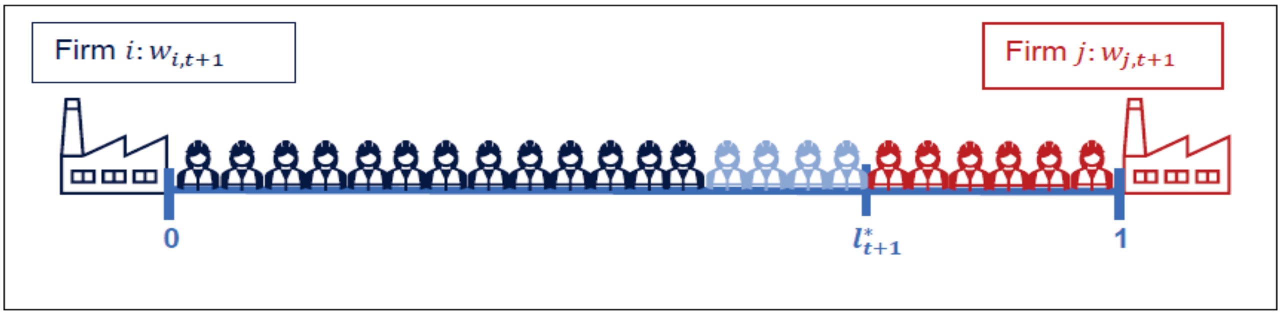


Figure 12 Hotelling model at time (t+1)

Evidence

There are a number of studies developed that quantify the impact of NMS labs' support on employment growth. The econometric work in this space started from a study commissioned to Frontier Economics by BEIS and Innovate UK. The aim being able to establish whether supported firms see a statistically significant impact when compared to those not supported. The study evaluated the effects of innovation grants and support schemes primarily on SMEs. This was done by considering firms supported by both Innovate UK and NMS labs during 2008-2012. Using propensity score matching to compare supported firms with similar non-supported ones, the study found that supported firms experienced **employment growth of 10–15%** (in other words, adding around 20 additional employees) within two to four years, and turnover rose by 10–25% for Innovate UK-supported firms and 0–10% for those supported by the National Measurement System, although not all results were statistically significant[R17].

Following on, Belmana was commissioned by the National Physical Laboratory (NPL) and Innovate UK to conduct an analysis that focuses on firms that received **regular support** from NMS laboratories, particularly NPL. The study applies Propensity Score Matching (PSM) combined with Difference-in-Differences (DiD) [24] to estimate the causal impact of NMS support on firm outcomes using observational data. For the analysis firm-level data from ONS and other sources[25] are linked to NPL's user data. For wage effects, the study leverages Annual Survey of Hours and Earnings (ASHE) microdata, a 1% PAYE-based panel, to track a subset of employees, focusing on job-switchers and estimating wage premiums through multivariate regressions and individual fixed-effects models.

The evidence demonstrates that NMS support significantly enhances business outcomes across multiple dimensions including employment growth and wage premium. It finds that

- regularly supported firms (175 in the core sample) experienced an average annual increase of **6.31 jobs per firm**, translating to over 23,000 additional job-years between 2009 and 2015. Approximately 80% of this growth was additional, not observed in matched control firms.
- employees switching to NMS-supported firms earned an average annual wage premium of **£4,083**. Combined with job creation and retention, this results in an estimated £21,835 in additional annual wage value per supported firm [R39].

[24] PSM constructs a matched control group of unsupported firms with similar baseline characteristics. PSM addresses observable differences between supported and unsupported firms, it does not account for unobserved characteristics that may influence both treatment and outcomes. To mitigate this, the study combines PSM with a **Difference-in-Differences (DiD)** framework wherever pre- and post-support time-series data are available. DiD compares changes in outcomes rather than levels between treated and matched control firms, effectively differencing out any time-invariant unobserved heterogeneity.

[25] Business Structure Database (BSD) – annual snapshot of all UK businesses from VAT and PAYE records, covering employment, turnover, sector, age, and survival.
Annual Respondents Database (ARD) – longitudinal dataset from the ONS Annual Business Survey with firm-level data on GVA, capital expenditure, and employment.
Business Enterprise Research and Development Survey (BERD) – ONS survey capturing business R&D expenditure, funding sources, and R&D employment.
Financial Analysis Made Easy (FAME) – a UK company accounts database providing detailed financial information such as sales, profits, assets, wages, and R&D expenses.

In addition, an inhouse study was also conducted to evidence these outcomes. Using advanced econometric techniques and data from 2012 to 2021, the analysis shows that firms regularly supported by NPL experienced a **3.0% increase in employment growth**, a **5.1% rise in real fixed assets**, and a **7.1% wage premium** for workers transitioning into these firms, equating to approximately £60 extra per week. Additionally, R&D investment grew by 5.8% among firms with moderate R&D growth[R41]. These outcomes further underscore the importance of the NMS as an enabler of innovation and productivity[26].

Moreover, the survey[R23] conducted for the private businesses in 2023 – an essential part of the NMS evaluation plan, reveals that the businesses that work with the NMS labs make great contributions to the UK's economy. These businesses employ ~711,500 people in the UK. The business sites that have worked with the NMS labs have an aggregate turnover of £154 billion. The revenue per employee for the sites that work with the NMS labs is ~£216,450. Around half of these businesses operate within the UK's manufacturing sector, and these businesses account for **13% of employment in UK manufacturing**. About 15% of the users report that innovation activities supported by the NMS lead to a **3% increase in employment**, while **basic wages rise by 7.5%[27]**. These findings are consistent with the econometric studies which highlight the strong performance of the supported businesses across various economic indicators.

Through the econometric study by Belmana, a key conceptual advancement emerged: the identification and formalisation of "**regularly supported firms**". This term helped the analysis and evaluation team to develop a quantifiable metric which quantifies NPL's direct economic impact on the private sector through these long-term relationships. Regularly Supported Firms (RSFs) is defined as the firms that engage with NPL at least five times over a six-year period[R14]. RSFs account for ~70% of NPL's private sector income (from 2012-2021) despite being only ~18% of supported firms. RSFs show a significantly higher employment growth i.e. an average RSF sees 6.31 additional employees and £4,083 wage premium per new hire. During 2023, NPL had 429 UK-based RSFs. The benefits going to supported firms, endure for around six years (discounted due to time preference - 5.12). Each of these firms grew by ~6.3 employees each year due to support. On average, employees who switch to one of these new jobs see their annual wage increase by £4,080.

