Institution: London School of Economics and Political Science - LSE

Unit of Assessment: 10 - Mathematical Sciences

1. Unit context and structure, research and impact strategy

Departmental structure and research areas

The Unit of Assessment 10 (Mathematical Sciences) is represented at LSE in the two Departments of Mathematics and of Statistics. The research areas in these departments relate mainly to the social sciences, to benefit from and complement the position of LSE as the UK's foremost social science research institution. The topics are therefore relatively applied. Research is loosely structured around themes or groups.

The four research groups in the Department of Mathematics are:

- Discrete Mathematics and Algorithms,
- Financial Mathematics and Control Theory,
- Mathematical Game Theory,
- Operations Research.

The four research groups in the Department of Statistics are:

- Data Science,
- Probability in Finance and Insurance,
- Social Statistics,
- Time Series and Statistical Learning.

The administrative unit is the department. The division into research groups is informal, and colleagues interact freely and actively across research groups and departments.

The REF-submitted academic staff numbers in the UoA are (FTE, as of 31 July 2020):

- Department of Mathematics: 27.0
- Department of Statistics: 20.8

In addition, the departments have currently 9 junior researchers (postdoctoral researchers and fellows).

Research objectives and strategy

The UoA aims to conduct outstanding research in mathematical sciences, with the following objectives:

- to develop mathematical and statistical foundations in areas relevant to the social sciences,
- to meet the challenges of new forms of social and economic data to address important and pressing real-world research challenges,
- to be an internationally recognisable “place on the map” in our areas of specialism,
- to keep this research sustainable and future-relevant,
- to enhance and contribute to diversity and inclusion in the field at all levels of research activity.

These objectives direct the hiring of new faculty, and the structuring of the research environment. New appointments have been made across all research groups. The remaining parts of this section describe, separately by group, developments and achievements over the current REF assessment period, and strategic plans for future research. Some faculty belong to more than one group and are listed in each. *Newly hired staff are listed in italics.*

In line with LSE policy, the majority of hiring is at the Assistant Professorial level, which offers an

attractive career path and attracts outstanding applicants. New posts are typically advertised for one of the research groups, with the aim to recruit the best candidate so as to, as far as possible,

- complement the existing expertise of the group,
- bring in new and modern perspectives of the field,
- maintain a “critical mass” of researchers,
- take diversity and inclusion into account.

Sometimes a new research group is established, under the direction of a newly hired full Professor. In the current REF period, the departments added two new research groups:

- the Data Science group under the direction of Prof *Vojnović*,
- the Operations Research group, which moved from the LSE Department of Management into the Department of Mathematics.

Further details on the implementation of this strategy are given in Section 2, which also documents how the UoA's research environment puts great emphasis on the support and development of Early Career Researchers.

The researchers in the UoA work on the mathematical foundations as well as on quantitative and methodological aspects of their disciplines. Their research therefore helps to sustain the foundations of the disciplines, which have significant open problems and challenges. Most research in the UoA is on mainstream topics in their areas. It contributes to setting the research agendas, and promotes new developments and emerging applications.

In line with this strategy, the research groups have evolved over the period, including the creation of the two new groups in Operations Research and in Data Science. In particular, substantial institutional support has allowed considerable expansion in the area of data science, which intersects many other research areas in the UoA (and other LSE departments). This expansion followed recommendations from external reviews of both departments in 2015 and is a key element of the LSE2030 strategy.

All research groups are highly regarded internationally, as reflected, for example, in prestigious editorial roles and prizes in the field (see Section 4).

Discrete Mathematics and Algorithms

This group in the Department of Mathematics has Allen, Anthony, Batu, Böttcher, Brightwell, van den Heuvel, Skokan, and Swanepoel as its members. The research areas covered by this group vary from pure mathematical ones (including extremal and structural properties of graphs and hypergraphs, random structures, probabilistic methods, and combinatorial geometry) to more applicable ones (including machine learning, sublinear algorithms for massive data sets, and algorithmic aspects of discrete mathematics in general). Increasing collaboration with the Operations Research group has encouraged the expansion of research in discrete algorithms, as well as the development of new approaches to approximation, heuristic and randomised algorithms.

Financial Mathematics and Control Theory

The researchers in this group are *Czichowsky*, Danilova, Gapeev, Lokka, Ostaszewski, *Ruf*, Sasane, Veraart, and Zervos. This group has well-established links with the Probability in Finance and Insurance group in the Department of Statistics. Taken together, they form one of the biggest concentrations of researchers in Financial Mathematics internationally. Within LSE, the group also has strong links with the Financial Markets Group in the Department of Finance.

The research of the group covers a wide range of topics in mathematical finance and optimal control, ranging from applicable ones to pure mathematical ones. During the REF period, the

group has made major contributions to the theories of: market equilibrium, markets with transaction costs or asymmetric information, martingales, optimal order execution, optimal investment, optimal control and stopping, principal-agent contract design, risk-management, systemic risk, stochastic portfolios, and others. In the future, the group plans to maintain its momentum in the shaping of these areas, and to expand its interests in important emerging areas, such as the mathematical foundations of Artificial Intelligence in finance.

Mathematical Game Theory

Game theory is a major tool and paradigm for economic theory. As a result, most game theory scholars now work in economics departments. Along with Paris and Jerusalem/Tel Aviv, LSE has one of the few mathematics departments with a concentration of game theorists, who are *Dütting*, Gossner, *Lewis-Pye*, Simon, and von Stengel. The mathematical aspects of game theory are the main focus of the group. Research topics include the economics and strategic use of information, entropy methods, models of bounded rationality, games of incomplete information, stochastic games, the computational and geometric structure of equilibria in games, and algorithmic game theory and mechanism design.

Operations Research

An explicitly stated strategy for REF2014 was to increase collaboration with mathematically oriented researchers in the management science group at the LSE Department of Management. This has been achieved by the transfer of the Operations Research group (and associated teaching) from the Department of Management to the Department of Mathematics in 2015, with the existing faculty Papadaki, Sorkin, Végh, and Zambelli. It has been expanded with the two new hires *Abdi* and *Olver* in 2018 and 2019.

The group members have a wide range of interests, from the highly theoretical to the applied, many of which connect with those of other groups in the departments. The group has a particular strength in mathematical aspects of Operations Research. This theoretical research includes methods for solving linear and integer programs and network flows, polyhedral combinatorics, combinatorial optimization, network reliability, average-case analysis of algorithms for graph problems, formula satisfiability and constraint satisfaction problems, phase transitions in the same contexts, and exact algorithms for NP-complete problems. Applications include mobile network efficiency, car and truck fleet scheduling, and search and patrolling games. They are motivated by practical problems and commercial development.

Data Science

Researchers in the Data Science group during the period were: *Yining Chen*, Kalogeropoulos, *Qiao*, *Shi*, and *Vojnović*. The group was formed in 2019 from several members of the department. Since then it has had a healthy and steady growth: two further appointments have been made after the REF period and two other posts have been approved.

