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Measuring the economic benefits from R&D: improvements in the MMI model of the United Kingdom National Measurement System

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Abstract

The benefits and priorities of public funding of R&D programmes are the subject of considerable research and debate and a number of methodologies have been suggested which might allow us to arbitrate on the issues involved. This paper looks at one method that is actually used in practice to evaluate and rank publicly funded R&D programmes in the UK. We describe the improvements that have been made to the mapping measurement impact (MMI) model, which is used by the UK Department of Trade and Industry to assess the economic benefit to industry of different research projects funded as part of the United Kingdom National Measurement System. The model has been in use for more than 5 years as a means to compare publicly funded R&D programmes. It allows evaluation of their benefit and prioritisation of future funding schemes and has potential for wider application in other areas of public R&D investment both inside and outside the UK.

JEL classification: O32; O38

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1. Introduction

The importance of R&D in creating and sustaining economic growth is now well established and a huge literature investigating the underlying processes and the magnitude of the impact of technological innovation has been created. A comparatively neglected aspect however lies in the importance of basic technology infrastructures upon which innovation depends.

In this paper we look at metrology and measurement applications, which can be viewed as an underpinning or infra-technology, supporting the development and use of new techniques and products (see for example, Link and Tassey, 1993; Leydon and Link, 1994; Tassey, 1997, 2001). In this respect they are likely to have similar benefits to other aspects of technology infrastructure such as industrial standards, which have been studied widely and shown to have an important

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economic impact, for example, through transactions cost reductions, avoidance of replication of effort and encouragement of international trade (see Temple and Williams, 2002a; Blind, 2001; Swann et al., 1996).

Measurement techniques affect all stages of economic activity from R&D through production and then to marketing. More generally, these types of infra-technologies provide a pervasive, underpinning structure upon which industrial economies rely for measurement quality assurance. This is essential for commerce, science, engineering, consumer and environmental protection and public health and safety. All industrial economies therefore provide public support for some form of national measurement system (NMS). However, despite this pervasive, underpinning character measurement technologies and metrology research are not well known and are often taken for granted. As a result, public budgets for this type of research are often under considerable pressure.

In this paper we hope to make a contribution to the understanding of the importance of measurement infra-technologies to the UK by describing an econometric approach to evaluating the economic impact of public funding in this area. The mapping measurement impact (MMI) model is to our knowledge unique in assessing publicly funded science policies; firstly because it provides a forward-looking econometric approach as opposed to the more common retrospective case study assessment and secondly, because it is actually used in practice by the UK Department of Trade and Industry (DTI) to evaluate and prioritise their funding programmes in this area.

The paper is organised as follows: Section 2 described the scope and dimensions of measurement activity in the UK; Section 3 surveys the existing literature on the economics of measurement and public R&D programmes; Sections 4 and 5 describe the MMI model and its revisions; Section 6 provides some illustrative results; and Section 7 concludes.

2. The UK measurement infrastructure

The United Kingdom National Measurement System is a set of publicly funded programmes, which aim:

> to maintain and develop, at the national level, an infrastructure that ensures measurement in the UK is valid, fit for purpose, consistent and internationally recognised. This infrastructure exists primarily to promote the economic competitiveness of UK and support regulatory needs.

The work of the NMS is mostly carried out at four national metrology institutions (NMIs): the National Physical Laboratory (NPL), the Laboratory of the Government Chemist (LGC), the National Engineering Laboratory (NEL), and the National Weights and Measures Laboratory.[1] The LGC and NEL are fully privatised companies; NPL is run under contract to the DTI by NPL Management Ltd.[2] An independent, unpaid body, the Measurement Advisory Committee (MAC) of industrial users, academics and members of relevant government departments, guides prioritisation of NMS funding and the national measurement system policy unit (NMSPU) at the DTI directs the overall policy strategy.

Public funding for the NMS was around £38 million in 1999/2000, but has been gradually reduced both in absolute and real terms during the last decade due to tighter controls on general public expenditure and an increase in income from other sources, mostly public–private partnerships and commercial activity. The 1999/2000 NMS budget was distributed between the laboratories as follows: NPL 74%, LGC 9%, NEL 12% and others, including the NWML 6%. Public funding for the NMS is an important source of income for the labs accounting for around 40% of their total income, 60% in the case of NPL, 20% for NEL and 15% for LGC, which reflects the commercial orientation of the private companies.[3]

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[1] The National Weights and Measures Laboratory (NWML) deals largely with measurement application in regulation and other legal metrology activity rather than research. NWML also calibrates the equipment for the UK National Lottery and other gaming machines. Its turnover in 1999/2000 was around £2.9 million of which 75% or £2.2 million came from the DTI.

[2] NPL Management Ltd. is a wholly owned subsidiary of the Serco Group, however the DTI retains ownership of NPL land and buildings and major items of scientific equipment.