[26] The benefits reported refer to the average growth per year.
[27] Average growth per year.

Using these stats, an extra wages equation is developed that shows labour productivity equates £56.5m per annum.

'Extra Wages' = 429 (No. of RSFs) × 6.3 (Employment Growth at RSFs) × 5.12 (Lifetime of benefits (discounted)) × £4,080 (Wage Premium for job switchers)

Figure 13 Wage equation

These benefits are only those received by the workers themselves. The investors see the same amount of benefit as workers, implying a flow of direct economic benefits amounting to ~£112 million. Indirect benefits from the diffusion of technological knowledge are typically the same as the direct benefit to the original innovator. A lower bound for the total benefit (direct plus indirect) approximates to **£225 million**[28].

Evidence used:

R17. Frontier Economics (2017) The impact of public support for innovation on firm outcomes. Department for Business, Energy & Industrial Strategy (BEIS). https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/604841/innovation-public-support-impact-report-2017.pdf

R39. Nayak, S., Olakojo, S. and King, M. (2023) NMS support for innovation and business outcomes: A synthesis of evidence from Belmana's econometric analysis: http://eprintspublications.npl.co.uk/9682

R41. Olakojo, S. (2025) Impact of innovation support delivered through the National Measurement Programme on Business Outcomes: Summary. http://eprintspublications.npl.co.uk/10152

R23. Katanguru, D.R., Qureshi, Z. and King, M., 2025. A survey of UK-based businesses using laboratories funded through the National Measurement System (2023). NPL Report IEA 28. National Physical Laboratory: http://eprintspublications.npl.co.uk/10151

R14. Dias, C. and King, M. (2023) Growth and survival of supported firms: http://eprintspublications.npl.co.uk/9634

28 Infographic can be found on this link.

4.4 Survival of Firms

The support NMS labs give is institutional for small and medium-sized enterprises (SMEs) and other economically vulnerable firms, which often lack the internal resources to independently ensure compliance with technical regulations and quality assurance protocols. By facilitating conformity assessment, reducing transaction costs, and enhancing product credibility in both domestic and international markets, NMS laboratories contribute to improving the likelihood of firm survival. While NMS laboratories do not provide grants or direct subsidies, they play an important role in supporting younger firms and high-risk projects that are particularly vulnerable to external factors. Their work helps incubate innovation by offering technical expertise and measurement capabilities that might otherwise be inaccessible to early-stage ventures.

Two econometric studies[R39,41] discussed above also demonstrate that firms receiving regular NMS support exhibit significantly higher survival rates than comparable firms. Olakojo (2025) finds that **100% of treated firms survived from 2012 to 2021, compared to a 14.8% closure rate among controls.** The hazard ratio for supported firms was significantly below 1, indicating a lower risk of exit. The Belmana synthesis corroborates these findings, showing regularly supported firms experience a **death rate of just 4% over seven years**. This is in stark contrast to a 12% death rate among a matched control group and a 35% rate in the general UK business population. These findings are reinforced by Frontier Economics (2017) which also showed that public innovation support increased the likelihood of firms surviving beyond three years by approximately 11 percentage points.

Another study [R14] explores how sustained engagement with NPL enhances the survival and growth of UK firms. It finds that **firms that regularly engage with NPL are significantly more likely to survive and grow**. As covered above these firms also show higher employment growth and wage premiums, suggesting that NPL's support is not merely keeping firms afloat, but actively enabling them to thrive. The report also introduces a framework for tracking firms along a "support pathway," from initial engagement to regular support. Firms on this pathway i.e. those "close to treatment" or on the "pathway to treatment" show intermediate levels of benefit, reinforcing the idea that **impact scales with the intensity and regularity of support**. Importantly, firms that fall out of regular engagement face a steep decline in outcomes, with many entering a "cliff edge" of inactivity or dissolution. This highlights the importance of maintaining relationships and identifying at-risk firms before they disengage. Moreover, the study also offers to predict how firms move between support categories using Markov chain which ultimately helps guide business development and customer retention strategies.

This survival advantage is not incidental. It reflects the value of long-term access to NPL's measurement expertise, which helps firms innovate, improve product quality, and meet regulatory standards. These capabilities are often too costly or complex for firms to develop in-house, making NPL's services key for the industry. In effect, firms are "renting" high-value knowledge and infrastructure from NPL an arrangement that supports continuous innovation and operational resilience.

Evidence used:

R39. Nayak, S., Olakojo, S. and King, M. (2023) NMS support for innovation and business outcomes: A synthesis of evidence from Belmana's econometric analysis: http://eprintspublications.npl.co.uk/9682

R41. Olakojo, S. (2025) Impact of innovation support delivered through the National Measurement Programme on Business Outcomes: Summary: http://eprintspublications.npl.co.uk/10152

R17. Frontier Economics (2017) The impact of public support for innovation on firm outcomes. Department for Business, Energy & Industrial Strategy (BEIS). https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/604841/innovation-public-support-impact-report-2017.pdf

R14. Dias, C. and King, M. (2023) Growth and survival of supported firms: http://eprintspublications.npl.co.uk/9634

4.5 Business R&D

In the UK economy, the development of national capabilities in research and development (R&D) plays a pivotal role in driving employment growth, particularly in high-value sectors such as advanced manufacturing, life sciences, and digital technologies. As public and private investment in R&D expands, it fosters innovation ecosystems that attract skilled labour and stimulate job creation. This employment growth, in turn, enhances firms' absorptive capacity, their ability to identify, assimilate, and exploit new knowledge which is a key determinant of their own R&D activity. Consequently, firms become more inclined to undertake in-house R&D, not only to remain competitive, but also to take advantage of the growing talent pool and collaborative opportunities within the UK's innovation ecosystem.

Consequently, an econometric study[R42] investigates this relationship between employment growth and R&D spending among firms that engage with the NMS laboratories, particularly the National Physical Laboratory (NPL).