Research during the period has contributed to many aspects of data science in the areas of computational statistics, machine learning, and optimisation. In particular, research areas include high-dimensional statistical models and inference, latent variable stochastic processes, causal graphical modelling, kernel methods, data-driven methods for optimisation, reinforcement learning, and scalable computational methods. The research has been supported by various industrial research grants (see Section 4).

Future goals include development of new data science and machine learning methods and theoretical foundations in the areas of fair and responsible machine learning, safety-critical learning, causal inference, interpretable machine learning, object-oriented data analysis, machine learning for complex time series data, data-driven algorithms for optimisation, inverse reinforcement learning and transfer learning. The work will continue to address important societal challenges by engaging in collaborations with various industrial partners, and pursuing

projects on topics interfacing with other disciplines such as computer science, and economic and social sciences.

Probability in Finance and Insurance (formerly, Risk and Stochastics)

Researchers in the Probability in Finance and Insurance group during the period are: *Acciaio*, Barrieu, Baurdoux, *Campi*, Cetin, Dassios, Kardaras, and Xing. Research during the period has contributed to many aspects of stochastic analysis and its applications in finance and insurance, and economic theory. In line with one of the research aims stated during REF2014, research on insurance and finance has progressed into a coherent quantitative unit, under the general framework of risk management. In particular, there was work on financial equilibrium including contract theory, model uncertainty and model risk quantification, stochastic game theory including mean field games, default risk, and stochastic analysis and simulation of stochastic processes.

Future goals include the development of machine learning and the study of quantum computing for analysing increasingly complex models used by academia, industry, and financial regulators. Research will still be motivated by problems in economics, finance and insurance, but with greater emphasis on the theory and application of numerical methods in light of recent advances in computational modelling.

Social Statistics

Researchers in the Social Statistics group during the period were: Bergsma, *Yunxiao Chen*, Geneletti, Kalogeropoulos, Kuha, Moustaki, Skinner* and *Steele*, the last-named hired as Professor to build further critical mass in this area. Goals of REF2014 were to strengthen links with social science disciplines, thereby motivating new lines of methodological research, and building on areas of expertise, such as in latent variable modelling. The longer-term ambition is to be the group undertaking the strongest research in statistical methodology within the UK social statistics community.

Research during the period has contributed to many aspects of social inquiry, including: study design, measurement, data quality, data linkage, causal inference, and statistical models for complex data structures. Other highlights include research on independence tests, modelling and testing using reproducing kernels and Bayesian techniques, pairwise likelihood and penalized estimation for high-dimensional multivariate data, and mediation analysis of associations of categorical variables. This research has involved collaborations with researchers from demography, education, epidemiology, political science, psychology and sociology.

Future goals include the development of statistical and machine learning methods to meet the challenges of new forms of increasingly high-dimensional social science data (potentially drawn from multiple sources) to address substantive questions and improve tasks such as causal inference. Another area is computationally efficient methods for reliable inference and accurate prediction from large-scale data to investigate impacts of potential causes and to gain insights about social phenomena. The aim is to use evidence from these analyses to facilitate decision-making through collaboration with social scientists and non-academic organisations.

*Deceased (February 2020).

Time Series and Statistical Learning (formerly, Time Series)

The broadening of the group members' research interests during the assessment period has led to the renaming of the Time Series research group to Time Series and Statistical Learning (TSSL). The TSSL group saw a departure (Barigozzi, to Bologna) but will see one new Associate Professorial appointment starting in 2021. The current members of the TSSL group are *Yining Chen,* Fryzlewicz, Kalogeropoulos, Lam, *Qiao,* and Yao.

The group is actively engaged in several frontiers of time series and statistical learning research

including high-dimensional modelling, nonstationarity and change detection, spatial econometrics, complex time series (dynamic networks, spatio-temporal data, functional time series) and nonparametric regression. These areas of interest largely overlap with the 'future research' areas identified at REF 2014.

The group has also engaged with many users of time series and other statistical methods, providing substantial consultancy to major industrial companies and banks. The group is determined to maintain its presence at the international frontier of time series research. In particular, future research will feature complex time series modelling such as autoregressive networks, spatial cointegration, nonlinear factor models, causality in time series, networks and time series, object-oriented data analysis, reinforcement learning, quantifying uncertainty of change-points and change, and robust estimation. It is in several members' plans to further integrate recent advances from machine learning into their respective areas of research.

The Centre for the Analysis of Time Series (CATS) is affiliated with the Department of Statistics. Its research addresses data analysis in forecasting and simulation.

Impact strategy

Since REF2014, the departments have sought to promote impact of their research through two main routes: engagement with individual professionals and practitioners from the private or public sector (e.g. through organising or giving research presentations at events oriented to non-academics, or providing software and training to make research accessible), and direct engagement with non-academic organisations (e.g. government departments and financial institutions, which may arise from consultancy, advisory body memberships, or fully collaborative research). The departments strongly support such activities, are flexible in granting leaves of absence when a longer-term engagement is appropriate, and credit these activities as part of departmental workload (along with teaching and administration). The importance of research impact is emphasised to all academic staff, and pathways to impact are explored at departmental away days supported by central knowledge exchange and impact (KEI) services. Notable examples of the departments' non-academic collaborations and the subsequent impacts generated are discussed below.

Veraart received a George Fellowship for a secondment at the Bank of England. Her research on financial networks was used in one of our impact case studies. Veraart's application for the fellowship received feedback from departmental colleagues. Her secondment was arranged flexibly by the department. Veraart's research led to improved stress testing models at the BoE.

Yao's collaboration with Barclays Bank arose from an invitation from the Director of Quantitative Exposure to join a project to improve estimation of potential future exposure to counterparty credit risk based on his expertise in time series analysis. This led to a long-term research collaboration and another impact case study.

The other submitted impact case studies are in the area of survey methodology, a long-standing area of expertise within the Social Statistics group. Skinner's work for the Department of Health and Social Care (DHSC) is one example of his long track record of consultancy work and membership of advisory boards for organisations conducting surveys and censuses. A key impact was an improvement of the models DHSC use to price NHS prescriptions. Kuha's research on methodology for political polling arose from collaborations with academic political scientists and professional survey organisations. Kuha's improved methodology has influenced regulation of UK political polling, polling methodology, media reporting of polls, and the reputation and commercial prospects of the polling industry.

Dütting is an expert on mechanism design (such as automated auctions for advertisements displayed with internet searches). His research results have been used by internet search companies. The practical relevance (as well as theoretical strength) of his research was one of the reasons for Dütting's recruitment as an Assistant Professor in 2016. Since August 2019, he

has been granted leave of absence to work for Google Research in Switzerland. His salary changed from LSE to Google, but he kept his research allowance and office and library use at LSE.

Further examples of non-academic engagement are given in Section 4.