[3] The UK has a high level of private funding for the NMS because of its semi-private structure. Most other countries have a higher proportion of public funding as, for example, in Germany where 90% of NMS funding comes from public sources. However the UK is not unique, The Netherlands and Denmark also have a semi-private structure (see the Panorama report of European Commission, 2002 or Spencer and Williams, 2002).

Table 1
The distribution of NMS spending by generic activity

Activity	Description	Share of budget (%)
Research	New technologies and standards	25
Development	Developments and improvements to the existing NMS suite of standards	21
Maintenance	Maintaining existing standard reference measures	18
Dissemination	Technology transfer programmes and initiatives	17
International traceability	Establishing and maintaining international comparability of standards	5
Regulation	Contributing to legal metrology applications	5
Management	Project management and delivery	5
International liaison	Representing UK interests on international measurement standards bodies such as EUROMET	4

Source: NMSPU (1999).

NMS research activity is carried out across a range of programmes from mass, length and flow through to ionising radiation and valid analytical measurement (VAM) in chemical and physical applications. The foundation programme and the national measurement partnership (NMP) support management strategy and technology transfer projects and the legal metrology programme supports measurement research for regulatory purposes, often related to health and safety or environmental protection.

The number of programmes and the number of individual projects vary between funding rounds, but the overall distribution of activity is available as shown in Table 1.

The NMS is often viewed as the top layer of the measurement infrastructure in the UK. Industrial use of measurement technologies is diffuse and mostly carried out by a network of calibration, testing and inspection organisations, which form part of the technology infrastructure in the private sector. Voluntary third-party validation is often obtained from the United Kingdom Accreditation Service (UKAS), which is designated by the UK government as the sole accreditation body for conformity to international standards in measurement procedures (e.g. EN 45000 or ISO 9000).

Around 342 calibration labs and 1161 testing and inspection bodies have taken UKAS accreditation. The aggregate costs of accreditation to these firms can be judged from UKAS turnover, which was around £7.3 million in 1999/2000 for accreditation of laboratories, certification bodies and inspection bodies.[4]

Calibration laboratories sold around 600,000 UKAS authorised calibration certificates and around 10 times as many non-UKAS calibration certificates in 1999, mostly to SMEs. Spencer and Williams (2002) suggest that a lower bound for the costs to industry from accredited calibration organisations would be around £440 million. In addition calibration is carried out by non-UKAS organisations and by measurement departments within firms such as aerospace and automobile manufacturers. The number of these certificates and their associated costs are unavailable but are likely to be many times greater than those associated with accredited organisations.

Most measurement activity is carried out within industry and a way of quantifying the lower bound costs is to look at the sales of measurement and testing equipment (PRODcom classification 33,200), which was around £4.5 billion in 1998. Net trade was around

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[4] Source: UKAS Annual Report 2000, total turnover was £8.3 million with sales of £5.4 million. Laboratory accreditation accounted for 71%, certification body accreditation 14% and inspection bodies 5%. The remainder accrued from training and publication sales. They have a core staff of around 106 people and employ around 300 technical assessors. The UK has one of the most developed accreditation systems in Europe. France has 292 (COFRAC) accredited calibration labs and 1100 accredited testing labs; Germany (DAR) has 245 and 1254, respectively, and the next largest, Italy, has 120 SIT accredited calibration labs and 239 SINAL accredited testing labs.

£1 billion. Alternatively we can look at in the UK instrumentation industry, which has a high measurement requirement where net sales were in excess of £9.2 billion in the same year. Therefore that despite being a little known part of the technology infrastructure, the evidence suggests that the size of the economic activity supported by the NMS is large even by lower bound estimates.

3. The economics of measurement

The literature on the economics of measurement and the quantification of its impact is rather sparse but is growing. Tassey (1982) provides an early assessment of the importance of publicly funded measurement infrastructures and Don Vito (1984) provides an early estimate of the average value added from measurement to the US economy which he puts at 3.5% of gross national product (GNP). Studies by Drath (1986) for the case of Germany and Andersson and McEvoy (1991) for the case of Australia are unable to give a figure for the impact of measurement, but conclude that it is likely to be large relative to its cost.

Link and Tassey (1993), and Leydon and Link (1994) provide estimates of measurement impact using case studies based on surveys of the producers and users of high-tech products. They demonstrate high multipliers to the infra-technology spend of the US National Institute for Standards and Technology (NIST). A set of more recent case studies is provided on the NIST web site each demonstrating substantial benefit from measurement infrastructures and research.[5] These claims are supported in the UK by case studies carried out for the review of the UK NMS in 1999 (NMSPU, 1999). In addition, this report provides estimates based on growth theory and patent counts that show that the impact of total domestic R&D related to metrology can account for as much as 1% of UK gross domestic product (GDP). Since this figure is for research impact alone, not industrial development, it represents a significant minimum or lower bound for measurement impact.