Using a panel dataset of over 4,000 firms that interacted with NPL between 2009 and 2015, the study applies a robust econometric framework including Heckman selection models[29] and correlated random effects, to estimate the elasticity of R&D spending with respect to employment. The headline finding is that a 10% increase in employment leads to a 3.68% increase in R&D spending (average growth per year). Employment growth alone accounts for approximately 13% of the variation in private R&D investment.

The study is grounded in the accelerator principle, which posits that firms experiencing growth, especially in employment are more likely to invest in both tangible and intangible assets, including R&D. It also draws on the work of Coad and Rao (2010), who found that employment growth precedes R&D investment, rather than the reverse.

Importantly, the study provides a novel method for estimating the leverage effect of public support on R&D. By combining the estimated elasticity with prior findings that 5.5% of job-years among supported firms are attributable to NMS support, the authors estimate a **short-run R&D leverage ratio of 0.29**. This implies that every **£100 of public funding through the NMS generates £29 in additional private R&D spending**. When extrapolated using long-run multipliers from macroeconomic studies, the leverage ratio could rise to 1.5. The NMS contributes to national R&D intensity not only through direct support but also by catalysing employment growth in innovative firms.

By linking employment growth to R&D investment, the study strengthens the case for continued and expanded public investment in measurement infrastructure. It also supports the design of future innovation policies that focus on workforce development and skills as

[29] The Heckman Selection Model is a two-stage econometric technique used to correct for selection bias in samples where the outcome variable is only observed for a non-random subset of the population. Stage 1 estimates the probability of selection using a probit model. Stage 2 adjusts the outcome equation using the inverse Mills ratio derived from the first stage.

levers for boosting R&D – reinforcing the role of the NMS labs in achieving the UK's 2.4% R&D intensity target.

Evidence used:

R42. Olakojo, S. and King, M. (2023) Employment growth and R&D spending among companies that engage with the NMS Laboratories: http://eprintspublications.npl.co.uk/9680

5 Integrated Economic Impact of the NMS

As discussed above, the impact of the UK's National Measurement System (NMS) is realised through two economic channels. The first is Delivering the Measurement Infrastructure, where high-quality, traceable calibrations, reference materials and metrology knowledge reduce uncertainty, improve reliability and lower the risk of costly Type I/II errors across production and conformance testing. The second channel is Enabling Technological Change (Innovation Benefits), where collaborative R&D and targeted technical support convert measurement capability into firm-level outcomes.

The Business Case Model[R38] consolidates these two channels into a single framework to estimate the value of the NMS programme. **Measurement Infrastructure** stream comprises the physical capital (equipment, hardware, software) and the essential human capital—experienced scientists—needed to maintain the UK's National Measurement Standards and NPL's CMCs. It also includes activities such as decommissioning outdated assets, maintaining UKAS accreditation, and undertaking international comparisons to validate measurement standards. The underlying analysis draws on data from 2009–2015 to estimate these benefits. **Innovation benefit stream** covers the NMS's collaborative work with firms, helping them solve measurement problems through bespoke or off-the-shelf solutions that can improve innovation success, regulatory compliance, and customer value. It also includes innovation support schemes aimed at SMEs that typically cannot access NMS capabilities. The underlying analysis draws on data from 2009–2015 to estimate these benefits.

The analysis computes two types of return to highlight the difference between, *if the NMS saw a cut in its entirety* or *saw a proportion of its funding cut.*

- **The average rate of return** relates to the effect of scrapping the entire NMS programme. It gives us an estimate of the benefits attributable to the whole of the NMS. We use this estimate to determine the average rate of return on public investment.
- **The marginal rate of return** relates to the effect of cutting a fraction of to the NMS funding for development projects. We assume here that the cut applies to funding for development of the measurement infrastructure but not the maintenance of it, which

will remain safeguarded. If maintenance takes a cut, we default to the average cut scenario.

A key part of the model developed is that assuming that it takes 6 years for the effect to cascade through the economy (Frontier Economics, 2024) and a discount rate of 3.5% (HMT's Green Book) is used, the **marginal private return is calculated to be 66% of the corresponding average private return**. To calculate the rates of return, the model uses £80m as the figure for the level of funding NMS received which was accurate at the time the model was estimated. However, due to inflation which was nearly 23% in the period from 2019 to 2024 this required the NMS budget to be increased to £100 million to allow for the NMS labs to maintain the same output. The BCR ratio, return on public sector cost and NPSV-DEL ratio are inclusive of the scaleup in the NMS funding.

As a recap to the evidence discussed above, for the **measurement infrastructure stream**, the evidence shows that defunding NMS labs would cause around one-third of businesses to shift from precise to basic calibrations, increasing measurement uncertainty so that the Relative Standard Deviation rises by 1% and false positives increase from 0.30% to 0.35%. This reduces the optimal inspection frequency by 1.1%, lowering UK conformance-testing expenditure by £317 million from its annual £28.8 billion baseline. The decline in measurement reliability also reduces capital intensity by 0.09%, contracting UK output by £1.1 billion (given a £1.2 trillion GVA). Using these figures, the average private net-benefit of using NMS instead of foreign NMIs is £783 million, yielding an average private return of 9.79 per £1 of public funding; the average social return is 8.79 based on a £703 million social net-benefit. Applying the rule that marginal private returns equal 66% of average returns gives a marginal private return of 6.46, while deducting public costs yields a marginal social return of 5.46 per £1 invested.

The **innovation impact stream** estimates the benefits by examining Regularly Supported Firms (RSFs), that are reported to be 429 in 2023. Such firms grow at an average of 6.3 employees each year. These employees experience an annual wage premium of £4,080 for 5.12 discounted years[30]. These 'Extra Wages' are doubled to derive 'Direct Benefits' based on a 50:50 wages to profits split and doubled again to account for 'R&D spillovers'[31], yielding

[30] According to the NMS Customer Survey, the benefits going to these firms endure for 6 years which comes down to 5.12 years post discounting.

[31] Dearden et al (2005) suggests that the increase in a firm's profits is roughly equal to the increase in wages.

a conservative £225 million total benefit each year. If the NMS programme were discontinued, the UK would lose this £225 million GVA, partly offset by £55 million private savings and £80 million government savings, giving a £170 million private loss and a £90 million social loss. From these, the average private return to public investment is 2.13, and the average social return is 1.13, while the marginal private and social returns fall to 1.40 and 0.40, respectively, per additional £1 of government funding.