Another component of our impact strategy is to increase externally funded research as a key means to promote research on real-world problems and to achieve impact. The corresponding infrastructure is described in Section 3.

Beyond REF2021, the UoA's impact strategy will be enhanced with new initiatives to create new links with industry and government, with a particular focus on data science and machine learning. This is one of the purposes of the new Data Science group in Statistics. This effort has been appreciated by the School, and the UoA has been extensively involved in the Data Science Initiative, resulting in the creation of the LSE Data Science Institute.

In addition, a recent fixed-term External Engagement Officer position in Statistics will be made permanent. With the School's visiting appointments scheme, a data scientist from a multinational consulting company has been appointed as Visiting Professor in Practice, and collaborations with other practitioners will be formalised in this way and properly resourced.

In Mathematics, an OR practitioner is appointed as Visiting Senior Fellow, and assists with the organisation of non-academic projects for the MSc in Operations Research and Analytics students. The department is using the connections with practitioners in these projects to explore new directions of research.

Supporting interdisciplinary research

Much of the research in the UoA is cross-disciplinary, not least because of the close connection to the social sciences. This pertains in particular to data science, where the departments (with the Department of Methodology) established the interdisciplinary research unit for Social and Economic Data Science (SEDS) to foster the study of data science and new forms of data with a focus on their social, economic, and political aspects. SEDS was subsumed in the new LSE Data Science Institute in September 2020, in which the UoA plays a leading role.

Examples of cross-disciplinary research include Kuha's extensive collaboration with sociologists Bukodi and Goldthorpe on intergenerational social class mobility in Britain, funded by ESRC. Another is Vojnović's work with computer scientists and computational social scientists at Facebook and Microsoft Research on predicting content popularity in social networks. His new methods for efficient training of machine learning models were published as a NeurIPS 2017 spotlight paper (550 citations).

The LSE promotion system recognises good cross-disciplinary work. Researchers are always encouraged to choose the best outlet for their work, without restriction to journals in a particular area. Mathematical sciences at LSE are therefore very attractive for researchers with cross-disciplinary interests.

A number of research topics in the departments naturally lead to an interdisciplinary approach. This is supported by inviting seminar speakers from related disciplines. For example, one of the research seminar series of the Department of Mathematics is the seminar on Combinatorics, Games, and Optimisation. The majority of the talks are on mathematical topics, whose methodology (e.g., probability, or computational complexity) is nevertheless of interest across the three seminar areas. Some game theory talks are from areas such as theoretical and experimental economics or evolutionary biology, and are attended by scholars from other LSE departments such as Economics and Philosophy. Another seminar is run jointly by the Statistics and Economics departments.

Some PhD theses supervised in Mathematics arose from other fields (in one case with a change of the student's department from Philosophy to Mathematics, a successful move supported by both departments). Some Statistics faculty have co-supervised students in the Department of Social Policy.

Seminars as support of the research environment

The seminars run by the departments:

- enhance the reputation of the UoA with high-profile speakers,
- integrate Early Career Researchers into the research environment - new academic staff are strongly involved in seminar organisation,
- broaden the network of faculty and research students;
- support interdisciplinary working,
- foster contacts with practitioners, with some dedicated events for practitioners and alumni in industry.

The departments run several widely advertised seminar series on:

- Combinatorics, Games and Optimisation (with a separate “PhD-student speaker-only” branch),
- Financial Mathematics, Risk and Stochastics,
- Statistics,
- Joint Statistics and Econometrics,
- Data Science,
- Women in Mathematics, and
- the prestigious London Mathematical Finance Seminar, co-organised with other London universities.

The seminar series aim to maintain a balance between senior and more junior speakers. They provide a platform for collaboration and exchange, and for being well-informed about new developments. Seminars have various formats and may feature:

- the most established speakers from the field (for example, leading auction theorists at a two-day symposium organised in 2018 by LSE Mathematics, including Robert Wilson, recipient of the 2020 Nobel memorial prize in Economic Sciences),
- "rising stars" (some of whom will be future agenda-setters), to stay updated with the full breadth of the subject,
- speakers from industry (for example, OR, finance, insurance) to stay in touch with industry-related developments and issues,
- speakers for LSE public lectures (to engage with wider society),
- PhD students (both internal and external) to help build a community,
- speakers for 3-week courses for PhD students.

Open research environment

As a rule, all significant mathematical research articles are published, before submission to a journal or conference, as preprints on repositories such as the arXiv, which has open access and provides widespread dissemination.

Software created by researchers in the departments is open-source. Open-source scientific software packages created and maintained by members of the UoA are: for statistics by Yining Chen, Yunxiao Chen, Shi, and Fryzlewicz (see also Section 3), for systemic risk by Veraart, and for game-theoretic analysis by von Stengel.

Research integrity

All researchers in the departments uphold as a matter of course the highest standards of integrity in their research. The departments have an open culture of discussion and responsible

mentoring of junior colleagues. This includes advice on potential conflicts of interest, for example when acting as a referee or editor for journal submission. The UoA is committed to ethical conduct in line with field-relevant ethical research codes and Equality, Diversity and Inclusion (EDI) principles and practices, described in REF5a. Academic staff need to complete an ethics form that is submitted to the School's Research Ethics Committee when staff cannot self-certify that their research is compliant with standard guidelines, such as on informed consent and anonymisation.

From the beginning of their research careers, PhD students are alerted to the strictest standards of attribution of the research of others, not least as part of scholarly quality. Workshops for PhD students are held once per term on scientific writing, refereeing, and ethical requirements. Participation in these workshops is mandatory.

2. People

Staffing strategy and staff development

Research excellence is paramount to the UoA's recruiting strategy. All REF Category A eligible staff are on permanent contracts. New staff are almost exclusively hired at the Assistant Professor level, on attractive permanent contracts. The research field is typically specified rather generally (for example, "mathematics of operations research" or "data science") in order to attract the best candidates. This also helps to maintain a broad base of research interests as well as to avoid a concentration on a specific "school of thought".

The departments have seen very healthy growth. During the REF period there were 14 new appointments from academically strong and diverse global backgrounds: six Assistant Professors in the Department of Mathematics, and two Professors, one Associate Professor and five Assistant Professors in the Department of Statistics. One Professor (Vojnović) was hired to provide leadership in the area of data science and heads the Data Science group in the Department of Statistics. The field of applicants for any position has been very strong (100 applicants on average for each available post). The retention rate is also very high; three colleagues (Barigozzi, Campi, Xing) left for senior academic positions (Bologna, Milan, Boston).

The promotion system of LSE is solely merit-based, with research evaluated by output quality (independent of grant income), and without resource constraints such as a limited number of professorships. This is a great attraction to the people hired by the departments. Two excellent new Assistant Professors left more senior positions at their (very reputable) institutions to join the UoA. During the REF census period, the departments had 15 promotions to Associate Professor and 12 to Professor.

