Impact case study (REF3)

Institution: London School of Economics and Political Science

Unit of Assessment: 30 - Philosophy

Title of case study: Managing severe uncertainty

Period when the underpinning research was undertaken: 2011-2018

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
Richard Bradley Roman Frigg	Professor Professor	1997 to present 2003 to present

Period when the claimed impact occurred: 2016-2020

Is this case study continued from a case study submitted in 2014? No

1. Summary of the impact (indicative maximum 100 words)

Professor Richard Bradley and Professor Roman Frigg developed a method of confidence-sensitive decision-making which provides a technique for using "model ensembles" in the assessment of alternative courses of action that fully accounts for the uncertainty in the projections yielded by these models and which allows decision-makers to calibrate their decisions to their confidence in them. The method is now being used to reform the way in which uncertain decisions are addressed both in the insurance industry and the financial sector. The insurer AXA XLC takes it into account when dealing with the problem of pricing of insurance contracts against natural hazards; it has shaped the structure, business model, and operations of two new risk management companies working in the insurance industry and the financial services sector; and it has informed independent advice on financial stability provided to the Bank of England.

2. Underpinning research (indicative maximum 500 words)

Bradley and Frigg's work on scientific uncertainty and its implications for decision-making has yielded a method of confidence-sensitive decision-making which draws on two complementary strands of research, both pursued in the AHRC-funded project "Managing Severe Uncertainty" (March 2013 to February 2016): Bradley's on decision-making under severe uncertainty and Frigg's on uncertainty in environmental modelling. Both Bradley and Frigg were full-time professors in the Department of Logic, Philosophy, and Scientific Method at LSE over the entire period during which the research was carried out (and indeed during the entire assessment period of the current REF).

Bradley's work **[1] [2]** draws on the emerging fields of imprecise probability and decision-making under ambiguity in which a representation of uncertainty by a set of probability measures on the space of outcomes is combined with a decision rule that takes such sets as inputs and prescribes actions that are robust across them. The main challenge for these theories is to specify the relevant set of probabilities. Bradley solves this problem by introducing a confidence grading of them which is determined by the weight of scientific evidence supporting them. Decision-makers are then required to set the required level of confidence in these probabilities in view of what is at stake in the decision and how ambiguity-averse they are and then adopt an action that is robust with respect to the smallest set of probability functions meeting this confidence level.

Frigg's work **[3] [4] [5]** investigates the impacts of structural model error on the predictive ability of environmental models. There is significant uncertainty about many factors influencing both weather and climate systems, making such errors a major concern in using model outputs to inform public policy. Frigg argues that the effect of these errors is such that neither refining a single model nor adding statistical error terms to a model's dynamical evolution increases the informativeness of its projections on local scales. Effective decision support is best provided by taking the outputs of a range of different models into account, each accompanied by a realistic assessment of both its input and output uncertainties, even if there are well-specific theoretical relations between different models.

Both strands come together in joint work by Bradley and Frigg, with their PhD student Joe Roussos, on uncertainty-sensitive decision algorithms in cases in which the relevant probabilities are the outputs of the models in a *model ensemble*, a collection of different and often conflicting models of the same target system **[6]**. They show that the standard practice of basing decisions

on weighted ensemble averages can have detrimental consequences because prevalent uncertainties are not reflected in the final decision, and decisions can be taken on the basis of results that all models regard as overwhelmingly unlikely. Bradley, Frigg, and Roussos develop an alternative method of rational decision-making with model ensembles, and they show how the method can be used to price insurance policies against hurricane damage on the basis of a multi-model ensemble of so-called CAT models (catastrophe models) in a way that helps in determining both fair and sustainable premiums while also continuing to comply with vital sector regulations.

Their "confidence approach" consists of constructing a nested set of probability intervals based on model outputs; confidence-grading them based on the best available scientific evidence; evaluating the decision-maker's stake in a certain decision; eliciting the decision-maker's cautiousness; and finally making a decision based on the chosen interval using a decision rule for imprecise probabilities. The application of the method is aided by the provision of workable recipes for constructing the required nestings for different kinds of model ensembles. The confidence approach is explicit about uncertainty at every stage and therefore offers a structured process of value-elicitation and decision-making that takes both the scientific knowledge in field and the decision-maker's position into account. Such an approach offers a better and more accountable way of making decisions under uncertainty than the opaque "technical" process of weighted model aggregation.