Based on the benefits accrued through these two streams and taking the £80m funding, the **social rate of return** that measures how much social value the NMS generates per £1 of public funding, after accounting for all public and private costs is calculated as

Channels	Average Social Rate of return	Marginal Social rate of Return
Measurement Infrastructure	9.79	6.46
Innovation	2.13	1.40
Both	**10.91**	**6.86**

Table 3 Social Rate of Returns for the channels of impact

Taking the social rate of return as a given parameter and scaling up the funding to £100m, the model analyses the value for money for the NMS programme which includes both streams/ channels of benefit. The following measures are calculated:

- **the Benefit–Cost Ratio (BCR)** compares the total social benefits with the total social costs (public plus private). Under this approach, the NMS achieves an **average BCR of 2.94** and a **marginal BCR of 2.22**, meaning that every £1 of total economic cost returns between £2.94 and £2.22 in social value.

$$\textbf{Direct Benefit} = \frac{\text{Extra Wages}}{\underbrace{0.50}_{\substack{\text{Wages to Profits}^{31} \\ \text{Ratio}}}} = \text{Extra Wages} \times 2$$

Based on the highest quality studies including Frontier (2023), the social returns are deemed to be around twice as high as private returns on average.

$$\textbf{Total Benefit} = \frac{\text{Direct Benefit}}{1 - \underbrace{0.5}_{\substack{\text{Spillovers}^{31} \\ \text{Ratio}}}} = \text{Direct Benefit} \times 2$$

- **Return on Public Sector Cost**, isolates the value created per £1 of government spending alone, excluding private costs leveraged by the programme. Because NMS funding draws in significant private-sector investment, this measure is higher than the BCR, with an **average return of 10.34** and a **marginal return of 6.50**,
- **Net Present Social Value – Departmental Expenditure Limit (NPSV–DEL)** ratio assesses how much net social value is produced per £1 within the Departmental Expenditure Limit, after subtracting rent paid back to government. On this basis, the programme produces an **average NPSV–DEL ratio of 12.79** and a **marginal ratio of 8.04**.

Value for Money for NMS (Measurement Infrastructure & Innovation Stream)	Average	Marginal
BCR	2.94	2.22
Return on Public Cost	10.34	6.50
NPSV-DEL	12.79	8.04

Table 4 Value for Money analysis

Overall, the integrated analysis shows that the National Measurement System delivers strong economic value by combining both the streams. The findings underscore that the NMS programme functions as an enabler of productivity, competitiveness, and long-term growth, providing a robust foundation on which wider societal and strategic benefits can also be built.

Evidence used:

R38. Nayak, S., Dias, C. & King, M. (2026) The Economic Impact of the National Measurement System Programme: A Business Case Model. National Physical Laboratory. Forthcoming

6 Wider Public Value delivered by NMS

Beyond the core economic channels, the work of NMS labs deliver significant benefits that can be classed as societal: Quality of life benefits; and Environmental benefits. These are not easily captured in monetary terms but are critical to national well-being and strategic priorities.

Moreover, the evidence can also be cut through a different lens ‘National Challenge Areas’ providing a complementary perspective to the economic and societal benefits. These are missions designed to drive economic growth, reform public services, improve safety, and foster innovation through clear, measurable, and time-bound goals. Within this space, benefits have been measured across two key areas: **Quality of Life Benefits**, driven by improvements in healthcare outcomes, and **Environmental Benefits**, supporting the UK’s transition to net zero.

6.1 Societal Benefits

Quality of Life Benefits

The evidence presented here is based on a study [R26] that evaluates the impact of improved dose control in radiotherapy and a survey conducted for healthcare professionals that assesses the support provided by the NMS labs to the Life Sciences and Health sector.

NPL provides the measurement infrastructure and expertise that underpin accurate radiation dose delivery in UK hospitals. Radiotherapy is a critical component of cancer care, but its success depends on accurate dose delivery to maximise tumour control while minimizing side effects.

NPL’s calibration and audit programmes aim to reduce dose uncertainty across UK radiotherapy centres. The analysis combines two widely used radiobiological models: Linear Quadratic (LQ) Tumour Control Probability (TCP) and Lyman-Kutcher-Burman (LKB) Normal Tissue Complication Probability (NTCP) Model[32]. These models were integrated to

[32] Linear Quadratic (LQ) Tumour Control Probability (TCP) Model – Estimates the probability of eradicating cancer cells based on delivered dose.
Lyman-Kutcher-Burman (LKB) Normal Tissue Complication Probability (NTCP) Model – Predicts the likelihood of significant side effects, specifically grade 2 rectal bleeding within five years.

calculate the joint probability of tumour control without major complications. The study published in 2019 focused on prostate cancer patients treated over a 20-year period (1995-2015), using historical audit data showing dose variation reductions from 0.8% to 0.4%. Model optimisation identified an optimal total dose of 65.5 Gy. By reducing dose uncertainty, the probability of successful treatment improved measurably. Applying this improvement to prostate cancer patients treated annually, the study estimates that NPL's efforts results in **15 additional successful treatments per year** without significant side effects. While only quantified for prostate cancer, this mechanism applies broadly across radiotherapy, demonstrating the tangible health benefits of precise measurement and calibration in radiotherapy.

The NMS through NPL and NML, provides traceable standards and technical expertise that healthcare organisations rely on for accurate and reliable measurements – critical for hospitals, industry, and academia alike. The 2025 Healthcare NMS survey[R20], carried out by IFF Research on behalf of the National Physical Laboratory shows that in **hospitals, measurement is most valued for quality assurance and compliance with standards**, while in **industry it drives new service development and operational efficiency**. **Academic institutions rely on it to validate research and improve data comparability**.

Healthcare organisations engage with NMS labs primarily for calibration, reference materials, and process validation, which is cited as the most important reason for engagement. These services strengthen confidence in measurement and support operational safety, particularly within the NHS, where cost efficiency and adherence to standards are paramount. Survey findings show that **88% of users consider NMS support beneficial, and over half regard it as essential to their work**. NHS organisations demonstrate the highest dependency, with three-quarters viewing NMS support as a requirement. Four in ten users said their work would be greatly affected if these services were unavailable, highlighting their critical role in maintaining healthcare standards.

