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Setting Science & Technology Research Funding Priorities

The Council for the Mathematical Sciences (comprising the Institute of Mathematics and its Applications, the London Mathematical Society, the Royal Statistical Society, the Edinburgh Mathematical Society and the Operational Research Society) is pleased to present its response to the House of Lords Science & Technology Committee's call for evidence on the setting of research funding priorities.

The CMS welcomes the Committee's attention on this issue, as this subject is a source of concern to us. Our response focuses on a subset of the Committee's questions which are particularly relevant to mathematical sciences research.

Is the balance of Government funding for targeted versus response-mode research appropriate?

1. We believe that the balance between targeted and response-mode research has now shifted so far towards the former as to threaten the viability of basic science in this country.

2. The Engineering and Physical Sciences Research Council's annual budget for mathematical sciences has been slashed in the last few years specifically to accommodate high level expenditure in targeted multidisciplinary themes such as *Energy*, *The Digital Economy*, *Nanoscience through Engineering to Application*, and *Towards Next Generation Healthcare*[1]. **In 2006/07 the Mathematical Sciences Programme budget stood at £21M; in 2009/10 the figure is £14M.** Meanwhile, the total commitment in 2008/09 in the programmes referred to above was over £128M[2].

3. Mathematical sciences underpin all other science subjects, and developments in maths often go hand-in-hand with advancements in biological, chemical and physical sciences. The reduction to the Mathematical Sciences Programme budget will require a 50% increase to return to the 2006/07 level and will have a negative impact across science; we believe that the budget is now below the minimum needed to sustain mathematical sciences research. The effects of 'turning the tap off' will be felt for a long time.

4. Mathematical Sciences has much to contribute to RCUK's mission themes, and the opportunity to demonstrate the value of mathematics, statistics and operational research to societal challenges such as energy consumption and an ageing population is welcome. However, we have been told explicitly by EPSRC that investment in these areas has been at the expense of response-mode research, and it is our view that in the long term this is a mistake. The impact of advancements in mathematical sciences can take many years to have an economic pay-off, and a decision to

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[1] For a complete list of RCUK priority themes see www.rcuk.ac.uk/innovation/ktportal/priority.htm. The list given above is those led by EPSRC.
[2] *Pioneering Research and Skills: EPSRC Annual Report and Accounts 2008/09* available from www.epsrc.ac.uk/Publications/Corporate/ARA08-09.htm

decrease investment in fundamental research now is a decision to limit innovation further downstream, even in the targeted areas that the Research Councils are aiming to support. The Haldane Principle should offer protection from external pressures towards taking a short-term view, but the principle appears to have been eroded.

To what extent should publicly funded science and technology research be focused on areas of potential economic importance? How should these areas be identified?

5. Fundamental scientific research is itself of economic importance. As President Obama put it in his address to the National Academy of Sciences in April 2009[3]:

> *At such a difficult moment, there are those who say we cannot afford to invest in science, that support for research is somehow a luxury at moments defined by necessities. I fundamentally disagree. Science is more essential for our prosperity, our security, our health, our environment, and our quality of life than it has ever been before.*
>
> \- Barack Obama

6. We append for the Committee's reference a short paper giving examples of fundamental mathematical sciences research that have had a considerable economic impact. These range from benefits to the pharmaceutical industry to face-recognition software.

How does the UK's science and technology research funding strategy and spend compare with that in other countries and what lessons can be learned?

7. The UK cannot afford to lose out to other countries in science and technology research – it is essential for continuation of scientific research in the UK that talented individuals are not lured away to other countries by more attractive research prospects. This is particularly true in mathematical sciences, where investment is in people rather than large scale equipment. The USA has now committed to increasing expenditure on science to 3% of its GDP, which will greatly overshadow UK expenditure:

> *Although the UK government has made similar commitments in the past, it needs to redouble its effort if we are to compete and collaborate with the US in the future.*
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> \- Nick Dusic (Director, Campaign for Science & Engineering)[4]

Council for the Mathematical Sciences
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[3] www.whitehouse.gov/blog/09/04/27/The-Necessity-of-Science/

[4] http://news.bbc.co.uk/1/hi/sci/tech/8020930.stm

Examples of the interplay between mathematics and leading-edge technologies

- **Digital communications.** The mathematical development of *error correction codes* has had a huge impact on a range of communication systems where high volumes of data need to be communicated across noisy networks. Most striking examples of their application have included satellite communication, and, very recently, third generation mobile telephony. Most recently, the development of *turbo codes* has for the first time enabled transmission at almost the maximum theoretical volume of data - a feat achieved by, amongst other things, the mathematical understanding of *derived likelihoods* to resolve uncertainties in the received data.