The recruitment process involves the entire department. Posts are widely advertised in the period September-November, making extensive use of international recruitment sites and mailing lists. The long-listing process involves senior faculty and members of the relevant research group. The short-listing process involves all faculty. In this stage research papers proposed by the applicants are read by several faculty members. Each short-listed candidate is invited to a one-day visit in the period January-February. During this visit, the candidate makes a seminar presentation and meets with all relevant stakeholders in the department. Overall, the process offers a wide range of opportunities for all members of the department to contribute to forming an opinion about the candidates and their suitability for the post. The views of the department are reported to and taken into account by the recruitment committee, which, for Assistant Professor posts, consists of two members of the department, a member from a different but related department, and the independent committee chair (a senior academic from LSE). The recruitment committee is balanced in terms of gender and, as far as possible, ethnicity. For a Professorial appointment, the process is the same except that the committee has two additional external members.

Staff development

The departments have an ethos, reputation and practice of strong collegiality. Decisions are taken democratically and with maximal consultation. In particular, teaching arrangements, citizenship tasks and research leaves are decided after extensive consultation with staff by the Heads of Departments, who monitor for balanced and fair workloads across the groups. Details of who-does-what are communicated to all staff, so that the workload allocation is transparent to all. The strong sense of collegiality means that colleagues are helpful and supportive, e.g. in providing teaching replacement to enable a conference absence during term, or in covering the needs that arise from parental leaves.

Assistant Professors receive a generous initial research allowance and have lower teaching loads during their first year, and light administrative duties until promotion. Every Assistant Professor has two mentors. Formal mentor-mentee meetings are monitored by the Departmental Managers. Beyond the formal meetings, mentors and mentees often have several informal meetings and discussions over the year.

The career progression of all Assistant and Associate Professors is reviewed annually by the professoriate. This review, which takes place in spring, also identifies cases for possible promotion. All reviewed staff have an annual Career Development Review (CDR) meeting with their Head of Department. During their CDR, staff discuss their research development and their future research plans and aspirations, as well as their other contributions to the department, and receive constructive feedback. The cases identified for possible promotion are further discussed during the September meeting of the committee of Full Professors. Thereafter, staff put forward for promotion receive extensive feedback on the drafts of the documents required for their promotion.

Sabbatical leave is planned in advance to achieve a balance of staff on leave. It has always been possible to arrange the timing of sabbaticals in agreement with colleagues, thanks to established flexibility and cooperation.

The demographic profile overall and within the research groups is balanced (72% are younger than 50). This ensures continuity of the research activities.

Research visitors

Leading scholars are continually drawn to work with our researchers. As a result, some of them have become long-term visitors to the School. These include:

- Bouchard, Université Paris Dauphine (Financial Markets),
- Cvitanic, Caltech (Financial Mathematics),
- Jacod, Université Paris Pierre et Marie Curie (Stochastic Processes),
- Orlin, MIT (Network Flows),
- Roughgarden, Stanford/Columbia (Algorithmic Game Theory),
- Shiryaev, Moscow State University (Probability and Financial Mathematics),
- Young, Oxford (Game Theory), 2015-2018 LSE Centennial Professor.

These research visitors are inspirational for younger researchers, and enhance the research environment through their interaction with faculty and PhD students, as well as by teaching a number of stimulating advanced graduate courses (Bouchard, Cvitanic, Jacod, Shiryaev), and giving research talks.

Postdocs and Fellows

Postdocs at LSE include externally funded researchers (including a recent Marie-Curie Fellow) and LSE Fellows on up to three one-year contracts. Their number has steadily increased over the REF period and currently stands at nine. LSE Fellows are viewed as equivalent to junior faculty; they have their own research agenda and a teaching load similar to Assistant Professors. Each postdoc or fellow has an academic mentor. They are fully integrated into the

research environment, e.g. as regular seminar contributors, and collaborate with faculty. Average tenure is two years before they move on to career-track posts.

In addition to external applicants, good internal PhD graduates are considered for an LSE Fellowship. This policy, applied in three recent hirings, supports academically promising graduates to develop further and publish research that originated from their PhD, and acts as a starting point for an academic career. The policy puts emphasis on increasing diversity, and takes specific circumstances, such as child-care responsibilities, of the candidate into account.

Research students

Beyond educating highly skilled and successful future academics, researchers and employees, our strategic aim has been to produce PhD graduates who will actively influence the future shaping of their areas of expertise in the wider sense. In particular, our strategy has been to have a doctoral training environment that promotes sharing of ideas between students and academics, as well as to educate doctoral students so that they (a) gain deep knowledge and understanding of their own research field, (b) develop a critical appreciation of the interplay between their own expertise and related areas, and (c) increase their understanding of the social context and potential implications of their expertise for practice.

The departments have been among the founding members and have contributed consistently to the provisions of two doctoral training centres: the *London Graduate School in Mathematical Finance* (LGSMF) and the *London Taught Course Centre* (LTCC). Both of these doctoral training centres have run for almost fifteen years. They support a vibrant research community in which students interact with each other as well as with academics other than their supervisors. Furthermore, our students are actively encouraged to attend events and courses, as well as receive training offered by the *LSE PhD Academy.*

The LGSMF is run by a consortium of research groups in seven London universities (Birkbeck College, Cass Business School, Imperial College, King's College, LSE, Queen Mary and UCL). It provides a programme of advanced courses in mathematical finance, primarily but not exclusively for first-year PhD students in the various member institutions.

The LTCC is run by a consortium of universities in London and beyond (Birkbeck College, Brunel University, City University, Imperial College, University of Kent, King's College, LSE, The Open University, Queen Mary, Royal Holloway and UCL). It offers a programme of high-level five-week courses in mathematics and statistics for PhD research students in the consortium, as well as short intensive courses on new research topics open to students more widely in the UK and Europe.

More recently, Mathematics has joined the *National Taught Course Centre in Operational Research* (NATCOR), which provides PhD-level courses in areas related to OR.

Skills development

To broaden their mathematical education, research students attend courses offered by LGSMF, LTCC and NATCOR, as well PhD level courses offered by the departments. These courses are typically taken during the students' first year of study, advised by their supervisors. Beyond the taught component, PhD students benefit from:

- attending the regular research seminar closest to their area; they are strongly encouraged to attend occasional presentations in other regular research seminars suggested by their supervisors,
- taking an active role in reading groups,
- attending termly seminars on research skills such as giving talks, writing mathematics, writing referee reports, conference networking, etc.,
- presenting their work at conferences ranging from local PhD-focused ones, such as the

annual LGSMF PhD day, to major international ones,
- participating in PhD seminars organised by the students themselves,
- attending specialist short courses organised by the departments and delivered by internationally prominent research visitors,
- attending international summer schools relevant to their research,
- attending events and courses, and receiving training offered by the LSE PhD Academy,
- taking part in social activities such as (fully sponsored) dinners with seminar speakers.