Beyond compliance, NMS support fosters innovation. Nearly a **third of users reported that changes introduced with NMS involvement were new to their organisation, and some even represented a step-change for their industry**. While the labs provide strong support at research and development stages, users would like to see more support in the commercialisation stage. Overall, the services offered by the NMS labs deliver measurable value by reducing uncertainty, improving accuracy, and enabling innovation—ultimately enhancing patient outcomes and quality of life across the healthcare sector.

NMS Healthcare Survey Impact Case Studies project[33] conducted by Briscoe Advisory Ltd, further reinforces these findings. NHS hospitals depend on multi-year calibration partnerships to maintain safety in high-risk areas such as radiotherapy dosing and diagnostic imaging, while SMEs, universities, and med-tech companies rely on the expertise of the NMS labs to validate early-stage technologies and overcome technical barriers that would otherwise prevent progress. Regulators, including the MHRA, engage with NPL for standards, technical advice and policy input with high strategic input.

Across all cases, the value delivered by NMS support is marked as it reduces clinical risk, prevents costly downtime, accelerates innovation, and strengthens compliance with national and international regulation. NPL's involvement routinely shortens pathways to clinical trials, improves operational efficiency, and boosts confidence in new technologies across the NHS and industry. Beyond direct impacts, the system-wide benefits are substantial i.e. greater standardisation across hospitals, enhanced UK scientific leadership, higher trust in emerging technologies, stronger reputational standing for clients, and improved resilience during crises. In short, NMS support not only safeguards patient safety but also plays a role in accelerating the adoption of validated innovation across the UK healthcare ecosystem.

[33] Briscoe Advisory Ltd. *NMS Healthcare Survey – Impact Case Studies: Review & Recommendations*. National Physical Laboratory. *Forthcoming*

Environmental Benefits

The National Measurement System (NMS) laboratories also provide essential measurement services that support environmental monitoring and climate-related objectives. Their work includes developing accurate methods for greenhouse gas measurement, air quality monitoring, and emissions verification. These services help organisations meet regulatory requirements, improve data reliability, and inform strategies for reducing environmental impact. By offering calibration, testing, and technical expertise, NMS labs contribute to building a robust evidence base for actions aimed at sustainability and net zero goals. NPL's work underpins accurate and traceable measurements for greenhouse gases such as CO_2, CH_4, and N_2O, which are critical for understanding and mitigating climate change. NPL develops high-accuracy reference materials, advanced spectroscopy techniques, and field-deployable solutions to ensure compliance with international standards and improve confidence in emissions data.

Using a model based on invoicing data for the greenhouse gas monitoring and reduction services offered by NPL, the study estimates that services provided between 2016 and 2020 saved **0.51 mega tonnes of CO_2 equivalent emissions**, translating into a **social value of £67.8 million** (domestic and international combined). This impact represents **1.3% of the UK's total emissions reduction** during the same period. By enabling real time measurement, detection, mitigation of methane leaks—a gas 28 times more harmful than CO_2, NPL helps reduce environmental harm and supports clean growth objectives[R45].

Moreover, NPL has systematically tracked its **scope 1, 2, and 3 emissions**[34] from 2020–2023, reporting annual totals of approximately 9,000 tonnes CO_2e across its operations. NPL's regularly supported firms see GVA growth but doesn't account for emissions. To account for this, emission factors indexed by industry (SIC codes) were applied to GVA growth from regularly supported firms. GVA per firm was calculated to be £131,600 and estimated emissions to be approximately 9,000 tonnes CO_2e per year.

[34] Scope 1 (approximately 3800 tCO_2e for 2023) covers direct emissions from owned sources, scope 2 (approximately 4800 tCO_2e for 2023) relates to purchased energy, and scope 3 (approximately 400 tCO_2e for 2023) includes value-chain activities such as business travel and waste.

For 2023, NPL's work on reducing fugitive gas emissions has delivered a reduction of 0.02% in UK emissions[35] as shown in the graph below.

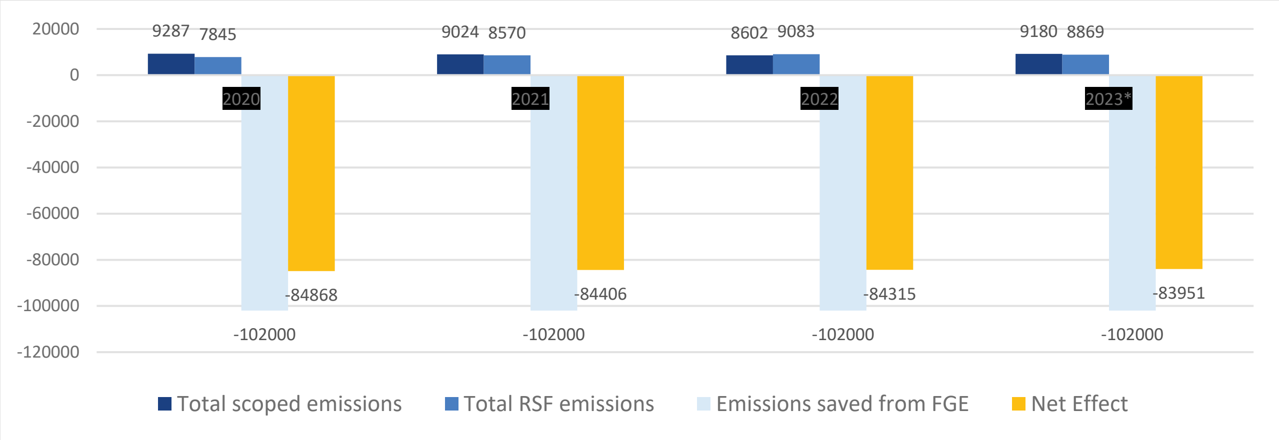


Figure 14 NPL's effect on tCO2e between 2020-2023

NPL is currently a net reducer of greenhouse gas emissions and continues its efforts to reduce emissions. For instance, in 2023, NPL introduced measures such as enhanced recycling, reduced single-use items, and donation schemes, supported by robust emissions tracking that enables progress toward the **carbon neutrality target by 2040**[36]. Beyond operational reductions, NPL also plays an important role in UK climate action through the **GEMMA Programme**, which will deliver an integrated national emissions dashboard for accurate, sector-level monitoring of greenhouse gases. This capability is essential for improving models and informing policy to achieve net zero.

