

Institution: King's College London

Unit of Assessment: Department of Mathematics

a. Context The Department of Mathematics consists of six research groups, three of which (Analysis, Geometry, and Number Theory) are in *Pure Mathematics*, and three (Disordered Systems, Financial Mathematics, and Theoretical Physics) in *Applied Mathematics*. Although research in the Department is primarily conducted as curiosity-driven fundamental research, it has generated several instances of significant impact outside academia.

During the assessment period, the impact agenda of the Department has been mainly driven by two groups in Applied Mathematics, viz. the *Financial Mathematics* group and the *Disordered Systems* group. However, some members of the Pure Mathematics groups are developing fields of research which have the potential to generate future impact (see section c below).

The main non-academic beneficiaries and audiences of research performed in Department include the *financial industry and financial regulators*, as well as *biotechnology and foodstuff industries, and health professionals*. The main types of impact generated by research performed in the Department can broadly be characterised as *impact on practitioners and professional services*, resulting – in some cases – in *measurable economic benefits, or impact on public policy and services*.

Relation to research. The impact realised by members of the Financial Mathematics group can be directly linked to the research focus of that group, which includes the development and analysis of stochastic models for asset price dynamics and trading, the empirical analysis of financial time series data, as well as the practical implementation of optimisation and risk management tools for use in the financial sector. These address in particular a need for innovation in financial methodologies that has become acute in the wake of the 2007-2009 financial crisis.

The impact of research projects conducted by members of the Disordered Systems group has mainly been derived from theoretical work on the dynamics of glassy and amorphous systems. Though mostly curiosity-driven, this line of research has been further developed and applied to problems as diverse as survival analysis in medical statistics, the analysis of systemic risk in networks of financial exposures, and the analysis of phase behaviour of poly-disperse systems.

b. Approach to impact The unit's approach to impact is very much defined by and adapted to the nature of the research performed in the six groups of the Department and by its specific potential for impact outside academia.

Maintaining links with the financial industry. In the case of the Financial Mathematics group, the collective research interests of its members and the Department's privileged location close to the City of London clearly suggest a strategic approach to impact defined at group level. A principal element is to maintain close links with the banking industry and other financial institutions.

Both the group and the Department have consistently followed a staffing strategy aimed at ensuring that a significant level of industry experience is represented in the group at any time. As a result, the group has been able to leverage pre-existing contacts of several of its members with the financial industry to build a comprehensive network of interactions with the banking industry, regulatory bodies, law entities, and other financial institutions. Moreover, the group has taken care to further strengthen its links with the industry by having some modules of its Financial Mathematics MSc programme taught by lecturers from financial institutions located in the City of London, by ensuring that a significant proportion of speakers at its Financial Mathematics Seminar (since 2012/13 co-organised with other HEIs, including UCL and LSE) is recruited from the financial industry, and by widely circulating its seminar programme in the City, thereby regularly attracting audiences from professional circles.

These activities have permitted the Financial Mathematics group to gain and maintain a privileged perception of the relevant practical problems in finance and economics, and to develop cutting-edge and efficient methodologies to address them. The visibility of the group's research in the financial

industry was further enhanced by disseminating results via online repositories that are consulted and used by practitioners (SSRN, defaultrisk.com, glorimundi.org). This strategic approach to dissemination contributed to the group's research being noted by practitioners, and being cited and appearing in industry magazines and relevant working paper series (Risk Magazine, Deutsche Bundesbank research paper series), which reinforced links with parts of the industry.

This has in turn resulted in group members receiving contracts for consultancy work (Nomura, FSA, Winton Capital Management, Bank of Finland, The State Pension Fund and Ministry of Social Affairs and Health, Finland), and training requests or requests for delivering master-classes on various aspects of financial risk from the industry (WBS, Marcus Evans, Incisive Media, ICBI, 7city, Wilmott CQF, 14-10 Club @ The Royal Institution, Professional Risk Managers' International Association, Federation Bancaire Francaise, Man Investments). Finally, group members have received frequent invitations to present their results at key industry conferences (ICBI Global Derivatives, Risk Minds, Quant Congress, Risk Summit), and invitations to networking dinners (Sungard, Royal Society, NumeriX), which are both indicative of strong links to industry, and conducive to further strengthening them.