In many cases, the research of PhD students may benefit from interaction with industry practitioners. Such interaction is facilitated in several ways. For instance, two seminars of the *London Mathematical Finance Seminar* per term are organised in a context that attracts large numbers of practitioners (attended by about 200 people).

Studentships and recruitment

PhD places are advertised on research networks and permanently on the departmental webpages. Prospective students are invited to apply for competitive funded studentships, which provide funds totalling £18K per annum, plus fees, for 4 years. On a recurrent basis, the departments offer about 8 such studentships per academic year: 5-6 of them are LSE-funded, 1 of them is ESRC-funded and 1-2 of them are funded by the departments themselves. Further PhD studentships are funded by personal grants, such as the ERC starting grant “ScaleOpt” by Végh (see Section 3), which supports 2 PhD studentships over the 5-year grant period, and occasionally through industrial partnerships.

After an initial contact phase to identify potential supervisors, promising applicants are invited for interviews. The recruitment process involves their prospective supervisor.

The equivalent of a high distinction at MSc level from a top mathematics and/or statistics department (at an international level) has been our usual PhD offer condition. Selecting applicants for PhD programme admission and studentships involves an intensive collegial process. The admitted candidates over the REF period have outstanding academic records.

Monitoring and support mechanisms

Each PhD student has a first and a second supervisor. The first supervisor is responsible for looking after the student through to successful completion of their study. At a minimum, the second supervisor acts as an “insurance” supervisor. In practice, the arrangement has worked in several different ways. In some cases, the student works exclusively with the first supervisor. In other cases, the student works on two different projects, one with each of the two supervisors. Sometimes the student works with both supervisors on the same research topic. Overall, the flexibility of this supervisory arrangement has been greatly appreciated by all stakeholders.

Doctoral students are originally registered for the MPhil degree. The process of upgrading to PhD status is rigorous and involves a presentation by the student and the examination of a written report, as well as the successful completion of PhD-level taught courses.

During their studies, PhD students are expected to have regular meetings with their supervisor(s), typically weekly. Their academic progress is monitored in several ways. The students formally register their progress and topics discussed during each supervisory meeting in PhD logs on the faculty-student electronic platform *LSE for You.* These logs are complemented by independent progress reports that are submitted by the students and their supervisors each academic term. We take great care in making sure all aspects of the process are clearly communicated to the students from the very beginning.

The supervisory and support activities are coordinated by the departmental Doctoral Programme Director (DPD). DPDs also independently monitor each student’s progress and play a leading role in the MPhil-PhD upgrade process. Administrative support and communication is facilitated

by dedicated Research Managers.

In terms of research funding, each PhD student is automatically entitled to an allowance of £500 per year for conference visits or other research expenses, with an extra flexible top-up (with no fixed limit, but often taken up to another £500). Further funding that has been extensively used by the PhD students is available from LSE to support (a) medium-term visits to LSE's partner universities such as Berkeley or Columbia, and (b) attendance of major international conferences.

Evidence of quality of training and supervision of PhD students

The success of the PhD programme in the UoA is reflected in the fact that nearly all PhD students have graduated within the allocated 4 years, giving a very close to 100% completion rate. Of the 55 PhD graduates during the REF period 2014-2020, 17 continued to academic posts.

Equality and diversity

The departments are committed to the LSE EDI Strategy, which seeks to advance diversity in our community and promote an inclusive staff and student environment. The UoA is extremely international and multicultural, with about 80% of its submitted researchers from outside the UK and 15% of these from China and India. Twenty per cent are women, with many of them holding leadership roles in their disciplines (see Section 4) as well as in their department (Professors Barrieu, Moustaki and Steele are former or current Heads of Department). During the REF period, there were two appointments (Acciaio, Steele) and eight promotions of women. The UoA is committed to increasing the percentage of women and other under-represented groups in future recruitment.

In PhD recruitment, the departments aim for at least one third of their intake to be female, and this aim is actually met on merit alone. Currently 20 out of the 56 research students are female. The background of the research students is extremely international and diverse.

EDI considerations have been central to the departments' philosophy and practice. They are an integral part of the recruitment process, as outlined in the departments' Athena SWAN action plans. The recruitment committees, including for the pre-screening stage, are balanced in terms of gender and, as far as possible, ethnicity. All staff have undertaken unconscious bias training.

The departments have been most sensitive to being flexible with colleagues who have caring responsibilities. For instance, our seminars and other research and social activities are always held during core working hours.

The departments have long campaigned for expenses for child-care during research-related travel to be reimbursable from staff research funds. This has now been successfully implemented as School policy for conference attendance. The departments are also keenly aware of the importance of making childcare provision/arrangements for visitors during conferences. At the planned IPCO conference 2020 it ensured contact had been made with local nurseries and that delegates were aware of available options. (Due to Covid-19 the conference was held online.) The experience thus obtained will be used in future meetings.

As elsewhere in the School, generous parental leave is provided for both parents. After the standard period of parental leave, faculty are offered a period of research leave of four months. One very strong career couple (Allen and Böttcher) originally joined Mathematics on a split position. Both are now full-time Professors in the Department.

The departments are fully committed to the implementation of the Concordat to Support the Career Development of Researchers. This includes a promotion system where everyone's CV is considered by the departmental review panel each year, so that full applications can be

encouraged where merit suggests. All panels have representation from both genders. Recruitment shortlisting and interviews explicitly consider the gender/diversity balance in the composition of interview panels and in the organisation of informal tours, lunches, and meetings with faculty members.

Each department has an EDI committee that meets regularly to lead on and monitor implementation of the departmental EDI policies. Our determination and inclusive approach has led to the Athena SWAN bronze award for the Department of Statistics (October 2020). The Department of Mathematics is in the final stage of an application for an Athena SWAN award. Their applications include ambitious action plans to improve the culture and working practices to promote a positive environment for all. This includes strategies to address the gender imbalance for academic staff and increase the visibility of women in the departments, improvements to staff induction and mentoring, and an email charter.

The departments are piloting a harassment prevention approach called 'Where do you draw the line?' for staff and PhD students. Two members of staff in the UoA are 'safe contacts' whose role is to offer confidential signposting for staff and students who have experienced some form of bullying or harassment.

Outputs and impact case studies selection

The process of selecting our outputs portfolio and impact case studies was *wholly merit-based*. Our final submission was independently assessed by LSE to check for any inequality with regard to protected characteristics and/or career stage as set out in the School's REF Code of Practice. This final check revealed that (a) while 19% of the UoA identifies as female, 23% of outputs submitted were by colleagues who identify as female, and (b) while 18% of the UoA identify as BAME, 19% of submitted outputs were from staff identifying as BAME.

3. Income, infrastructure and facilities

Major and prestigious competitively awarded research grants

During the period 2014-2020 the UoA received 57 external grants with a total value of £6,743,795 over their full funding time (which may extend beyond 2020). Indicatively, we describe the four largest grants.