The international character of metrology is also important since it affects the UK both in terms of imports of foreign R&D and in terms of the comparative advantage of UK. Spencer and Williams (2002) show that the measurement infrastructure in the UK is large in comparison to other countries, and Temple and Williams (2002b), drawing on the concept of R&D spillovers (Griliches, 1992), show that not only is measurement important in investment decisions, but also benefits key exporting sectors. Williams (2002), using the idea of international R&D spillovers (Grossman and Helpman, 1991; Coe and Helpman, 1995) shows that for those countries in Europe where the domestic measurement system is underdeveloped, such as Ireland, Greece and Denmark, for example, imports of foreign measurement techniques, often from the UK, play a key role in their development of infra-technology.

Given the evidence that measurement provides significant benefits to industry, the rationale for public as opposed to private funding is often questioned indeed in the United States, the 1993 Government Performance and Results Act requires formal assessment of the benefits of and rationale for public funding programmes (see Cozzens, 1995; Tassey, 1999). In the UK pressures on general government spending have led to a rash of impact assessments across the range of activities of which the 1999 NMS review is an example.

There is of course a large academic literature on the rationale for public funding of basic research of which Mansfield (1991), Pavitt (1991), Kealey (1996), Swann (1996), Tassey (1997), and Georghiou and Roessner (2000) are a small selection. The economics of measurement has been analysed from a theoretical perspective by Tassey (1997, 2001), Swann (1999), and Antonelli and Patrucco (2002). Taken together this literature highlights on three generic arguments for public support of measurement infra-technologies; under provision by markets, regulation requirements and industrial or competitive strategy.

Antonelli and Patrucco (2002) argue that measurement techniques can arise de facto from the specification of dominant products within markets or ex post from competition amongst firms producing the dominant product. If appropriation mechanisms, such as patents, exist, proprietary measurement techniques can affect industrial activity by providing a lead advantage for the firms that develop them. Competitors have to spend time and money replicating the tech-

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[5] This site is at http://www.nist.gov/director/planning/ [strategicplanning.htm].

niques or may have to purchase them under license restricting their potential diffusion. Public provision potentially allows techniques to diffuse more quickly by removing the need for replication or by providing the technologies cheaply. Without public provision, monopolistic advantage can lead to general under provision of technologies and may hold back growth.

From a related perspective, Swann (1999) argues that measures have many of the characteristics of a public good and may offer considerable positive externalities, which can be maximised if measurement knowledge is made publicly available. This is a generally under researched area, but NMSPU (1999) provides some tentative estimates of the lower bounds of some externalities identified from the set of case studies used there.

Public support for measurement infra-technologies also allows the regulation of other forms of market failure such as the negative externalities of pollutants. Almost all countries have a legal metrology infrastructure to enforce weights and measures standards and for wider consumer protection and health and safety. A national measurement infrastructure therefore reduces risk for consumers and industrial users by establishing common standards and compatibilities, by requiring minimum quality levels, by reducing variety and by defining common information sets.

Just as proprietary technologies can lead to competitive advantage for firms so national technology infrastructures can provide competitive advantage for nations (see for example, Tassey, 1992; Blind, 2001). This can be helpful in supporting and protecting domestic industries, helping to create technology clusters and helping to encourage foreign direct investment (see for example, Temple, 1998). This provides a strategic rationale for public funding.

These qualitative arguments are often accompanied by quantitative evaluation of public programmes, which has also become the subject of a significant research effort (for example, Link and Tassey, 1993; Cozzens, 1994, 1995). Georghiou and Roessner (2000) provide an extensive survey that highlights case studies, output measures (such as patents, licenses, bibliometrics and citation counts) and econometric modelling as the most common methods of evaluating the benefits from publicly funded R&D. A set of such studies and a discussion of methodology in the area of measurement are available from the NIST web site.

The MMI model is an econometric model and so fits into the latter category. It is however to our knowledge the only example of such a model that is actually used in practice and certainly the only model used to evaluate the impact of measurement infra-technology.

4. The MMI model

The MMI model was developed in the light of the background described in the previous section; a belief that measurement has an important role and should be publicly funded but with little firm evidence on the exact size of the benefit or on the priority areas for funding. This ambiguity often makes metrology budgets prime targets for cuts when general government expenditure is tightened and proper evaluation can therefore be useful in their defence.

The original structure of the MMI model is described in Klein et al. (1996). This section therefore provides only a brief overview to highlight the main features of the approach. The MMI model characterises metrology as having an impact on industrial activity via the following mechanisms.[6]

A. Providing traceability to internationally recognised primary standards.
B. Generating exploitable new measurement technologies.
C. Using leading edge metrology to support advanced products.
D. Providing an expert service, usually consultancy, to diagnose and solve measurement related problems in industry.
E. Providing leadership and dissemination in frontier technologies.
F. Representing UK interests on international bodies.