3. References to the research (indicative maximum of six references)

[1] Bradley, R. (2017). *Decision Theory with a Human Face.* Cambridge University Press. 9781108793612.

[2] Bradley, R., Helgeson, C., and Hill, B. (2017). Climate Change Assessments: Confidence, Probability and Decision. *Philosophy of Science,* 84(3), pp. 500-522. DOI: 10.1086/692145.

[3] Frigg, R., Bradley, S., Du, H., and Smith, L. A. (2014). Laplace's Demon and the Adventures of His Apprentices. *Philosophy of Science* 81(1), pp. 31-59. DOI: 10.1086/674416.

[4] Frigg, R., Stainforth, D. A., and Smith, L. A. (2015). An Assessment of the Foundational Assumptions in High-Resolution Climate Projections: The Case of UKCP09. *Synthese,* 192(12), pp. 3979-4008. DOI: 10.1007/s11229-015-0739-8.

[5] Dizadji-Bahmani, F., Frigg, R., and Hartmann, S. (2011). Confirmation and Reduction: A Bayesian Account. *Synthese,* 179(2), pp. 321-338. DOI: 10.1007/s11229-010-9775-6.

[6] Roussos, J., Bradley, R. and Frigg, R. (2020). Making Confident Decisions with Model Ensembles. *Philosophy of Science* (forthcoming). DOI: 10.1086/712818.

Evidence about the quality of the research

Publications **[1]**-**[4]** were produced in the context of the AHRC funded project "Managing Severe Uncertainty" (AH/J006033/1, GBP725,000, March 2013-February 2016), awarded to Richard Bradley as principal investigator, and to Roman Frigg, Katie Steele, Alex Voorhoeve, and Charlotte Werndl as co-investigators. In the year in which the project drew to a close, Roman Frigg won the Friedrich Wilhelm Bessel Research Award of the Alexander von Humboldt Foundation, which is given to internationally renowned academics who have produced cutting-edge achievements within their field. **[3]** was one of the four publications upon which his nomination for the award was based. Bradley's book **[1]** was published with a world-leading publisher (CUP) and the articles **[2]**-**[6]** have published in world-leading peer-reviewed journals. They have been widely cited and hence are considered a reference point for further research in the field and beyond the submitting institution.

4. Details of the impact (indicative maximum 750 words)

The new method of confidence-sensitive decision-making developed by Bradley and Frigg has reshaped the way in which decisions under uncertainty are addressed both in the insurance industry and the financial sector. Its concepts have helped to address the problem of pricing of insurance contracts against natural hazards, and have also underpinned the establishment, development, and operations of new businesses. Details of these impacts are provided below.

Improvements to model-based methods for pricing for insurance contracts against natural hazards

Prevailing practice in the insurance and reinsurance industry is to employ mathematical models of natural hazards such as hurricanes and earthquakes, and of the vulnerability of insured assets to them, to determine the exposure of the insurance company to losses arising from a catastrophic event and to use these projections to calculate insurance premiums and the capital holdings of insurance companies required to keep the risk of ruin below the level required by national regulators. Because of the sparsity of data concerning extreme events and the complexity of the underlying physical processes, these models are highly uncertain and their projections are not fully trusted by underwriters.

Since 2016, Bradley and Frigg have been working with the insurance company AXA XL (formerly XL Catlin) to overcome this problem by implementing an insurance pricing rule that directly applies the method for representing and managing scientific uncertainty developed as part of the research described above **[2] [3]**. AXA XL provides insurance and risk management products and services for mid-sized companies through to large multinationals, and reinsurance solutions to insurance companies globally. The AXA group operates in 62 countries, and has over 160,000 employees and over 105 million customers.

