Institution: The University of Edinburgh/Heriot-Watt University (Maxwell Institute)

Unit of Assessment: B10, Mathematical Sciences

Title of case study: Statistical models of mortality impact on the pricing and reserving of pensions

1. Summary of the impact

Research carried out from 2003 by Currie (Maxwell Institute) and his PhD students Djeundje, Kirkby and Richards (also Longevitas), and international collaborators Eilers and Durban, created new, flexible smoothing and forecasting methods. These methods are now widely used by insurance and pension providers to forecast mortality when determining pricing and reserving strategy for pensions. The methods were incorporated by the SME Longevitas in its forecasting package *Projections Toolkit* launched in 2009. This generated impact in the form of £400K turnover for Longevitas in licensing and consultancy fees, with further impact on the pricing and reserving strategies on Longevitas's customers. Since 2010 the methods have been adopted by the Office for National Statistics (ONS) to make the forecasts required to underpin public policy in pensions, social care and health and by The Continuous Mortality Investigation (CMI) to model and provide forecasts on mortality to the pensions and insurance industries. As a result, the research has changed practices in these advisory agencies and in the insurance industry.

2. Underpinning research

Pensions and annuities are future liabilities that depend on the future course of mortality. Research by a team led by Currie (Maxwell Institute, MI) has provided a suite of solutions to several of the modelling challenges facing the insurance and pensions industry in their forecasting of mortality.

Statistical research. In 2004, Currie, Durban (Carlos III Madrid) and Eilers (Leiden) proposed a new approach to forecasting mortality that uses a 2-dimensional smoothing model to reveal the underlying pattern in mortality by both age and time, and to forecast this pattern in time [1]. Fitting the 2-dimensional model in [1] is computationally intensive and in 2006 the authors formulated an algorithm that improves computational time by orders of magnitude [2]. Mortality data are usually indexed by age of death and year of death, and the methods described in [1] and [2] provided an immediate modelling solution to this scenario. Further research by Richards (Longevitas), Kirkby (MI) and Currie showed how the 2-dimensional model could also be applied when data are indexed by age at death and year of birth and demonstrated the importance of cohort effects in the modelling and forecasting of mortality rates [3]. In another strand of research, Richards and Currie [4] in 2009 showed how to produce more regular forecasts with the Lee-Carter model – a benchmark model widely used to forecast mortality – improving its actuarial performance. A common feature of mortality data is overdispersion (where the observed mortality rates are more variable in age and time than predicted by a simple random model). Djeundje (MI) and Currie [5] showed how the techniques developed in [1] and [2] could be extended to accommodate overdispersion. The forecasting of the mortality of the very old is of particular interest to annuity and pension providers but presents additional challenges since data quality can be poor at such ages. Currie formulated a new solution to this problem using the approach and computational methods in [1] and [2].

Implementation for users. All the techniques described above have been incorporated in the commercial package *Projections Toolkit* developed and licensed by Longevitas, a software and consulting company. The techniques proposed in [1-3] have also been implemented in the freely available R package *MortalitySmooth*, developed within the Max Planck Institute for Demographic

Research.

Attribution. I. D. Currie has been a member of the Maxwell Institute since 1973. J. Kirkby (graduated in 2009) and V. Djeundje Biatat (graduated in 2011) were PhD students, both supervised by I. D. Currie and funded by EPSRC and CMI. S. J. Richards completed a part time PhD at HWU in 2012. M. Durban was at Carlos III Madrid and P. H. C. Eilers at Leiden.

3. References to the research

References marked with a * best indicate the quality of the research.

[1]* Currie I.D., Durban, M. and Eilers, P.H.C., Smoothing and forecasting mortality rates, *Statistical Modelling*, **4**, 279-298 (2004). http://dx.doi.org/10.1191/1471082X04st080oa

[2]* Currie, I.D., Durban, M. and Eilers, P.H.C., Generalized linear array models with applications to multidimensional smoothing, *Journal of the Royal Statistical Society, Series B*, **68**, 259-280 (2006). http://dx.doi.org/10.1111/j.1467-9868.2006.00543.x

[3] Richards, S. J., Kirkby, J.G. and Currie, I.D., The importance of year of birth in two-dimensional mortality data (with Discussion), *British Actuarial Journal*, **12**, 5-61 (2006). http://dx.doi.org/10.1017/S1357321700004682