These impact mechanisms are now well understood from both an academic and practitioner perspective. For example, surveys of the importance of these mechanisms can be found in Tassey (2000) on standardisation (mechanism A); Bozeman (2000) on technology transfer (mechanisms C and E); Hagedoorn

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[6] The choice of mechanisms can be customised for different contexts and since the exercise for this paper was conducted a seventh mechanism, “facilitating compliance to regulation”, has been added for future assessments.

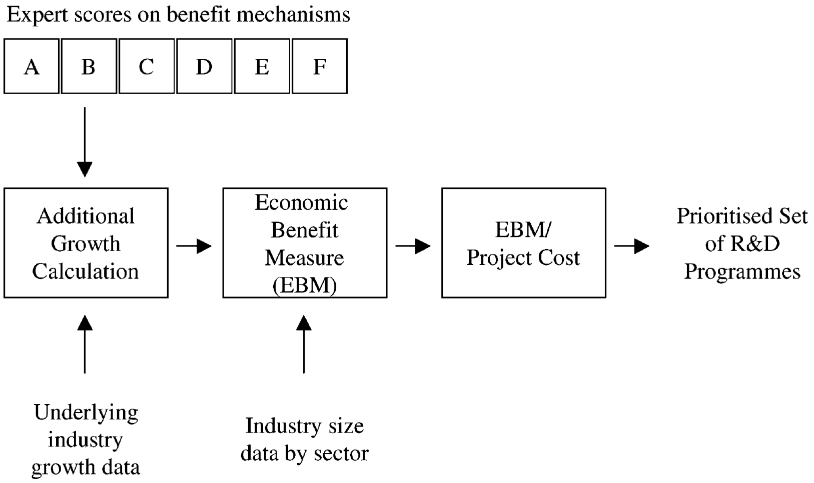

Fig. 1. The structure of the MMI model.

et al. (2000) on research partnerships (mechanism D); and Swann et al. (1996) on standards and competitiveness (mechanism F). Five of these mechanisms were identified by Klein et al. (1996), the final mechanism was added for the current revision.

The NMS programmes are assumed to provide extra growth to industry, in addition to underlying growth, via one or more of these mechanisms. A survey of expert practitioner opinion is used to provide a score for the importance of each of these mechanisms for the programmes and project themes. These are used to weight the impact from each mechanism in the total impact. In order to provide a balanced assessment, the expert advisors are made up of academics who are both users of measurement technologies and sources of new techniques, regulators and other members of the measurement infrastructure, for example, UKAS and UKAS accredited laboratories as well industrial users and other beneficiaries of the measurement infrastructure. This final group is extremely important in assessing the relevance of the research projects undertaken and includes representatives of government departments such as the Department of Health, the Health and Safety Executive and the Environment Agency who need to use measurement techniques in the public sector and for regulation. This helps to avoid bias, which might arise if only beneficiaries were asked to assess the potential of a project.

In the original model, the growth path is allowed to stretch over 30 years in two phases: (1) phase I takes place over 10 years at the historic growth rate for the industry sector affected; and (2) phase II takes place over the remaining period at half the historic growth rate. The economic impact is calculated as the net present value (NPV) of the extra growth discounted at a fixed rate per annum.

Fig. 1 shows the structure of the model. In essence it has an encompassing character that integrates qualitative and quantitative analysis, which is achieved through a set of small-scale accounting equations. This makes it intuitive and keeps down maintenance costs.

5. Revisions to the MMI model

The revisions to the model aimed to make it more transparent and realistic and to adopt best practice at each stage in the impact calculations. We retained the five original impact mechanisms and added a sixth, which reflected the growing role of the NMS in protecting UK competitiveness. Also, in addition to weighting the importance of each mechanism, experts are also invited to indicate whether this impact was direct; that is a specific or immediate effect, underpinning; that is a basic or supportive effect, or both. The rest of the revisions concentrated on the accounting methods and the assumptions made about underlying growth rates.

5.1. *Growth profiles*

The existing model has two growth phases with fixed linear growth profiles, growth in phase II is simply half the rate in phase I which in turn is set at the historic average. Making this assumption is expedient but can also be misleading. We know that the economic environment changes in observable and measurable ways, which should be used to condition the impact calculation. Not to do so means that we are neglecting important information in the state-space of the model which is methodologically inefficient.

To overcome this problem the new model was changed to allow information on sector growth to be imported from forecasts and analysis based on large-scale macroeconomic models. Studies like this are widely available commercially, for example, from groups such as Oxford Economic Forecasting Ltd. (OEF, 1998). It is therefore not necessary to assume linear growth and more realistic profiles incorporating normal economic fluctuations and even recessions can be used instead.

5.2. *Forecast and planning horizons*

A related issue concerns the time scale over which the impact assessment should be made. The fluctuations that we observe in economic activity mean that the confidence that can be placed in 30-year projections is very low. Also, for the methods used in the MMI model, the longer is the time span the greater is the sum of the discounted impact. This is especially true if the discount rate is low.