Collaborations with end users. The breadth of the research portfolio elsewhere in the Department entails that the approach to impact cannot be tailored to a specific constituency in the same manner as for the Financial Mathematics group. For this reason the Department and the groups encourage their researchers to identify the potential for impact of individual research projects and to develop impact strategies tailored to these projects. A common approach that emerged this way has been to collaborate on such projects either directly with potential "end users" of that research, or – if this proves infeasible – to collaborate with members of the scientific community who are closer to the end users than members of the Department with its primarily theoretical research focus. This allows group members to get a better understanding of the questions and problems that might be relevant for practitioners, and thereby enhances the potential for impact. This approach is complemented by a well-developed culture of grasping opportunities, and taking up research challenges presented to our groups by professional circles. For the Disordered Systems group, for instance, successful examples during the assessment period include collaborations with immunologists on cell signalling problems, with bio-informaticians on protein-networks, and with economists and risk-practitioners on questions of systemic financial risk.

Identification of research lines with high-impact potential. Specifically for the Disordered Systems group, a second strand, which has as much to do with the identification of promising research lines as it has with the group's approach to impact, consists in maintaining a strong interdisciplinary flavour of its research portfolio. A case in point is the continued strategic expansion of its research activities during the assessment period into the fields of systems biology and systems biomedicine. These research lines were adopted because they were identified as being both well matched to the research expertise represented in the group, *and* as having potential for substantial sustained demand and thus impact in the health sector, given their generally perceived important role in the development of new and in part personalised medical treatments in the post-genomic era.

Outreach and knowledge transfer. An element of the Department's strategic approach to impact in the long term is to contribute to the enhancement of public understanding of science in general, and of Mathematics in particular. For this reason, the Department has been organizing an *annual Teachers' Conference* for more than 15 years, which regularly attracts around 30-40 participants. It is devoted in part to exposing Mathematics and Science teachers to problems and questions which are related to the current research agenda of our staff and which illustrate the outstanding importance and beauty of Mathematics, thereby keeping teachers updated on modern directions in the field. Participants regularly report that these events provide them with background which they regard as very helpful in their efforts to instil and maintain enthusiasm for science among their pupils. A second regular event is our annual "*Taster Day*", at which sixth-formers (typically around 200) directly get the chance to learn about exciting current research in Mathematics.

Support, recognition and rewards. The Department supports the groups' efforts to enhance impact potential by liberally granting staff leave of absence to foster industry contacts, whenever

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compatible with teaching obligations. King's College London contributes its resources and infrastructure. It helps the groups to maintain a strong web-presence, and it provides a web-based *Directory of Experts* as contact point for consultancy work or for enquiries by science journalists.

The PR Department of the College takes care to publicise cases of impact prominently via press-releases or in College media, including the front page of its main web-site, Departmental or College news bulletins, or its magazine-style quarterly newsletter *Comment*. Moreover, it has leveraged its relations with the press to facilitate interviews of group members by magazines and newspapers (Times Higher, The Banker, Risk Magazine), thereby further strengthening the groups' visibility. To improve this latter aspect, the College provides courses on media interaction and interviews for academic staff.

Last but not least, the College recognises and rewards impact outside academia by including it in measures of excellence that feed into promotion rounds or annual pay reviews.

c. Strategy and plans The unit has a comprehensive strategy to enhance impact, the elements of which can be broadly classified according to their principal dimension under one of four main headings, as outlined below – starting with research portfolio development (content), moving on to dissemination and outreach, further on to infrastructure development, and finally a long-term view and long-term commitment expressed in the creation of institutions.

Research portfolio development is a key element of the groups' strategy to enhance impact potential. For the Financial Mathematics group, this is specifically implemented by further developing research lines in areas that are of paramount importance for the industry at the moment. These include the methodological aspects of the new regulatory framework of Basel III (Collateral Modelling and Counter-Party Risk, Credit Risk and Credit Valuation Adjustments), and Solvency II, as well as modelling of ageing related risk factors (Longevity Risk, Disability Risk) that affect both the public and private sectors. The Disordered Systems group continues the strategic expansion of its research efforts in the area of systems biology and systems bio-medicine, by addressing topical problems associated with network-inference, which are highly relevant for the proper identification of signalling pathways from experimental protocols. A second area with high impact potential that is being further developed is research on systemic risk, specifically on black-out risk in power grids, and on unexplored collective effects associated with a recently initiated global move to trading financial derivatives via central clearing mechanisms. On a different level finally, the Department is currently exploring the possibility of hiring in the areas of statistical inference or computational statistics, both with inherently high potential for impact, to round off the research portfolio of the Department as a whole.

