Institution: London School of Economics and Political Science

Unit of Assessment: 10: Mathematical Sciences

a. Context

In their research, the Departments of Mathematics and Statistics engage with four key types of non-academic audience. First, their research informs individual professionals and practitioners working in public and private sectors using quantitative methods. The main impacts consist of strengthening of professional standards and skills, and improvement of the quality of work undertaken. Second, their research engages directly with organisations in public and private sectors, such as government departments, statistical agencies, banks, hedge funds, and software companies. The main impacts consist of improvements in public services, such as more accurate statistical outputs, or economic benefits to private companies, such as those arising from new trading or investment strategies. Third, public outreach activities are undertaken, where the impact is the stimulation of public interest in science. This is done by individual researchers and especially by the Centre for the Analysis of Time Series (CATS). Fourth, there is engagement with public policy bodies, so that policy decisions are informed by research insights.

b. Approach to impact

Impact for each of the four kinds of audience is achieved through a variety of pathways.

Engagement with individual professionals and practitioners
Staff research funds and grants support staff presenting their research at events orientated to professionals and practitioners. Examples of such participation include: EDF workshop 'Industry and Price Forecasting' (Yao, Keynote Speaker, 2010); Winton Capital seminar (Yao, 2011); Telefonica workshop 'Regulatory and Economic Policy in Telecommunications' (von Stengel, 2011), 'Istanbul Stock Exchange' (von Stengel, 2012), Microsoft Research 'Big Data Analytics' lecture (Batu, 2012); Office for National Statistics seminar (Skinner, 2013). Staff are also supported and encouraged to participate in professional bodies. These include: Bachelier Finance Society (Gapeev, Relations & Education committee); American Statistical Association (Smith, Advisory Committee on Climate Change Policy); Royal Statistical Society (Steele, Professional Development Centre steering committee).

The departments' Research Committees support the hosting of events and visiting positions in the departments. The Worshipful Company of Actuaries holds an annual seminar at LSE, while the London Mathematical Finance Seminar, co-organised by the two departments, is regularly attended by practitioners. The Department of Mathematics has a Senior Visiting Fellow (Brockhaus) who works for the financial company MathFinance AG in Frankfurt. His presence exposes staff to practical research problems. He also gives series of guest lectures, aimed at providing staff and students (MSc and PhD) with an insight in applications in the financial industry.

Grants and consulting support training for practitioners through short courses, for example under the ESRC-funded Latent Variable Modelling of Categorical Data (LCAT) project (Kuha, 2012). This training can also be done in-house; for example for Man Investments (Baurdoux, 2011).

In addition to direct contacts between staff and practitioners, the departments also seek to achieve impact indirectly through collaborations with other LSE departments, as part of their strategy to promote mathematical sciences research in the social sciences. For instance, the discrete mathematics & algorithms and the mathematical game theory research groups now have joint research projects with the management science group in the LSE Department of Management.

Certain types of research lead to new algorithms, made accessible to practitioners through software, often for free. Those include packages in R and Mplus for methods developed on the LCAT project, see stats.lse.ac.uk/lcat/ (Kuha); the R packages 'unbalhaar', 'haarfisz' and 'tilting' for time series methods, see stats.lse.ac.uk/fryzlewicz/articles.html (Fryzlewicz); the 'Gambit' software

tools for game theory, see www.gambit-project.org (supported by *Google Summer of Code,* von Stengel); and the 'Premia' software for pricing financial derivatives, see www.premia.fr (Veraart).

Direct engagement with non-academic organisations
The previous approaches to engagement with individuals may spawn various forms of relationships with their organisations, from consultancy and advisory body memberships through to full collaborative research, including that centred on PhD projects. Initiatives to develop such relationships are supported by the departments' Research Committees, both for research exploration and for more formal projects.

Examples of consulting or collaborative research with government and public sector organisations are: Ministry of Justice (Steele, estimation of effect of employment on recidivism, 2012), Department of Health (Skinner, design of Medicines Margin Survey, 2013); BBC (Kuha, exit poll analysis and results prediction for 2010 General Election); Bank of England (Yao, identifying factors influencing economic growth across EU countries, since 2012). Some private sector examples are: EDF (Yao, forecasting daily electricity consumption, since 2010); John Street Capital (Fryzlewicz, changepoint-based detection of trading signals, since 2012); INTECH Investment Management Princeton (Kardaras, development of sophisticated quantitative tools, 2012-13); Munich Re (Cetin, Smith, climate change, 2008-12); Deutsche Bank and MathFinance Frankfurt (Gapeev, improvements in sequential change-point detection schemes for finance, since 2011).

Examples of organisations supporting or co-funding PhD research projects on problems they face are: Lloyd's insurance (two CASE awards), Munich Re and the Met Office.

Advisory body memberships include: Government Statistical Service Methodology Advisory Committee (Kuha, 2010-present); Home Office Science Advisory Council (Skinner, 2011-present).