For practical reasons also the 30 years time span was seen as rather too long. Most of the NMS projects have a 2–3 years funding life and for many programmes the technology is quickly superseded by innovations. So for planning purposes and as a reflection of the nature of technology impact a 30-year time frame was seen as unrealistic. We therefore adjusted the time frames to allow a 2-year forecasting horizon, a 5-year strategic view and a 10-year prospective view, which is useful for programmes whose impact develops slowly.

5.3. *Impact profiles*

The diffusion of the returns to R&D can be modelled in a number of ways (see Geroski, 2000). For the new MMI model we generated impact profiles that allow the impact mechanisms described above to be affected by competitive behaviour and product life cycles within different sectors. The new profiles assume that the impact follows a series of phases; an acceptance or take-up period, a growth period, a maturity period when the technology is in wide-spread use and a period of decline when the technology or the products which use it are superseded. These ideas were formalised using sigmoid curves. These are often used when modelling situations in which change is taking place over time and reaching a known end-point, for example, in the substitution of an older generation of goods or services by something new and innovative. The equation we use to deliver these profiles takes the following form:

$$e_i = m_i \times \min\left\{ b\left[1 - \frac{1}{1+\exp(da-(dka\times t_2))}\right] + b^{\mathrm{l}}\left[\frac{b}{1+\exp(ga-(gka\times t_1))}\right]\right\} \quad (1)$$

where e_i is the extra growth provided by the measurement component m_i in industry sector i, which is a function of the delay between the initiation and initial impact for the mechanism t_1, the overall life span of the impact t_2, the peak benefit obtained b and the half life of the growth and decay rates g and d, respectively.[7] If the project in question delivers benefit beyond the horizon of the impact assessment then we set the long-term benefit coefficient, $b^{\mathrm{l}} > 0$ otherwise $b^{\mathrm{l}} = 0$. We assign a certainty factor to the growth and decay half-lives, c, to define $gka = \ln(c)/g$ and $dka = \ln(c)/d$, and $ga = gka \times g$ and $da = dka \times d$. Each of the coefficients in Eq. (1) is a factor whose value can be adjusted to calibrate the profile to represent those seen in particular cases. This gives the model a great deal of flexibility and allows it to incorporate many different diffusion processes.

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[7] Taken together these deliver an equivalent life (EL) for each impact profile of $\mathrm{EL} = g + d + (t_1 - t_2)$ and for a 10-year impact assessment the range of g, d, b, t_1 and t_2 range is assumed to be 0–10.

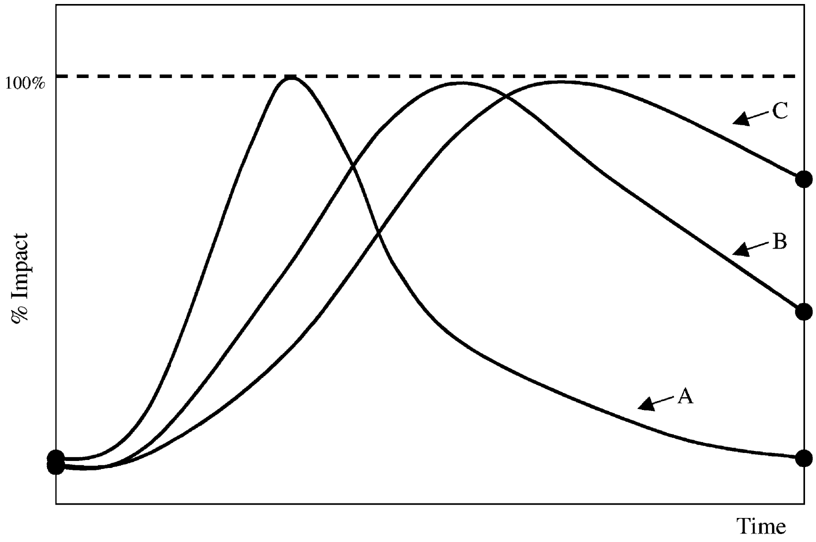

Fig. 2. Stylised impact profiles.

Fig. 2 shows some stylised impact profiles generated by Eq. (1) under different values for g, d, b, t_1 and t_2. Profile A describes a technology with rapid take-up and growth but which is quickly superseded by new innovations so that $b^1 = 0$. Profile B describes a technology with a rather slower rate of take-up and decline and which therefore has a longer period of usefulness so that $b^1 > 0$. Profile C describes research that leads to a basic or standard technology whose usefulness lasts for a long time beyond the horizon of the impact assessment so that again $b^1 > 0$.

5.4. Discount profiles

A final revision was to change the way in which the discount rates were calculated for each of the industry sectors. The original model calculated the economic impact as the NPV of the extra growth generated, discounted linearly at the standard 8% per annum rate for public investment as described in HM Treasury (1998), “Green Book”. However, this method neglects non-trivial differences in discounting across sectors and does not take into account variations in innovation life cycles. To solve these problems we incorporated a new formulation for calculating the discounted benefits, the basis of which is the following non-linear equation:

$$\delta^i = 1 - \left[\left(\frac{50/A^i}{100}\right)\right]^{1/(A^i - 0.5)} \quad (2)$$

This is a constant proportion, or reducing balance, discounting process (see for example, Williams, 1998). For each sector i, a discount rate δ^i is chosen to reduce the original impact to some small proportion of its value at a point half a year before the end of the useful life span of the technology A^i. In the version used here this value is set to equal $50/A^i$ percent at that point so that depreciation is as defined in the equation above.