Another study developed, applies an **input-output modelling framework** to quantify the wider economic and environmental effects of NPL's measurement activities across UK industries. This approach traces how improvements in productivity and efficiency ripple through supply chains, influencing both economic output and resource use. A key finding is the **decoupling of economic productivity from emissions**. Several factors underpin this decoupling:

- **Sectoral Shifts**: NPL's support appears to be concentrated in areas such as Digital and Quantum technologies, which are less carbon-intensive compared to traditional manufacturing sectors.

[35] UK's total emissions in 2023 were 384 million tonnes of CO_2e
[36] Reference: Addendum: Net Emissions from NPL's Work by Magda Sulek

- **Decarbonisation Trends**: Broader UK efforts to reduce emissions through cleaner energy sources and efficiency improvements are likely to amplify the environmental benefits of productivity gains.
- **Measurement and Standards**: NPL's role in disseminating calibration and measurement knowledge enhances process efficiency, reducing waste and energy use across industries.

Traditionally, economic expansion correlates with higher carbon emissions due to increased energy consumption and industrial activity. However, between **2016 and 2021**, the analysis shows a **11.6% increase in economic impact** (measured through Gross Value Added and related productivity indicators) while **emissions fell by 11.4%** over the same period. This reversal of the expected trend suggests that NPL-supported sectors are contributing to a more sustainable growth model[R15].

Despite the above, there is a needed caveat concerning the emissions being tracked. As the UK deindustrialises, it could be argued that the UK is "offshoring" its emissions rather than eliminating them[37]. Therefore, broader decoupling of emissions from economic growth needs to account for this offshoring effect. Nevertheless, this evidence positions NPL's impact as not only economically beneficial but also environmentally aligned, supporting the UK's transition toward **low-carbon growth**.

Evidence used:

R26. King, M. & Renedo, E. (2019) Estimating the impact of improved dose control on clinical outcomes in radiotherapy. NPL Report No. IEA 1. Teddington: National Physical Laboratory: https://eprintspublications.npl.co.uk/8556/

R20. IFF Research. (2025) NMS Healthcare Survey. Teddington: National Physical Laboratory (NPL). https://www.npl.co.uk/getattachment/447b229f-31af-4894-a2ce-e339600a1a41/IFF-Healthcare-Survey-Report.pdf

R44. Qureshi, Z., King, M. and Nayak, S. (2023) Quantifying Impact in the Environment Sector: A Greenhouse Gas Emissions Monitoring Study. NPL Report IEA 14. National Physical Laboratory: https://doi.org/10.47120/npl.IEA14

R15. Dias, C. and King, M. (2024) NPL Report IEA 21: Input–Output Analysis – A Pilot Study Assessing the Flows of NPL's Impact into Final Demand. National Physical Laboratory. https://eprintspublications.npl.co.uk/9961/1/IEA21.pdf

[37] Reference (link)

6.2 National Challenge Areas

The UK faces a set of strategic national challenges that require coordinated scientific, technological, and industrial capability. The national challenge areas are designed to respond to these emerging and long-term priorities, ensuring that public investment supports areas of greatest national need. NPL's activities connect directly to four of these strategic areas:

1. **Prosperity:** This area drives advanced manufacturing, digital infrastructure, and innovation, enabling economic growth through world-class measurement solutions.
2. **Environment:** Through cutting-edge measurement science, this area supports climate action and sustainability, helping to achieve net zero goals and improve environmental monitoring.
3. **Health:** It advances healthcare, life sciences, and the bioeconomy by supporting diagnostics, medical devices, and research into ageing and related health challenges.
4. **Security & Resilience:** It focuses on developing robust infrastructures such as time, communications, and quantum technologies while enhancing national security and societal resilience.

These provide the measurement and standards backbone for innovation in sectors such as clean energy, digital transformation, and life sciences, ensuring that scientific infrastructure supports progress on national missions like Net Zero, health resilience, and security.

Although this framing is still evolving, initial work has mapped NMS labs' contributions to these areas. For instance, work has been undertaken to update Logic Models and Theories of Change, ensuring they more effectively capture how NPL's activities generate outcomes and impact. These have been developed for each challenge area and used to articulate the value of programmes delivered through the NMS.

Moreover, the NMS labs have actively explored how their work aligns to the UK's strategic priorities by mapping business engagement across these four Challenge Areas and a set of Significant Technology Areas such as green energy, biotech, and quantum technologies. This has involved:

- Surveying businesses to identify connections between their activities and these challenge/technology areas along with quantifying attribution of innovation outcomes to NMS support within these areas.
  The survey conducted in 2023 finds that:
  - Nearly half of all users (**49%**) operate in areas linked to **environmental protection**, and over a third of these firms (**37%**) attribute innovation the support given by the NMS labs.
  - Around **47%** of the userbase works in sectors connected to **healthcare or public health**, with **31%** reporting that NMS support played a role in enabling innovations in these areas.
  - **44%** of the userbase has a line-of-business that's connected to **security/defence** with **34%** of these businesses attributing innovations to support from the NMS labs.
  - **7%** of the userbase are connected to the development of quantum technologies with **38%** of these businesses attributing innovations to support from the NMS labs.

- Analysing patterns of engagement, including geographical spread, firm size, and sectoral distribution.
- Evaluating impact metrics such as attributed revenue, employment growth, and innovation spillovers.
- Developing multi-perspective frameworks to interpret challenge areas from the viewpoints of users, NMS labs, and innovators.
- Highlighting emerging areas like quantum technologies, where NMS support is especially valued despite small sample sizes.

PROSPERITY

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

HEALTH

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

ENVIRONMENT

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

SECURITY

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

Figure 15 Perspective of National Challenge Areas

Additionally, substantial effort has gone into developing metrics that assess the performance of the NMS programme. NMS indicators are structured around three pillars aligned to the logic model. Activity–Output indicators (10 in total), introduced in 2017, monitor whether NMS delivery is generating the intended activities and immediate outputs in line with the Strategic Themes (Research; Trade & Standards; Innovation; Skills). Part A indicators (21) are designed to assess outcomes related to the UK Measurement Strategy and the enduring NMS themes. Part B indicators, the Challenge-Focused Indicators (14), assess outcomes against the UK Measurement Strategy's three societal challenges Prosperity, Health, and Environment while maintaining continuity with the core NMS themes.

