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

Unit of Assessment: B10 Mathematical Sciences

Title of case study: Stochastic models of longevity risk adopted by the pension industry

1. Summary of the impact

Research carried out by Cairns (Maxwell Institute), Blake (Cass Business School) and Dowd (Nottingham, now Durham) in 2006 produced the 'CBD' model for predicting future life expectancy. The CBD model and its extensions developed in 2009 by Cairns and collaborators have had a major impact on pensions and life industry risk management practices: multinational financial institutions [text removed for publication] and other stakeholders have relied on the CBD model to risk assess, price and execute financial deals [text removed for publication] since 2010. CBD is also used by risk management consultants to advise clients, is embedded in both open-source and commercial software, and is used by the UK's Pension Protection Fund to measure and manage longevity risk.

2. Underpinning research

The papers of Cairns, Blake and Dowd (2006, [1]) and Cairns *et al*. (2009, [2]) concern the development and application of new stochastic models – the CBD model and its extensions – for the forecasting of mortality rates. These are part of a broader programme of longevity risk research which continues to the present day.

CBD model. The last 100 years have seen large decreases in rates of mortality at all ages resulting from advances in medicine, technology and public health policy. However, the pattern of improvements has been unpredictable, and this results in considerable uncertainty over what might happen in the future. The motivation for the work in [1] came from the pensions and life insurance industry where future mortality trends and the uncertainty around them are of obvious importance. The work responded to the industry's need to estimate the 'longevity risk', that is, the risk that people live, in aggregate, longer than anticipated, a risk that causes pension schemes and annuity providers to incur financial losses.

Compared with earlier work in this field, [1] emphasized (a) the need for models of underlying mortality improvements to be driven by more than one source of randomness, (b) that, at higher ages, the mortality curve can be approximated by a simple parametric form, and (c) that forecasts going beyond a 10-year time horizon need to take account of parameter uncertainty. The relative simplicity of the basic CBD model, and its ability to capture the big picture, meant that it has risen rapidly as a highly-cited and robust benchmark model with a number of important descendants.

Extensions. In 2007, [text removed for publication] Cairns, Blake and Dowd were engaged as research consultants as a direct result of their work in [1]. The commission was to develop a body of published research on longevity modelling that would: (i) help practitioners measure and understand their exposures to longevity risk; and (ii) give them the confidence to make active decisions on how to manage this risk. The collaboration lasted for 4 years resulting in 7 peer-reviewed publications (including [2-5]) in international journals. The initial phase of work had two objectives: to develop new mortality models that built on the advantages and disadvantages of previously published models; and to conduct the first comprehensive comparison of all important stochastic mortality models (five existing models 'M1' to 'M5' and three new models 'M6' to 'M8' that built on the team's knowledge of the advantages and disadvantages of models M1 to M5). This produced four out of the seven papers (the most influential being [2] which was awarded the

2009 Society of Actuaries Prize). Apart from the development of new models, the team pioneered a forensic approach to analysis of individual models and groups of models, setting further benchmarks for model selection criteria, communication of risk, and assessment of model risk. This initial phase also resulted in the production of a suite of open-source software in R (written by Cairns) for fitting models M1-M3 and M5-M8, and simulation models for M1 and M5 [text removed for publication]. The research papers were written in a style that ensured accessibility of their methodology to stakeholders in the developing longevity market. Their influence is attested by the fact that the names M1 to M8, labelling various models, as well as the name 'CBD' are now in common usage amongst longevity-risk experts.

Attribution. A. J. G. Cairns has been a Professor of Financial Mathematics in the Maxwell Institute since 1992. His co-authors were with the Cass Business School (D. Blake), Nottingham University Business School (K. Dowd) [text removed for publication] during the period of the underpinning research.

3. References to the research

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

[1]* Cairns, A.J.G., Blake, D. and Dowd, K., A Two-Factor Model For Stochastic Mortality With Parameter Uncertainty: Theory And Calibration, *Journal of Risk and Insurance,* **73**, 687-718 (2006). http://dx.doi.org/10.1111/j.1539-6975.2006.00195.x

[2]* Cairns, A. J. G., David, B., Dowd, K., Coughlan, G. D., Epstein, D., Ong, A. and Balevich, I. A, Quantitative Comparison Of Stochastic Mortality Models Using Data From England And Wales And The United States, *North American Actuarial Journal*, **13**, 1-35 (2009). (Awarded the 2009 Society of Actuaries Prize). http://dx.doi.org/10.1080/10920277.2009.10597538

[3] Dowd, K., Cairns, A.J.G., Blake, D., Coughlan, G.D., Epstein, D. and Khalaf-Allah, M., Evaluating the Goodness of Fit of Stochastic Mortality Models, *Insurance: Mathematics and Economics*, **47**, 255-265 (2010). http://dx.doi.org/10.1016/j.insmatheco.2010.06.006