5.5. Model summary

So in summary, the base growth for each industrial sector, q_i, is provided by forecasts based on the full economic background for the sector. The extra growth, e_i, provided by the measurement project in question is calculated from Eq. (1) using parameter values calibrated by expert input based on the six impact mechanisms A–F, so that the total impact in the sector is given by

$$\text{impact} = Y_i \times (1 + e_i + q_i) \quad (3)$$

where Y_i is the sector turnover. The economic benefit of the measurement project in each sector is then

Table 2
Comparative properties of selected versions of the models

	Old model		New model		New model (with time delay)				
	Total EBM	Rank	Total EBM	Rank	Total EBM	Rank	Direct EBM	Rank	Total (%)
Programme									
Mass	126	8	163	6	103	6	24	9	23
Length	206	1	184	3	118	3	61	2	52
Flow	64	11	112	10	69	10	27	7	39
Electrical	132	5	150	7	94	7	31	6	33
Time	40	13	48	13	29	13	6	13	21
Thermal	151	3	261	2	163	2	80	1	49
Optical	126	7	130	9	83	9	32	5	38
Photonics	121	9	88	12	54	12	20	10	36
Software	158	2	175	4	111	4	24	8	22
Acoustics	129	6	276	1	169	1	15	11	9
Radiation	52	12	111	11	66	11	3	14	4
Chemical	96	10	132	8	86	8	39	4	45
Physical	138	4	167	5	105	5	49	3	47
Legal	28	14	12	14	8	14	8	12	97
Total	1567		2010		1258		418		33
Lowest	28	(P14)	12	(P14)	8	(P14)	3	(P11)	
Highest	206	(P2)	276	(P10)	169	(P10)	80	(P6)	

EBM are in million pounds.

calculated from the NPV of the extra growth based on a discount rate derived from Eq. (2).

6. The results

In this section we show some aggregate results for fourteen of the NMS programmes identified by broad area of activity. Each programme is composed of a number of individual projects often involving a number of different public and private organisations, which vary from year to year. The MMI method is applied to these projects individually and the economic benefit measures (EBM) are then aggregated for the overall programme.[8]

The results of the models are presented in Tables 2 and 3. We show the EBM from the original model and its programme ranking along with the EBM and programme ranks of the new model with the assumption that the programme benefits accrue immediately. The final columns show the effects of allowing the more realistic assumption of a delay in take-up of the research from the individual programmes. Two sets of results are shown; first we show the total impact of the cumulated or, “underpinning”, research along with effect of the, “direct impact”, of the programmes, the final columns show the, “direct impact” only. In order to arrive at this distinction we use responses from expert practitioners who are invited to indicate whether projects have a direct effect on activity that is, change a particular processes or whether the research is more fundamental, providing longer-term benefits. Many projects have both characteristics.

Table 2 shows the EBM for fourteen programmes. In general the new model provides higher estimates of the EBM than the old version but when a take-up lag, or time delay is added the model produces more moderate assessments, although for four programmes the new estimate is higher. In the cases where this effect is greatest, the difference can be explained by slower discounting in the new model due the new impact life span profiles; that is, programmes 10 and 11 involve underpinning projects which have a higher weight in the new model.

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[8] Two additional NMSPU programmes, the national measurement partnership and the foundation programme, also provide funding for measurement projects and networks but were not assessed for this exercise.

Table 3
Direct vs. underpinning impact and cost/benefit ratios

	Old model	New model		Cost	Benefit/cost ratio					
	Total EBM	Total EBM	Direct EBM		Old model			New model		
					Total	Rank	Total	Rank	Direct	Rank
Programme										
Mass	126	103	24	5.0	25.2	7	20.7	6	4.7	8
Length	206	118	61	6.5	31.7	4	18.1	7	9.5	4
Flow	64	69	27	7.5	8.5	12	9.2	11	3.6	10
Electrical	132	94	31	15.0	8.8	11	6.2	13	2.0	11
Time	40	29	6	3.0	13.3	9	9.6	10	2.0	12
Thermal	151	163	80	5.0	30.2	5	32.6	3	15.9	2
Optical	126	83	32	6.0	21.0	8	13.9	8	5.3	6
Photonics	121	54	20	2.5	45.4	2	21.8	4	7.8	5
Software	158	111	24	1.0	158.0	1	110.7	1	24.0	1
Acoustics	129	169	15	3.5	36.9	3	48.3	2	4.3	9
Radiation	52	66	3	10.5	5.0	13	6.3	12	0.3	13
Chemical	96	86	39	8.0	12.0	10	10.8	9	4.8	7
Physical	138	105	49	5.0	27.0	6	21.0	5	9.9	3
Legal	28	8	8	na	na	na	na	na	na	na
Total	1567	1258	418	78.5	19.9		16.0		5.3	
Lowest					5.0	(P11)	6.2	(P13)	0.3	(P11)
Highest					158.0	(P9)	110.7	(P9)	24.0	(P9)

EBM and costs are in million pounds. The BCR for legal metrology is not calculated since the principle aim of this programme is regulatory not economic.