[4] Richards, S. J. and Currie, I. D., Longevity risk and annuity pricing with the Lee-Carter model, *British Actuarial Journal*, **15**, 317-365 (2009). http://dx.doi.org/10.1017/S1357321700005675

[5] Djeundje, V. A. B. and Currie, I. D., Smoothing dispersed counts with applications to mortality data, *Annals of Actuarial Science*, **5**, 33-52 (2011). http://dx.doi.org/10.1017/S1748499510000047

[6] Richards, S.J., Currie, I.D. and Ritchie, G.P., A value-at-risk framework for longevity trend risk. (with Discussion) Read before the Institute and Faculty of Actuaries in Edinburgh and London (November 2012), *British Actuarial Journal*, Available on CJO 2013 http://dx.doi.org/10.1017/S1357321712000451

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4. Details of the impact

Projections Toolkit. Significant impact has been achieved in the form of increased turnover for Longevitas, an SME formed in 2006, which offers its customers leading-edge software for modelling and analysing demographic risks, including mortality, longevity and critical illness. The increased turnover results from the licensing and marketing of a software application – *Projections Toolkit* – which was developed by Longevitas staff from code originally written by Currie. The *Projections Toolkit* is an important tool in the service provided by Longevitas to the pensions and insurance industry and embodies a wide range of forecasting models - specifically the 2-dimensional models [1-3, 5] and the Lee-Carter models [4]. [Text removed for publication.]

Impact on practices of advisory agencies. The research has generated further impact through the uptake of the smoothing and forecasting methods described in Section 2 by two bodies, the Office for National Statistics and the Continuous Mortality Investigation, whose respective remits includes the provision of statistical analyses for use by government and by the pensions and insurance industries.

The **Office for National Statistics** (ONS) provides official statistics on behalf of the UK government including the National Population Projections (NPP) which impact strongly on government policy on pensions, social care and health. Since 2006 the ONS has used the 2-dimensional smoothing model to remove fluctuations from age to age and year to year in formulating smoothed mortality surfaces for each gender [8]. During development of the new methodology, Currie provided direct support to the Principal Methodologist involved at ONS. Our contribution to the work of ONS is described in [9] which states (p4) that "Mortality rates for the UK in each calendar year in the period 1961 to 2009 have been smoothed to remove fluctuations from age to age and year to year, using a new methodology" - a direct reference to their use of our 2-dimensional smoothing model as described by them on p5: "A p-spline model was then applied to the resulting crude mortality rates to produce a fitted, smoothed mortality surface to the historical data for each gender."

The **Continuous Mortality Investigation** (CMI) is funded by the insurance industry and actuarial consultancies and has two main functions: (i) the collection of claims and exposed-to-risk data from across the insurance industry and pension schemes, the collation of these data by source (for example, by type of insurance), and the creation of a repository of the resulting mortality data sets; (ii) the modelling and forecasting of the data in (i).

The underpinning research, which has been partially supported by the CMI (see section 2), is now incorporated into their forecasting methodology [10]. Specifically, the research has provided the methods used in the CMI model for smoothing the data by fitting a 2-dimensional P-spline age-cohort model, as described in [3]; see the CMI 2010 Working paper [11]. The final model is used extensively by many insurance companies to assess pricing and reserving for various classes of assurance and annuities, and by pension schemes in valuing their liabilities for funding or risk transfer assessments.

5. Sources to corroborate the impact

[7] Projections Toolkit: Board Member, Longevitas, will confirm the central role played by the research in [1-6] in Projections Toolkit. www.longevitas.co.uk/site/ourservices/projectionstoolkit

[8] Senior Methodologist, Office for National Statistics: will confirm the use of the methodology by ONS.

[9] National Population Projections, 2010-based reference volume: Series PP2, published by the ONS. See Chapter 4, 'Mortality' for a description of how the research is used by the ONS. http://www.ons.gov.uk/ons/rel/npp/national-population-projections/2010-based-reference-volume--series-pp2/mortality.html

[10] Continuous Mortality Investigation: Senior actuary with Barnett Waddingham will confirm the use of the methodology by CMI.

[11] Continuous Mortality Investigation , The CMI mortality projections model, 'CMI 2010', Working Paper 49, November (2010). www.actuaries.org.uk/research-and-resources/pages/continuous-mortality-investigation

See under CMI working papers on the CMI web site above; in particular, section 5, p20.

Note: should links to web pages be broken, please use the website http://www.maths.ed.ac.uk/~mthdat25 to access pdf versions of the pages