- **Cryptography.** The famous RSA algorithm underpins much of modern secure communication, especially involving financial services. The secure encryption and decoding in RSA rely heavily on Number Theory, one of the oldest branches of pure mathematics, and in particular on the prime factorisation of very large numbers. It was first publicly described by researchers at MIT, but was in fact independently developed by the British mathematician Clifford Cocks together with Ellis and Williamson at GCHQ. More recent fundamental research in these areas has led to the exciting possibility of using so-called *quantum entanglement* to develop unbreakable codes.

- **Chemical & pharmaceutical industry.** Many industrial chemical processes require quantitative understanding of the dynamics of reacting multi-phase mixtures, often in turbulent fluid flow. These problems motivate an enormous international effort in mathematical modelling, ranging from study of the Navier Stokes equations describing the flow (often with unknown free boundaries), to developments in geometric measure theory describing the distribution of the components. Applications at very small scales, for instance in drug synthesis or chip manufacture, has stimulated the rise of micro and nano fluidics as new disciplines within fundamental applied mathematics.

- **Google.** The success of the multi-billion dollar internet search engine relies on developments in numerical linear algebra. In particular, the so-called *PageRank* algorithm starts with an exceedingly large matrix describing the relative importance of linkages between different web pages, from which the *importance vector* listing the connection to a given search term can be computed rapidly with, crucially, the strongest link appearing at the head of the list.

- **Intelligent paper.** Intelligent paper technology is concerned with the interface between traditional writing methods and computerised display and data storage techniques. A recent project between Oxford University and ArjoWiggins made use of the *De Bruijn sequences,* a pure mathematical concept concerning combinatorial arrangement of symbols dating from the end of the nineteenth century but with little previous practical application. The company estimated that this development alone was worth fifteen million Euros.

- **Brain Imaging.** Modern medical scanning techniques, such as Single Particle Emission Computerised Tomography (SPECT) and Magnetoenceophalography (MEG), allow non-invasive imaging of real-time brain function. These techniques are underpinned by recent crucial mathematical developments. For instance, SPECT involves the inversion of the so-called *attenuated Radon transformation,* and the formula for computing this was found only in 2001. In MEG it is known that different neural activities patterns can lead to the same scan results, but mathematical advances have shown what information can still be uniquely determined from the scan.

- **Understanding the human genome.** The development of statistical computational methods of stochastic processes, from finite *Markov chain Monte Carlo* algorithms to *point processes* and *Gaussian random fields,* have proven pivotal in allowing the advancement of biomolecular sequence analysis. This science involves analysing DNA sequences, amino acid sequences and global profiles of RNA in normal and pathological processes. The results yield an insight into how diseases can be stopped at a molecular level, leading to the development of highly effective new pharmaceuticals and the possibility of gene therapy. However, these modern biological experiments create vast amounts of complex and highly variable data, which could only be analysed by employing these emerging statistical techniques.

- **Uncovering environmental trends.** Determining the nature of global environmental change means measuring trends from the widely studied variable of global mean temperature to an array of less well studied parameters where variation is not clear cut. Understanding these trend components with their correlated errors presented a deep statistical challenge. Development of time series analysis such as the *Yule-Walker* equations allowed phenomenon like the El-Nino-Southern oscillations to be modelled and its impact on our global weather patterns to be understood for the first time.

- **Driving the digital economy.** A digital economy is one which communicates goods and services electronically, over the internet: orders may be made electronically, goods such as audio and video recordings and written materials may be traded electronically, and banking and other services may be carried out. Such activity generates vast amounts of data, which can be analysed to improve the goods and services on offer. But analysing gigabytes of data presents theoretical and practical challenges. The new area of *data mining* has developed to meet those challenges. Data mining enables the summarisation of vast amounts of data, the identification of important structures within large data sets, and the detection of anomalous behaviour (such as fraud) within those data sets.

- **What's in a face?** Developing systems that can recognise the human face is fraught with theoretical statistical problems, but the achievement has countless applications. Statisticians realised that the proposed kernel-based linear regression neural network solution, would need large amounts of training data to be stored and processed. This means the computational power required for facial recognition would be beyond our current systems. Theoretical statisticians overcame the problem of training these smart systems by developing *relevance vector machines* that sample much fewer data sets from images to undertake facial recognition. However, the level of dissimilarity of the human face is best suited to multivariate regression as many features have to be assigned to normal ranges to allow recognition. To achieve this *Bayesian regression* was applied to *relevance vector machines* to develop an application to automatically locate facial features using minimal data. This allowed the development of smart CCTV that could recognise the individual behind the human face.