- Végh received an ERC starting grant of €1,488,674 (£1,190,939 at the time of the award, January 2018-December 2022) on "Scaling Methods for Discrete and Continuous Optimization". This research addresses one of the most important open questions in optimization, that of finding a strongly polynomial algorithm for linear programming. The "strongly polynomial" property measures the running time of an algorithm in terms of its combinatorial steps, as they are used in practical implementations, rather than using a geometric distance measure for (non-strongly) polynomial algorithms that are mostly of theoretical use. The project combines novel techniques from two different domains: discrete optimization and continuous optimization. The aim is a new theory of geometric rescaling algorithms for linear and convex optimization. Végh's work draws on many breakthroughs that he has obtained in flow and graph algorithms that are strongly polynomial. The project includes research buyout, funds for two PhD students and three postdoctoral researchers (one of whom is moving on to a permanent academic position at the University of Twente). Notable publications include "A simpler and faster strongly polynomial algorithm for generalized flow maximization" (*JACM*, 2020) and four papers at the flagship conferences STOC and FOCS. The Department of Mathematics strongly supported Végh in the application for this grant, with reviews and many revisions of the application texts by colleagues, and multiple rehearsals of the grant presentations and interviews.

- Fryzlewicz's Early Career EPSRC Fellowship (April 2014-March 2019, £1,044,886),

entitled “New Challenges in Time Series Analysis”, was spent developing new methodologies for the analysis of non-stationary time series, and in particular time series data containing change-points, understood as abrupt changes in the level, trend, or other characteristics. Efficient randomised algorithms with performance guarantees were developed for this purpose, and encapsulated in publicly available R packages “hdbinseg”, “wbsts”, “factorcpt”, “not” and “breakfast”. A somewhat separate thread was the development of efficient randomised algorithms to enhance the performance of axis-aligned ensembles in modern statistical learning (R package “random.rotation”). The grant employed two postdoctoral researchers; both of whom have since moved on to permanent academic employment (University of Cyprus and University of Göttingen). A notable publication from the project, among many, is “Narrowest-Over-Threshold detection of multiple change-points and change-point-like features” (*Journal of the Royal Statistical Society, Series B*, 2019).

- Steele was awarded £633,392 in the ESRC Project “Methods for the Analysis of Longitudinal Dyadic Data with an Application to Intergenerational Exchanges of Family Support” (October 2017-March 2021). The interdisciplinary project team includes members of the Departments of Statistics and Social Policy. The project studies longitudinal data on pairs of subjects (dyads), which are challenging to analyse because they may be clustered into larger groups, and because variables of interest may be measured by multiple indicators. This research focuses on longitudinal multivariate dyadic data, with the important case study of the analysis of exchanges of support between parents and their adult children. Project outputs are methodological articles (such as “Estimation of dyadic characteristics of family networks using sample survey data”, *Annals of Applied Statistics*, 2020; “Random effects dynamic panel models for unequally spaced multivariate categorical repeated measures: an application to child-parent exchanges of support”, *Journal of the Royal Statistical Society, Series C*, 2021), R packages and software code, and other online resources. Aside from academic beneficiaries, the research aims to inform researchers and policymakers of the characteristics and circumstances that may put working-age or older people at greater risk of being unable to draw on wider family support, so that alternative provision can be made. The grant employed a postdoctoral researcher who will take up a permanent academic position at East China Normal University after the project ends. LSE financial support allowed the RO's salary to be covered for 3 months after ESRC granted a no-cost extension.

- Yao was awarded £392,909 in the EPSRC Project “Modelling Vast Time Series: Sparsity and Segmentation” (March 2014-April 2017). The project addressed challenges of the time series analysis of vast high-dimensional time series data that are now available in many practical “big data” scenarios. The dimension can be as large as, or even greater than, the length of the observed time series. The aim is to obtain simple and effective inference methods that can be implemented with ordinary computers for data of dimensions in the order of thousands. The projected impact of this research includes the analysis and forecasting of market demands, and environment protection and epidemic tracking for public service. Yao has worked since 2010 with EDF on electricity forecasting for 30-minute intervals over the next 24 hours (in its simplest form, a 48-dimensional time series). The methods developed in this project have been incorporated into EDF forecasting in both pointwise and interval manners. They outperform several state-of-the-art predictive methods in terms of forecasting accuracy, coverage rate, and average length of the predictive bands. Two postdoctoral research officers were hired on this project; they are now Associate Professors at Renmin University in Beijing and Lehigh University. One of several major publications from this project is “Principal component analysis for second-order stationary vector time series” (*Annals of Statistics*, 2018).

Furthermore, the Centre for the Analysis of Time Series (CATS) received a total of £2,081,108 from 22 grants, five of them having value over £200k. The projects were mostly about uncertainty and risk, applied to climate and environmental science and urban systems. Sponsors

include the Natural Environment Research Council (NERC) and the European Commission. A research officer position was funded from these grants, with interim support provided by LSE.

EPSRC early career starting grants (around £98k each) were awarded to Allen, Böttcher, and Végh. All three have been extremely productive and have recently been promoted to Professor.

Support for grant applications

The UoA highly encourages staff to apply for grants, and offers the following strong support for grant applications:

- A central Research and Innovation Division at LSE with knowledgeable and dedicated staff to identify grant opportunities. They support each application administratively and advise on writing a convincing case for support. Additional services include expert guidance on income generation, provision of training related to grant-writing and management, and interview training (including mock interviews) for applicants.
- A Deputy Head for Research to discuss applications on a peer level.
- A specialist Research Manager in each department.
- Systematic shared feedback from colleagues with previous similar applications and, where applicable, experience from review panels. Everyone has access to an electronic library of successful past submissions.
- A well-defined procedure of internal review provides feedback for preliminary grant application versions. It includes readers both from areas that are close to the field of the proposal, as well as slightly detached, in order to simulate potential panels.

The LSE's Research Infrastructure and Investment Fund (RIIF) provides a significant share of grant overhead income for distribution by the departments.

Incentive schemes reward the preparation and submission of grant applications, not only when they are successful. Depending on the size of the grant applied for, these incentives include, for example, research fund top-up or teaching relief. Such a formalised incentive scheme was pioneered by Mathematics; a similar scheme has been adopted LSE-wide.

Other internal support

The School's Library provides a wealth of essential books and articles, in both print and electronic formats. The Library has subscriptions to all subject-relevant journals in the mathematical sciences. To accommodate for the Library's natural focus on Social Sciences, there is a specialised library liaison for both departments, who promptly orders any requested book in mathematics and statistics. The Library has four Bloomberg terminals which provide access (also remotely) to the Bloomberg Professional service.