Initial contact was made by its science unit (headed by Dr Tom Philp and Dr Mike Maran) who had read Bradley and Frigg's work on uncertainty in climate models and on climate policy decision-making **[A]**. After signing non-disclosure agreements, Bradley and Frigg were given access to details of Risk Management Solutions' (RMS) suite of models, the evidential basis for AXA XL's decision-making, and detailed information on how they were used by AXA XL in insurance underwriting. Bradley and Frigg were asked to investigate how underwriters might make better use of the information yielded by the model suite. A series of extensive meetings with underwriters and business groups within AXA XL followed with a view to obtaining a complete picture of how RMS builds its models and how they are used by AXA XL. Based on these discussions, Bradley and Frigg, in collaboration with Roussos, derived an independent way of making decisions based on information contained in a model ensemble which is tailored toward the need of the insurance **[A]**.

Bradley and Frigg's recommendations were delivered to AXA XL in 2017 and circulated widely within the company, including by means of a series of presentations delivered by them to different business units within AXA XL. Bradley and Frigg held meetings with all units in the company that use their information, including (but not limited to) the Head of Property for US Reinsurance, the Head of Natural Perils Risk Management, the Head of Science and Natural Perils, as well as a number of underwriters. Their work has subsequently informed the practice of decision-making in different parts of the company, most notably concerning natural catastrophes in the North Atlantic, and discussions continue with the company's Reinsurance Chief Actuary, the Chief Executive of Insurance Pricing and Analytics, and the Global Head of Placements for Ceded Re to also apply the Bradley and Frigg scheme in these areas **[A]** of the business. Although an insurance company's pricing policies and underwriting decisions are highly sensitive, and so full details of this work cannot be divulged, the Manager – Science and Head of Science at AXA XL have attested to the importance of Bradley and Frigg research, citing **[2]** and **[3]** specifically:

> "*Professor Richard Bradley and Professor Roman Frigg have been influential in introducing new ways that AXA XL thinks about aspects of its decision-making under uncertainty. Their work is beginning to evolve the explicit consideration and treatment of uncertainty in different parts of the business, and we are currently assessing methods to implement some of their recommendations in our decision-making chains*" **[A]**.

Managing uncertainty based on Bradley and Frigg's confidence approach allows the insurer to include a realistic and substantiated risk premium in its contracts, thereby avoiding ad-hoc adjustments in pricing. This helps to protect against under-selling policies and thereby exposing their business to potentially destabilising losses. At the same time, it protects customers by ensuring that prices are equitable and grounded in a reasoned assessment of the relevant uncertainties.

Informing the establishment and development of Maximum Information, a new risk management consultancy

The new method of decision-making developed by the underpinning research has applications beyond AXA XL. Following his collaboration with Bradley and Frigg on the AXA XL work, Philp has subsequently pursued a new private venture to explore, use, and implement new and cutting-edge uncertainty management tools, establishing Maximum Information, a start-up company which aims to provide cost-effective, transparent, and reliable atmospheric catastrophe and climate change uncertainty analytics to a number of stakeholders, including but not limited to AXA XL **[B]**. Maximum Information is the first company to place uncertainty and its attendant sensitivities at key parts of the modelling chain and to integrate them in a comprehensive decision framework. This has the potential to be game-changing in the insurance industry. Bradley and Frigg are science advisors to the company and are closely involved in the development of its tools and strategies.

Explicitly citing **[6]**, along with two dissemination papers mentioned at the end of this section under "pathways", Philp has confirmed "*the valuable impact that the work of [Bradley and Frigg] has had on the development of [his] company*" **[B]**. The underpinning research has played an important role in shaping the vision, structure, and concept of Maximum Information, which is premised on the "*shift in mindset toward explicit decision theory right from the beginning of the risk modelling chain*" and will enable the new company to spearhead "*the development of optimally cost-effective climate risk-resilience solutions – ultimately underpinned by the foundational research of Profs Frigg and Bradley - in multiple sectors, such as re/insurance, banking, aid, and government*" **[B]**.