There remains scope to further develop the evidence base around the National Challenge Areas and identifying where targeted evaluation could fill remaining gaps.

7 Conclusion & Future work

The UK's **National Measurement System (NMS)** plays an important role in enabling economic growth, innovation, and societal well-being. Delivered through a network of specialist laboratories including the National Physical Laboratory (NPL, the National Metrology Institute of UK), it ensures the accuracy, traceability, and international comparability of measurements that underpin the UK's competitiveness and quality of life.

Focus of This Report

While the NMS labs deliver a broad spectrum of benefits, this report focuses primarily on evidence developed in the **two core economic channels** through which impact is disseminated:

1. **Enabling Technological Change (Innovation Benefits)** – achieved through collaborative and in-house R&D, which accelerates innovation and strengthens productivity.

2. **Delivering Measurement Infrastructure** – through calibration services traceable to national standards and certified reference standards that ensure reliability and reduce costly errors across the economy.

Beyond these, the NMS generates **societal benefits** such as improved healthcare outcomes and environmental gains. The work that has been done to reduce uncertainty in radiotherapy dosing, results in 15 additional successful treatments per year. The healthcare survey conducted finds that 88% of users consider NMS support beneficial, and over half regard it as essential to their work. Moreover, the greenhouse gas monitoring services that the NMS labs provide estimate a saving of 0.51 mega tonnes of carbon dioxide equivalent emissions, equivalent to a social value of £67.8 million. The report touches upon the NMS labs' contributions cut by **National Challenge Areas** (Prosperity, Environment, Health, and Security & Resilience). However, the emphasis in this report remains on the economic channels that form the backbone of the impact generated by the NMS labs.

Highlights from the Delivering Measurement Infrastructure Chapter

The **measurement infrastructure channel** is underpinned by a framework part of which is a macroeconomic model that quantifies the role of metrology in enhancing productivity. The framework is divided into two major components that form the basis of the framework:

- **Uptake and Fan-Out of Traceable Calibrations Model** – captures what benefits are reaped using precise calibrations from a domestic NMI.
- **Optimal Testing Frequency Model** – identifies the optimal level of testing (around 9–10 months) and estimates key components one of which is the scrap rate (0.3%).

Together, these models show that without NMS laboratories:

- The **relative standard deviation (RSD)** of measurements would rise by approximately **3.1%**, increasing the probability of Type I errors (throwing away good capital) by two thirds.
- Even partial reliance on foreign NMIs would lead to **increase in error rates**, causing measurable economic losses.

Highlights from the Innovation benefits chapter

Under the **innovation channel**, the evidence demonstrates that NMS support significantly enhances business performance:

- Firms regularly supported by NMS laboratories grow faster, adding **6.3 jobs annually per firm** and offering a **wage premium of £4,000 per new hire**.
- NPL support accelerates **time-to-patent by 26%** and increases the likelihood of patenting by **23%**, reinforcing its role as a catalyst for innovation.
- Public investment in NMS leverages private R&D, with every **£100 of funding generating £29 in additional private R&D spending**.
- Supported firms show an annual business-closure rate of around 0.6%, compared with roughly 2% per year in a matched control group and around 5% per year in the wider UK business population.

NMS Programme's net present social value (NPSV) to Departmental Expenditure Limit (DEL) ratio from both streams of benefits is estimated to be **12.79** on average and **8.04** at the margin, signifying the substantial value for money of the programme.

Complementary and future work

Complementary to the quantitative and econometric analyses presented in this report – a systems map of the National Measurement System has been developed to synthesise the relationships across the measurement, regulatory, and industrial landscape[R56]. Each connection in the map is guided by the availability and strength of evidence. The map illustrates the NMS as a central intervening node within a broader ecosystem spanning the public sector, industry, and the infrastructure and regulatory environment. In doing so, the map helps to articulate both direct pathways of impact and indirect pathways, and act as a framework to collate and validate stakeholder worldviews to enable the ecosystem map to adapt to changes in the ecosystem. Further details and an illustration of the map can be found in Annex B.

In addition to the bibliometric assessment presented in this report, further analytical work is underway examining global metrology capability using Calibration and Measurement Capabilities (CMC) data from 2001–2024. The CMC-based analysis will provide a complementary perspective to the earlier publication-based findings, offering a broader view of metrology fields and branches, and thereby strengthening understanding of international metrology performance.

Future work could explore an enhanced *calibration model* that builds on the existing frameworks. This would allow us to capture a complete picture of how calibration quality, traceability, and uptake affect businesses and productivity, complementing the macroeconomic and fan-out work already undertaken.

There is an opportunity to develop a dedicated *innovation model* that echoes the structure of the measurement-infrastructure model. This would bring together the different strands of evidence on how NMS support influences firm-level performance, providing a more unified framework for understanding the long-term contribution of innovation activities.

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Annex A – GDP of European Countries

GDP as reported by the World Bank (Link)