Compared to other School departments, the UoA needs faster and more powerful computing, especially given the recent focus on data science and statistical/machine learning. *Data and Technology Services* at LSE provide assistance and expertise across a variety of setups, including dedicated Linux specialists. They also advise on compliance with data protection regulations. LSE provides ample licences for specialised software in both research and teaching. A research cloud-computing team will be created within the Data Science Institute (launched September 2020) to make powerful, flexible cloud-based computing accessible to all LSE researchers.

The School's Digital Skills Lab provides training in several programming languages, including Python and R. This is complemented by computing expertise of faculty (a number of whom teach courses with a computational focus) and postdoctoral researchers who provide informal technical support to colleagues and PhD students.

LSE has also provided the departments with funding to support knowledge exchange and impact activities, including £10k annually per department and, through a competitive KEI fund, £190k

during 2014-2020 (see Section 4).

4. Collaboration and contribution to the research base, economy and society

Interactions with key research users

The research of the UoA involved interactions with key research users in industry, including:

- research with Addenbrooke's Hospital Cambridge on tools for surgical assessment of deceased donor kidneys,
- a research award from Facebook on development of new learning algorithms for scheduling in data processing platforms, won through the “Systems for ML” request for proposals,
- a two-year Visiting Scientist position held by Vojnović with the Core Data Science team at Facebook, where he contributed to the design of new scalable prediction and control methods for content moderation in online platforms,
- a research award by Criteo AI Lab on the design of new combinatorial bandits for matching problems,
- a project funded by Huawei on the design of new machine learning methods for anomaly detection in computer systems using graph data representations,
- research with AlgoCortex LLC (New York) on the price impact and implementation shortfall associated with large trades using an empirically testable market impact model to optimise the investment management process,
- research with R&D EDF in Paris, funded by Fondation Mathématique Jacques Hadamard, France, on analysing and forecasting daily electricity consumption curves,
- research with Andurand Capital Management (ACM) in London on forecasting oil prices based on quantitative methods; ACM funded a postdoc working 80% at LSE, 20% at ACM,
- research on financial stability and stress testing with the Bank of England (see the related ICS by Veraart),
- research on counterparty credit risk management jointly with Barclays Bank (see the related ICS by Yao).

Wider contributions to the economy and society

Many of our PhD graduates go on to leadership roles in non-academic settings in industry and government. This has a strong indirect impact of their research training.

Wider activities and impact of research carried out in the UoA not captured in submitted ICSs

The UoA has an extensive network of links with the financial and insurance industry, regulatory and professional bodies, as well as information, communication and technology services. This network has developed through (a) personal research collaborations, (b) regular meetings with practitioners attending our several research seminars, and (c) contact with former MSc and PhD students. Frequent formal and informal contacts with problem owners, who need new and innovative solutions, has been valuable in identifying research directions and problems that matter to the real economy.

As part of the strategy for enhancing knowledge exchange, LSE has a KEI fund of £10k annually for each department, which can be used for any knowledge exchange initiative. There is a straightforward approval process for additional larger funding. During the assessment period, awarded funds include:

- £170k to the Centre for Analysis of Time Series for communicating the character of climate change uncertainty, better uncertainty guidance, evaluating probability scores for the insurance sector, and the risk dynamics of insurance claims disputes.
- £8,600 to Papadaki for work on the development of a system of swarm path optimization for aerial drones for the civil defence ministry of Cyprus. The drones are surveying terrain

in case of fires or earthquakes, and the system has already been tested in the field. (Published as “Swarm path planning for the deployment of drones in emergency response missions”, IEEE, 2020.)

All faculty are encouraged to work on impact, which is taken into account as part of the general workload (in addition to teaching and administrative duties). The following are examples of staff-led impact activities without explicit funding.

With his expertise in algorithmic mechanism design, Dütting advised on the design of the Swiss Kidney Paired Donation System. By swapping donor-recipient pairs, the system increases the possibilities of using live kidney donations where the donor and intended recipient of the kidney are medically incompatible. Dütting provided advice on the algorithmic approach to computing ranked lists of possible combinations that satisfy different ranking criteria, and helped develop a specialised algorithm for computing the corresponding combinations. The system entered Swiss law under bylaw 810.212.3 in October 2017, with the first two kidneys transferred in October 2019. It is expected to lead to 24-32 additional transplants a year, an increase of 20-30% in donations from living donors.

Applying his change-point-based trend estimation methods, Fryzlewicz served as academic advisor for John Street Capital, consulted with Nanook Energy Advisors on business-critical weather simulation systems, and with Gooroo on forecasting hospital bed occupancy.

Gossner proposed and analysed the efficacy of pooled Covid tests in a much-cited article (“Group testing against Covid-19”, EconPol Policy Brief, 2020).

Yunxiao Chen has collaborated with Yi-Hsuan Lee from the Educational Testing Service in the US to develop statistical methodology for the monitoring of reused test items over time, to ensure the validity of the test scores and the fairness of the tests. Specifically, sequential change detection methods have been developed and compound decision theory has been proposed for the detection of compromised items. Chen has also collaborated with Fudan University and the Shanghai Municipal Educational Examinations Authority on the use of statistical and data mining methods for the simultaneous analysis of students' assessment results in middle school and high school, to provide insights on the students' education trajectory and provide suggestions to future students on their choice of subjects.

Kuha has served as the only statistician on the analysis and prediction team of the BBC/ITV/Sky joint exit poll for the last four UK General Elections. The team analyses the data from the exit poll during the election day to develop models which are used to produce a prediction of the numbers of MPs that each party will receive in the new parliament. It is published exactly when the polls close on election day, and provides the only broad-based hard evidence of the outcome of the election until the actual results are declared during the night. The exit poll prediction thus has widespread if short-lived impact on a very large audience among politicians, the public, and even the financial markets. Over recent elections the prominence and reputation of the exit poll have steadily increased as its predictions have proved consistently accurate. In the most recent election of 2019 it appeared to be immediately accepted as the main basis for the initial discussion of the expected election outcome and its implications.

Steele collaborated with Martyn Jones, Professor of Healthcare Research at Dundee, on a study of the impact of cardiac-related beliefs and mood, collected using real-time diaries, on subsequent attendance at cardiac rehabilitation. The research was presented at an event to discuss the redesign of cardiac rehabilitation guidelines in Scotland, and at a follow-up meeting with the chair of the Scottish Intercollegiate Guidelines Network.

Ruf is in regular contact with financial analysts in the City. His paper “Diversification, Volatility, and Surprising Alpha” joint with four people from industry was co-winner of the Savvy Investor Awards 2018. Ruf served as judge for the 2020 FinTech Award by the industry publication “The Technical Analyst”. He also advises the financial technology startup firm Enterprai. These

collaborations create significant synergies where the firm gains access to current research, and the academic gains access to data and relevant problems in the markets.

Contribution to the sustainability of the discipline

The UoA is using two main pathways towards ensuring sustainability of the discipline.