Recent appointments in the Analysis, Geometry and Number Theory groups have added research lines to the Department which raise the prospects of generating impact outside academia also from groups in Pure Mathematics. In Analysis, research on non-linear water waves and tsunamis by A. Constantin has already found experimental and simulational verification at the Department of Ocean Environmental Engineering of the National University of Taiwan, and by a Coastal Engineering group at Tokyo Metropolitan University, and it may in the long run contribute to improving tsunami early warning systems. In Number Theory, research on the characterisation of nodal lines in vibrating structures by I. Wigman has potential applications to optics and material science. The Geometry group is developing its expertise on the structure of surfaces in space (such as those with constant mean curvature), both from a theoretical viewpoint (G. Tinaglia), and a computer graphics approach (S. Salamon) of proven value for engineering and design. The group also has interests (N. I. Shepherd-Barron) in questions of effectivity concerning moduli spaces in algebraic geometry that have potential impact for the development of new standards in public key cryptography following revelations of NSA involvement in the choice of current standards.

Developing dissemination and outreach channels is a second important leg of our strategy to enhance impact potential. The recent initiative of KCL's and other London based Financial Mathematics groups to host a joint seminar series provides an example. It will improve the ability of participating groups to attract speakers of the highest calibre; it will allow tapping into a much wider

pool of speakers, including candidates from overseas, thereby increasing the attractiveness for audiences both from academia and the City, creating further opportunities for interaction. As part of the impact and outreach activities of the new Marie Curie training network NETADIS, led by the Disordered Systems group, a web-based resource called NETADIS-EXPERTS is currently being created as an information-rich portal, offering consultancy services, well-documented software solutions, seminars, or training courses by participating scientists in their field of expertise. The Department considers adopting it as a model for bundling and improving parts of its current impact and outreach activities.

Enhancing infrastructure. The recent acquisition by the Department of a suite of Bloomberg terminals has made a powerful new resource of financial information available for the activities in computational finance and in data-driven research in the Financial Mathematics and Disordered Systems groups. Data-driven research activities in Economics and Finance have gained considerable momentum and importance in the wake of the past financial crisis, and the new resource will significantly enhance the potential for producing high impact research in this very active field. This infrastructure investment will also generate impact in the long-term: graduate students who are going to do their research on such data-driven projects will have acquired a skill-set which combines fluency in rigorous mathematical analysis with the ability to handle and thoroughly analyse real-world (financial and economic) data sets – a combination for which there is likely to be growing demand in societies of ever increasing complexity.

Building institutions. The significant expansion of research activities of the Disordered Systems group in the fields of systems biology and systems biomedicine recently led the College and the Department to establish a new *Institute for Mathematical and Molecular Biomedicine*, with the intention to create a hub for stimulating collaborations with other research groups in the Health Schools. This initiative will increase the visibility of the group's research in the applied bio-medical research community and among health practitioners, and it will create more efficient channels of knowledge transfer between these constituencies, measures which are thought to improve the potential for impact outside academia.

In a related second major initiative, the College is currently in the process of creating a new philanthropically funded Institute for Quantitative Cancer Research. This is a joint initiative of the Department of Mathematics, the Cancer Division, and the School of Biomedical Sciences, and will focus on the development and application of novel mathematical and computational methods in the service of cancer research. The Institute is expected to start in the Summer of 2014, and will create further effective modes of interaction with clinicians and health professionals as well as a sustainable framework for high impact research.

Finally, the Department of Mathematics is one of the lead Departments in a recent initiative of the College to create a Specialist Mathematics School for sixth-formers, the first of its kind in the UK. This follows a policy announcement of the Department of Education to set up a system of flagship free Mathematics schools across the country. King's College London Mathematics School (KCLMS) has already appointed its Head Teacher, and will open in September 2014.

d. Relationship to case studies The submission includes three case studies underpinned by research of members of the Financial Mathematics group and two from the Disordered Systems group. Those from the Financial Mathematics group exemplify the importance attached by the Department and the group to having strong links to industry (Brigo, Pennanen), and the strategic decision to expand the group's expertise in data-driven approaches to Finance (Di Matteo) which have been gaining momentum after the financial crisis. Case studies submitted by members of the Disordered Systems group (Sollich, Kühn) generally highlight the important role of involving practitioners in shaping research questions perceived to have a potential for impact outside academia.