Isolating the direct effects allows us to look at the overall distribution of the programme portfolio. Nine out of 14 of the projects produce greater than average direct impacts and five can be considered as mainly underpinning. However, in all but one case underpinning still accounts for the majority of the impact and of the top four, ranked by absolute EBM, two are underpinning projects.

The total EBM amounts to around £2 billion or around £1.26 billion for the preferred model with the take-up lag. By comparison, NMSPU (1999) estimates put the cumulative economic benefit of domestic measurement R&D in the UK that is both publicly and privately funded, at about £5–6 billion in 1998 at constant 1995 prices. Temple and Williams (2002b) estimate the impact of measurement R&D at £6.7–7.4 billion for 1999 (at 1995 prices) from domestic sources and £7.2–8.2 billion from foreign sources such as trade, joint partnerships and multinationals. This comparison suggests that publicly funded measurement R&D accounts for around one-fifth to one-quarter of the domestic total, which is a significant proportion.

Table 3 shows the comparison of the benefit to cost ratios (BCR) for each programme. The BCR suggest a significant impact for the NMS programmes and reflect their public good character, which allows wide benefit diffusion. In terms of programme ranking the new and the old model match three out of their top four for total EBM and the same ratio for their bottom four projects. In each case two of the top and bottom four have below average direct impact and so are underpinning projects.

The robustness of these results can be assessed by comparison to similar studies. Tassey (1999) and NIST (2000) provide a set of 25 case studies of measurement projects in the US.[9] For 15 of these they provide a BCR ranging from 3.0 to 113.0 with an average of 28.8, very much in line with those shown here. The highest BCR was achieved by a project aimed at providing standard reference materials (SRM) for the measurement of sulphur in fossil fuels. Their estimate of the NPV of this research is US$ 409 million. In addition

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[9] A summary table of these studies is available at http://www.nist.gov/director/planning/studies.htm.

they provide calculations of the social rate of return (SRR) for all of the projects studied, which range from 33 to 1056%, with an average of 175%. The estimates provided by the MMI model therefore appear comparable to evaluations made using other methodologies even though case study input is kept to a minimum.

7. Conclusions

Measuring the impact of publicly funded R&D expenditure is the subject of considerable debate in the policy community and a number of competing and complimentary methodologies have been suggested to arbitrate on the issues involved. The MMI model provides an actual example of how evaluation of R&D programmes can be carried out in practice. Since its original development it as been used as a portfolio tool by the NMSPU at the UK DTI to assess and prioritise their research programmes.

The new MMI model brings together features that have been identified in application and have led to the following improvements.

- A clearly defined set of mechanisms that reflect practitioner opinion and academic research on the impact of infra-technology research on industry.
- A robust forecast base for underlying growth patterns in the industrial sectors influenced by NMS R&D spending.
- New forecast horizons reflecting our understanding of the time frames of policy and technology impact.
- A new set of, “impact profiles”, for each industrial sector reflecting the nature of the process life cycle for R&D programmes.
- A new method for discounting the impact over time which allows discounting to be customised for different programmes and industrial sectors.

We believe that the revisions described here provide greater realism in the way the MMI model describes the impact of publicly funded projects and as a result should better inform decisions about future funding. By building on the best aspects of previous work and identifying and refining key weaknesses, a more credible and useful tool has emerged.

The model continues to play a pivotal role in the decision making process both at the level of individual projects and in the assessment of the portfolio of all the NMS programmes. Its features allow a good deal of scope for customisation and control by users so that it could easily be used in other areas where economic impact assessments would prove useful in the analysis, evaluation and design of management strategies.

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References

Andersson, H., McEvoy, J., 1991. Analysis of CSIRO industrial research. Bureau of Industry Economics, Department of Industry, Technology and Commerce, Canberra.

Antonelli, C., Patrucco, P.P., 2002. The microeconomics of technical measures. EUWP1 European Measurement Project, Pembroke College, Oxford.

Blind, K., 2001. The impacts of innovation and standards on trade of measurement and testing products: empirical results of Switzerland’s bilateral trade flows with Germany, France and UK. Information Economics and Policy 13 (4), 439–460.

Bozeman, B., 2000. Technology transfer and public policy: a review of research and theory. Research Policy 29, 627–655.

Coe, D.T., Helpman, E., 1995. International R&D spillovers. European Economic Review 39, 859–887.