The obvious one is to focus on topics that will be increasingly relevant for the future in terms of applicability and impact, both scientific and societal. One of the main strategic areas where increasing emphasis is placed is *data science*. The relocation of the *Operations Research* group to Mathematics brings extensive know-how in the area of machine learning, complementing and strengthening the statistical learning counterpart in Statistics that has seen considerable growth in output in these fields. A further new *Data Science* research group has been initiated in Statistics, with active hiring of new staff at all academic levels. The UoA plays a central role in the new LSE Data Science Institute.

On the other hand, it is recognised that ensuring sustainability does not always involve tracking future changes closely. It is equally important in mathematical and quantitative sciences to ensure that fundamental research is appreciated and promoted. The UoA fully agrees with and adheres to this principle: researchers are given the opportunity to explore areas that are interesting to them at an abstract or conceptual level, even when these do not appear to have direct applications. For instance, while research in financial mathematics and statistics is typically considered applied, a major body of work in the respective groups concerns fundamental questions in the theory of stochastic processes. Major parts of research in the Social Statistics group involve methodological aspects of statistics that are relevant beyond their motivating applications. In short, pure research is rewarded and nurtured, thus able to be sustained in the future.

Indicators of wider influence

Journal editorships

Members of the UoA hold over 50 journal editorships, including very senior roles, such as

- Editor-in-Chief, *Psychometrika,* 2015-2018 (Moustaki),
- Joint Editor, *Journal of the Royal Statistical Society Series B*, 2014-2017 (Fryzlewicz),
- Joint Editor, *Journal of the Royal Statistical Society Series A*, 2019-2022 (Kuha),
- Editor, *Journal of Privacy and Confidentiality*, 2008-2017 (Skinner),
- Co-Editor, *International Journal of Game Theory,* 2008-present; Area Editor for Game Theory, *Mathematics of Operations Research*, 2015-2018 (von Stengel).

Journal editorial board memberships include:

- *Annals of Applied Probability* (Barrieu),
- *Annals of Statistics* (Yao),
- *Combinatorics, Probability and Computing* (Brightwell),
- *Electronic Journal of Combinatorics* (Böttcher),
- *Finance and Stochastics* (Acciaio, Kardaras),
- *Games and Economic Behavior* (Gossner),
- *International Journal of Theoretical and Applied Finance* (Zervos),
- *Journal of the American Statistical Association* (Yao),
- *Journal of the Royal Statistical Society, Series A,B,C* (Bergsma, Fryzlewicz, Kalogeropoulos, Steele, Yao),
- *Mathematical Finance* (Kardaras, Veraart),
- *Mathematics of Operations Research* (Végh, von Stengel),
- *Mathematical Programming* (Végh, Zambelli),
- *Operations Research* (Végh),
- *Psychometrika* (Yunxiao Chen, Moustaki),

- *Random Structures and Algorithms* (Böttcher),
- *SIAM Journal on Financial Mathematics* (Acciaio, Barrieu, Veraart).

Participation on grants committees

- EPSRC Reviewer Panel (Papadaki 2016, van den Heuvel 2020),
- EPSRC Prioritisation Panel, chair (Yao 2017),
- ESRC Reviewer Panel (Steele 2015),
- Horizon 2020 funding allocation committee, European Commission, 2017, 2018; INRIA (France) future plans evaluation committee, 2016 (Vojnović).

Honorary Doctorates and Fellowships (Honours)

- Honorary Doctorate, Uppsala (Moustaki),
- Honorary Doctorate, Aberdeen (Steele),
- Fellow of the Game Theory Society (Gossner, von Stengel),
- Fellow of the Institute of Mathematical Statistics; Fellow of the American Statistical Association; Elected member of the International Statistical Institute (Yao).

Fellowships (Grants)

- Simons Fellowship, Isaac Newton Institute (Yining Chen),
- U.S. National Academy of Education fellowship (Yunxiao Chen),
- Royal Society Fellowship (Lewis-Pye),
- George Fellowship (Houblon-Norman Fund, Bank of England); Bank for International Settlements Research Fellowship (Veraart).

Prizes

- ACM Conference on Economics and Computation (EC), best paper, 2018 (Dütting),
- ACM Symposium on Theory of Computing (STOC), best paper, 2018 (Végh),
- Adams Prize, 2019 (Veraart for her work on the mathematics of networks),
- Prize Louis Bachelier, 2018 biennial prize in applied mathematics (Barrieu),
- European Prize in Combinatorics, 2019 (biennial) (Pokrovskiy, PhD in Mathematics November 2013),
- Fulkerson Prize, 2018, awarded triennially (Allen and Böttcher for their work on chromatic thresholds graphs, *Advances in Mathematics* 2013),
- Lanchester Prize, 2015, awarded every five years by INFORMS (Zambelli),
- Waksberg Award, 2019, awarded jointly by the American Statistical Association and Statistics Canada (Skinner).

Membership of Research Council or similar committees

- Government Statistical Service Methodology Advisory Committee 2010-2017, Methodology Advisory Committee, Understanding Society survey 2014 (Kuha),
- Advisory Committee of ESRC Centre for Microdata Methods and Practice, 2007-2020, ESRC Administrative Data Research Network, Statistical Disclosure Control Expert Group 2014-2018; Advisory Group of ESRC Urban Big Data Centre, 2015-2017 (Skinner).

Hosted conferences and workshops (selection)

- Two-day Colloquium in Combinatorics, hosted yearly since 2013 by LSE and Queen Mary University of London, regularly over 100 participants,
- Symposium on Auctions and Computational Game Theory in Honour of Robert Wilson

(2020 Nobel memorial prize in Economic Sciences), 2018,
- 21st Conference on Integer Programming and Combinatorial Optimization (IPCO), 2020 (online).

Invited keynotes or conference chair roles (selection)

- Plenary talk, *9th World Congress, Bachelier Finance Society*, 2016 (Barrieu),
- Plenary speaker, *Random Structures and Algorithms* 2019 (Zurich); plenary speaker, *British Combinatorial Conference* 2017 (Glasgow) (Böttcher),
- Institute of Mathematical Statistics programme chair (invited sessions), 2019 *Joint Statistical Meetings*, Denver, USA (Fryzlewicz),
- Conference chair, *Approximation Algorithms for Combinatorial Optimization Problems (APPROX)* 2019; keynote talk, *Japanese Annual Symposium on Mathematical Optimization,* 2018 (Végh),
- Scientific chair and organiser, *5th World Congress of the Game Theory Society*, 2016, Maastricht, 800 participants (von Stengel),
- Keynote speaker, *French Statistical Society Annual Conference*, 2015, Lille (Yao).

Refereeing academic publications or research proposals

Refereeing is undertaken regularly by all researchers for all major journals in their fields as a matter of course. Many colleagues are reviewers of research proposals for funding councils, such as the Austrian, Canadian, Czech, Dutch, French, German, Hong Kong, Israeli, Italian, Polish, South African, Swiss, US, and other national funding councils, the US-Israel binational funding council, as well as EPSRC, ESRC, and ERC.