Public outreach
Staff are encouraged to present their research to a wider public. For instance, Lewis and co-authors analysed a mathematical model of racial segregation; the graphical representation of the dynamics in this model won the 'Infographics' category of the 2013 Royal Society Picturing Science competition. CATS has a particularly strong programme of outreach activities. These include its contribution on uncertainty and climate science to the Royal Society Summer Science Exhibition in 2011. CATS is also working jointly with UCL social psychologists (Harvey) to develop software for games, both to explore and improve the use of probability forecasts by members of the public and by insurance underwriters. Smith's book 'Chaos' in OUP's 'Very Short Introduction' series is among the most popular of its technical editions and has reached a very wide audience with translations into Italian, German, and Chinese. Many other instances of outreach occur through individual members of the departments giving talks, in the LSE and in schools, to school age children, and at presentations to events aimed at a general audience. The departments also contribute to LSE's public events series, which are open to the public and for which over 35,000 individuals receive the associated booklet. Presenters invited by the departments have included David Spiegelhalter (2010) and C.R. Rao (2011). Alvin Roth, 2012 Economics Nobel Prize Winner, presented a talk in 2013, as part of a workshop organised by Gossner and von Stengel.

Public policy
CATS (Smith) has participated actively in policy development processes related to climate change, as described in one of the Impact Case Studies. The social statistics group's work also contributes to policy engagement. For example, Skinner led an independent review of options developed by the Office for National Statistics for the future of the census and was invited to speak about this in 2013 at a meeting in Parliament aimed at members of both Houses.

A necessary step to achieve impact through any of the above pathways is for staff to have the skills to engage with research users. The ability and willingness to communicate with non-specialists is an essential requirement in all job descriptions. To guarantee that it is assessed, appointment panels always contain a non-specialist member. The LSE provides a range of further support and resources to promote communications. All staff have access to the Press and Information Office,

External Relations Division, Corporate Relations Unit, LSE Enterprise, Conference and Events Office, LSE Experts directory and the Office of Development and Alumni Relations. Each of these helps to increase research impact.

c. Strategy and plans

The departments seek to carry out excellent research in the mathematical sciences and recognize that the impact potential of such research will vary. Although they aim to maximise impact for all research, building on the approaches described earlier, there is a strategic focus on promoting research on topics where most impact is achievable. Real-world problems are seen as important sources of inspiration for successful and exciting research in the mathematical sciences, with particular potential for high impact. Access to such problems of relevance to the departments' research is greatly facilitated by LSE's location in the heart of London, with close proximity to government departments and to the City.

There is now a particular strategic focus on increasing externally funded research as a key method to promote research on real-world problems and to achieve impact. An important means of advancing this strategy has been the recent introduction by the school of a Research Infrastructure and Investment Fund (RIIF), which provides a significant share of grant overhead income to be distributed by the departments' Research Committees, and a new Research Incentives Scheme, which offers personal incentives to staff to engage in such projects. The departments' Research Committees have now begun to make use of the RIIF scheme, in particular as a seed fund for activities designed to promote external grants. Increased grant funding will lead to increased RIIF funds and the potential for further growth. Full-time research administrators in each department provide further support for staff in grant applications.

A second strategic focus is on promoting links with specific non-academic organisations, viewing research impact as a longer term aim, with student support and recruitment as well as intellectual engagement the more immediate goals. Thus, the first aim is to develop links with MSc and PhD programmes through internships, studentships and recruitment. Seminar series and other events will also receive strategic support when they are designed to increase intellectual engagement with non-academic organisations. Financial bodies in the City represent a particular target for such links. Important initial impact is expected through PhD students, and to a lesser extent by MSc students, the majority of whom take up positions in the private sector and who serve as ambassadors to disseminate new research findings. The longer-term aim is to develop research on real-world problems and achieve impact out of the cooperation developed through such links.

d. Relationship to case studies

Three of the four submitted Impact Case Studies (Sasane, Yao, Smith – weather forecasting) illustrate research that solves real-world problems or is inspired by real-world applications (as indicated in c. above). Each study involves direct engagement with non-academic organisations with a two-way exchange of ideas (the second kind of pathway in b. above). Fundamental to Sasane's work in mathematical control theory are problems that appear in applications such as engineering. These practical problems can often be translated into a mathematical model whose analysis provides approaches that can be translated back to the original problem. Yao's research in time series analysis has been used to address problems of risk management faced by Barclays and, conversely, Yao's interactions with Barclays led him to develop novel statistical methods. The study on weather forecasting describes several long-standing collaborative partnerships between Smith and weather forecast providers and business users of weather forecasts. These partnerships have benefited from the research of Smith and CATS colleagues, and have also stimulated their further research. The fourth study (Smith – climate change) is similar to the other studies in being driven by a real-world problem and by including collaboration with industry partners. It differs by also engaging directly with policy processes in government (the fourth kind of pathway in b. above).