Influencing the methods underpinning the operations of Syntherion KIG, a new risk management company

Syntherion KIG is a B2B risk management start-up based in Switzerland, which advises small and medium-sized banks on how to tackle their risk/return dilemma. It does so by providing them with a software tool optimising risk-return-ratios in real-time, allowing banks to respond to market dynamics immediately. This software incorporates artificial intelligence techniques and machine-learning algorithms. Syntherion's CEO, Christian Hoffmann, spent a period of five months as an external visitor at LSE's Centre for Philosophy of Natural and Social Science (CPNSS) in 2012, and since then has returned for shorter visits on a regular basis. Hoffmann developed some of the main concepts on which Syntherion KIG is based while at CPNSS, and he has remained in regular contact with Frigg (CPNSS director until August 2020). The concepts are documented in Hoffmann's book *Assessing Risk Assessment* **[C]**, where the work of Bradley and Frigg is frequently referenced. Hoffmann confirms that Bradley and Frigg "*have been influential in helping to pave the way for the Syntherion KIG*" **[D]**. He describes the influence of the research in a twofold sense: "*[f]irst, my team and I have built on the work by Bradley and Frigg to clarify the severe limitations of classical probability-based or statistical modelling once it comes to introducing scenario-based real-time risk management for coping with the risk/return dilemma as outlined in my dissertation*", citing **[1] [2] [3] [4]** specifically. Hoffmann has also emphasised "*that Bradley and Frigg had an important influence on the concepts on which the company's operations are based*" **[D]**. Secondly, "*on the constructive side, the Syntherion team makes use of causal modelling and Bayesian regression […] In this connection, Frigg's contributions to the philosophy of science, Bayesianism and causal modeling have proved to be helpful for designing our proprietary approach*" **[D]**. In this way, Bradley and Frigg's research has been important in understanding the limitations of traditional statistical modelling of risk and uncertainty management, and in designing Syntherion's software tools.

Informing independent financial advice given to the Bank of England

Bradley and Frigg's approach has also influenced work in the financial sector through advice provided to the Bank of England and the Sovereign Wealth Fund of Singapore by independent advisor Andrew Wong. In 2014, Wong contacted Bradley and Frigg after having read their work and having heard about the "Managing Severe Uncertainty" project. He was invited to give a talk in one of the project meetings at CPNSS and to discuss his ideas with colleagues. Since then, Wong and Frigg have met on a regular basis (about twice a year) for extensive discussions about uncertainty. Advice is strictly confidential and no content of his discussions with clients can be

shared publicly, but Wong has confirmed that the underpinning research **[2] [3] [4] [6]** has been helpful to him in the course of his work and informs the advice he gives to both bodies: *"[Bradley and Frigg's] work has helped me personally, as an individual, broaden and deepen my appreciation for the complexity of problems around models, uncertainty, and decision-making"* **[E]**.

The focus of Wong's work is on global markets and financial stability, advising on risks around the global financial system. What happened in the wake of the global financial crisis suggested that many of the risk models for complex derivatives were either somewhat or very materially incomplete, significantly underestimating the actual losses that were incurred. According to Wong, it is in this context that "*it becomes clear how important it is that progress be made on the related questions of how best to think about models for complex phenomena, what are the limitations and constraints on such modelling efforts, how do we think about decision-making under uncertainty, and are there better ways to use models for real-world decision-making...I believe [Bradley and Frigg's] work is important, theoretically and also in the translation of the work into the decision-making spheres in many fields, public and private*" **[E]**.

A note on pathways to impact

Sharing the underpinning research as widely as possible has been an important aspect of the "Managing Severe Uncertainty" project. A key part of the project's knowledge exchange strategy was to accompany top-level research publications - including **[1-6]** - with summary pieces that are accessible to a wider audience and published in high-visibility outlets. This strategy resulted in publications in *Philosophy Compass*, *Internet Encyclopedia of Philosophy*, and the *Oxford Handbook of Probability*. These publications turned out to be crucial to the impacts described above as AXA XL first established contact with Bradley and Frigg after having come across their *Philosophy Compass* pieces.

5. Sources to corroborate the impact (indicative maximum of 10 references)

[A] Supporting statement from the Manager – Science and Head of Science, AXA XL, 16 November 2018.

[B] Supporting statement from Chief Executive Officer, Maximum Information, 8 November 2020.

[C] Hoffmann, Christian Hugo (2017). *Assessing Risk Assessment: Towards Alternative Risk Measures for Complex Financial Systems*. Wiesbaden: Springer Gabler. ISBN: 9783658200329.

[D] Supporting statement from Co-Chief Executive Officer, Syntherion KIG, 14 October 2019.

[E] Supporting statement from Andrew Wong, Independent Advisor on Global Markets and Risk, 26 October 2019.