Cozzens, S., 1994. Methods for evaluating fundamental science. DRU-875/2-CTI, Critical Technologies Institute Report for the White House Office of Science and Technology Policy, Washington, DC.

Cozzens, S., 1995. Assessment of fundamental sciences programs in the context of the government Performance and Results Act. Rand Project Memorandum, PM-417-OSTP, Critical Technologies Institute, Washington, DC.

Don Vito, P.A., 1984. Estimates of the costs of measurement in the US economy. National Bureau of Standards, Gaithersberg, USA.

Drath, P., 1986. Zusammenfassung der Untersuchung des DIW über die Volkswirtschaftliche Bedeutung des Messwesens in der Bundesrepublik Deutschland. Mimeo PTB.

European Commission, 2002. A panorama over the European measurement system. DG-Trade, European Commission, Brussels.

Georghiou, L., Roessner, D., 2000. Evaluating technology programs: tools and methods. Research Policy 29, 657–678.

Geroski, P.A., 2000. Models of technology diffusion. Research Policy 29, 603–625.

Griliches, Z., 1992. The search for R&D spillovers. Scandinavian Journal of Economics 94 (Suppl.), 29–47.

Grossman, G.M., Helpman, E., 1991. Trade, knowledge spillovers and growth. European Economic Review 35, 517–526.

Hagedoorn, J., Link, A.N., Vonortas, N.S., 2000. Research partnerships. Research Policy 29, 567–586.

HM Treasury, 1998. Appraisal and evaluation in central government: the “Green Book”. HMSO, London.

Kealey, T., 1996. The Economic Laws of Scientific Research. Macmillan, London.

Klein, J.A., Stacey, E.P., Coggill, J., McLean, M., Sagua, M.I., 1996. Measuring the economic benefit from R&D: results of the mass, length and flow programmes of the UK National Measurement System. R&D Management 26 (1), 6–15.

Leydon, D.P., Link, A.N., 1994. The Government’s Role in Innovation. Kluwer Academic Publishers, Boston.

Link, A.N., Tassey, G., 1993. The technology infrastructure of firms: investments in infra-technology. IEEE Transactions on Engineering Management 40 (3), 312–315.

Mansfield, E., 1991. Academic research and industrial innovation. Research Policy 20, 1–12.

NIST, 2000. http://www.nist.gov/director/planning/studies.htm.

NMSPU, 1999. Review of the rationale for and economic benefits of the United Kingdom National Measurement System. Report for the UK Department of Trade and Industry, London.

OEF (Oxford Economic Forecasting Ltd.), 1998. Industrial Sector Forecasts. Blackwell, Oxford.

Pavitt, K., 1991. What makes basic research economically useful? Research Policy 20, 109–119.

Spencer, C.G., Williams, G.A., 2002. The scope and dimensions of measurement activity in Europe. EUWP10 European Measurement Project, Pembroke College, Oxford.

Swann, P., 1996. The economic value of publicly funded basic research—a framework for assessing the evidence. Report written for Branch 4, Technology and Innovation Division, Department of Trade and Industry, UK.

Swann, P., 1999. The economics of measurement. Report for the NMS review, DTI, London.

Swann, P., Temple, P., Shurmer, M., 1996. Standards and trade performance: the UK experience. The Economic Journal 106, 1297–1313.

Tassey, G., 1982. The role of government in supporting measurement standards for high-technology industries. Research Policy 11, 311–320.

Tassey, G., 1992. Technology Infrastructure and Competitive Position. Kluwer Academic Publishers, Dordrecht.

Tassey, G., 1997. Infratechnologies. Quorum Books, Westport, CT (Chapter 8). The Economics of R&D Policy.

Tassey, G., 1999. Lessons learned about the methodology of economic impact studies: the NIST experience. Evaluation and Program Planning 22, 113–119.

Tassey, G., 2000. Standardization in technology-based markets. Research Policy 29, 587–602.

Tassey, G., 2001. R&D policy models and needs. In: Feldman, M., Link, A. (Eds.), Science and Technology in the 21st Century: Toward a Global Policy Agenda. Kluwer Academic Publishers, Dordrecht.

Temple, P., 1998. Clusters and competitiveness: a policy perspective. In: Swann, P. (Ed.), The Dynamics of Industrial Clustering. Oxford University Press, Oxford.

Temple, P., Williams, G.A., 2002a. The Benefits of Standards. European Committee on Standardisation (CEN), Brussels.

Temple, P., Williams, G.A., 2002b. Infra-technology and economic performance: evidence from the United Kingdom National Measurement System. Information Economics and Policy, in press.

Williams, G.A., 1998. The stock of consumer durables in the United Kingdom—new estimates 1948–1995. Review of Income and Wealth 40 (3), 1–20.

Williams, G.A., 2002. The economics of underpinning technology in Europe. EUWP2 European Measurement Project, Pembroke College, Oxford.