[4]* Cairns, A.J.G., Blake, D., Dowd, K., Coughlan, G.D., Epstein, D. and Khalaf-Allah, M., Mortality Density Forecasts: An Analysis Of Six Stochastic Mortality Models, *Insurance: Mathematics and Economics,* **48**, 355-367 (2011). http://dx.doi.org/10.1016/j.insmatheco.2010.12.005

[5] Dowd, K., Cairns, A.J.G., Blake, D., Coughlan, G.D., Epstein, D. and Khalaf-Allah, M., Backtesting Stochastic Mortality Models: An Ex-Post Evaluation of Multi-Period-Ahead Density Forecasts, *North American Actuarial Journal*, **14**, 281-298 (2011). http://dx.doi.org/10.1080/10920277.2010.10597592

4. Details of the impact

Nature and reach of impact. Longevity risk leads to significant financial risk in pension schemes, which in turn increases volatility in balance sheets of companies sponsoring pension schemes. Many companies, especially those with long-established pension schemes, choose to hedge the impact of this risk through use of longevity swaps and other financial structures which transfer the risk to financial institutions such as multinational reinsurers. As a result, the pension industry has developed into a major global industry, encompassing major financial institutions as well as pension schemes and life insurers. The CBD model, its descendants and the R package written by Cairns have provided this industry with crucial tools to assess longevity risk and price their products. These tools were crucial in educating the market in the early days, in winning over the actuarial profession, and persuading investors to take longevity investments seriously. They have

since been adopted by a broad range of stakeholders including major US, UK and multinational institutions to inform transactions worth several billions of pounds. We list below several of these stakeholders and, for each, detail the impact of the CBD model and its descendants.

[text removed for publication] Collaboration between Cairns, Blake and Dowd and [text removed for publication] staff of a multinational company developed insightful new models, and a comprehensive methodology for the comparison of different models and the assessment of model risk. It helped leverage the resources of the [text removed for publication] company's longevity team; exploited complementary skill sets to develop rigorous and practical solutions; helped provide visibility and build the company's reputation [text removed for publication] as a market leader; and helped persuade clients to agree to do substantial deals with the company [text removed for publication] [6].

[text removed for publication] A very significant US-based buyer of longevity risk from pension schemes and insurers, [text removed for publication] is a major user of the results in [2]. They have adopted the model comparison methodology of [2] as the foundation of their efforts to understand and navigate their way through a diverse array of model choices. They most often base their assessments of risk and decisions on 'second-generation' CBD models (i.e. M6, M7 in [2]). Since 2010, they have used the methodology in their assessment of [text removed for publication] pension liabilities and have subsequently executed substantial transactions in the UK [text removed for publication] [7].

[text removed for publication] A rapidly-expanding, specialised consultancy that provides capital markets and actuarial advice to pension schemes and insurers considered a number of variants of the CBD models and of the earlier Lee-Carter model in their development of an in-house longevity model, concluding that the 2-factor CBD model [1] was best for their pensions client work. CBD is used for assessing risk and developing strategies for reducing risk, including the management of risk-based capital requirements [8].

[text removed for publication]

[text removed for publication] A provider of specialist software for modelling past and future mortality rates used by insurance companies [text removed for publication] incorporated CBD into its [text removed for publication] software from outset [text removed for publication] The software is in regular use by clients, [text removed for publication] finding particular application in the calculation of capital requirements for regulatory purposes [10].

UK Pension Protection Fund. The PPF receives a levy from pension schemes as insurance against possible bankruptcy of the sponsoring companies, leaving the scheme in deficit. In such circumstances, the PPF takes over the distressed scheme and assumes responsibility for paying scheme pensions. Assets and liabilities at July 2013 were £20 billion, with both expected to increase rapidly over coming years. The PPF has developed an internal, long-term risk model (LTRM) that covers all of its major risk categories including future mortality improvements. Mortality is modelled using the 'M7' second-generation CBD model in [2]. M7's use forms an important element of the PPF's overall programme of risk measurement, monitoring and management, including setting its funding strategy. M7 also influences setting of scheme levies (2013/14: £630 million). As the PPF matures the use of M7 will become even more important [11-12].

5. Sources to corroborate the impact

[6] [text removed for publication]

[7] [text removed for publication]

[8] [text removed for publication]

[9] [text removed for publication]

[10] [text removed for publication]

[11] [text removed for publication]

[12] Use of the CBD model M7 in the Pension Protection Fund is documented at http://www.actuaries.org.uk/research-and-resources/documents/financial-management-uk-pensions-protection-fund

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