UK = $3.34 trillion

Exchange rate $1 = £0.8042

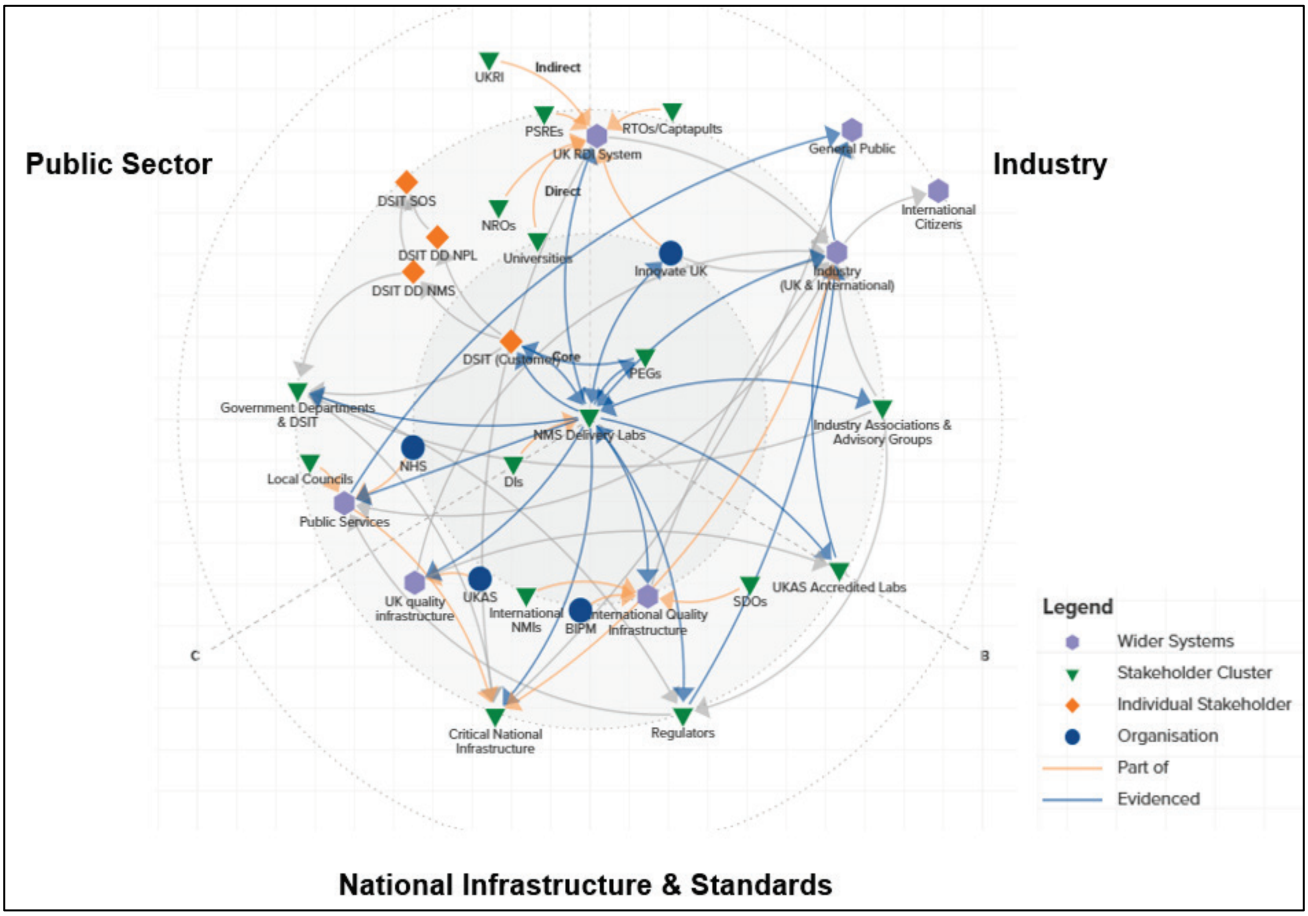
Europe = $26.8 trillion

European Union		**Other Countries**	
Country	**2023 GDP (USD Billion)**	**Country**	**2023 GDP (USD Billion)**
Germany	$4,456.1	United Kingdom	$3,340.0
France	$3,030.9	Russia	$2,021.4
Italy	$2,254.9	Türkiye	$1,108.0
Spain	$1,580.7	Switzerland	$884.9
Netherlands	$1,118.1	Norway	$485.5
Poland	$811.2	Ukraine	$178.8
Belgium	$632.2	Serbia	$75.2
Sweden	$593.3	Azerbaijan	$72.4
Ireland	$545.6	Belarus	$71.9
Austria	$516.0	Iceland	$31.0
Denmark	$404.2	Georgia	$30.5
Romania	$351.0	Bosnia and Herzegovina	$27.1
Czech Republic	$330.9	Armenia	$24.2
Finland	$300.2	Albania	$23.0
Portugal	$287.1	Moldova	$16.5
Greece	$238.2	North Macedonia	$14.8
Hungary	$212.4	Kosovo	$10.4
Slovakia	$132.9	Montenegro	$7.4
Bulgaria	$102.4	Monaco	$8.7

Luxembourg	$85.8	Liechtenstein	$7.4
Croatia	$82.7	Andorra	$3.7
Lithuania	$79.8	San Marino	$2.0
Slovenia	$68.2	Vatican City	No official data reported
Latvia	$43.6		
Estonia	$41.3		
Cyprus	$32.2		
Malta	$21.0		
TOTAL GDP of EUROPE		**$ 26.8 trillion**	

Annex B – An illustration of the NMS Systems Map

The systems map of the National Measurement System has been developed to synthesise the relationships across the measurement, regulatory, and industrial landscape. Each connection in the map is guided by the availability and strength of evidence. This approach ensures the structure of the map reflects not only conceptual understanding of systemic actors and their roles in the NMS ecosystem, but also progressively validates and develops the understanding of these roles and connections as the underlying evidence base strengthens and new evidence emerges. The map illustrates the NMS as a central intervening node within a broader ecosystem spanning the public sector, industry, and the infrastructure and regulatory environment.



The map provides a combined view of the NMS that incorporates NMS-designated delivery laboratories and a wider ecosystem of actors. By situating these actors within a shared system boundary, the map supports consistent reference and alignment across the ecosystem and contributes to a shared perspective of system roles, dependencies, and interactions. This further supports the articulation of direct and indirect pathways of impact and provides a framework that supports the collation and validation of stakeholder worldviews, enabling the map to be adapted as the NMS ecosystem evolves.

The map further identifies the cross-cutting nature of the NMS across national-level UK systems, including the UK's Research, Development and Innovation (RDI), public services, and wider industrial activity systems. By representing how the NMS contributes across these systems the map provides a basis for engaging with the NMS at a broader strategic level.

The methodology used to develop the map draws on Soft Systems Methodology (SSM) and participatory systems mapping, which enable the integration of diverse stakeholder worldviews, iterative modelling and testing of assumptions, and structured representation of system complexity. This methodological approach aligns with the increasing use of systems thinking within the UK Government **(Government Office for Science, 2022),** where there has been an identified need to understand interconnections, system structures, and the need for holistic approaches when engaging with complexity.

The map organises stakeholder connections into emergent subsystems that communicate high-level NMS purposes within the ecosystem. These include Accreditation, Regulation, International, Standards, National Capability and Security, Knowledge Transfer, Innovation, and Skills.

National Physical Laboratory

A Summary of the Evidence for the Economic Impact from the NMS Programme

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