**Institution:** Maxwell Institute for Mathematical Sciences

**Unit of Assessment:** UoA 10 – Mathematical Sciences

**Title of case study:** Improved Understanding of Population and Mortality Data Benefits the UK and International Pensions and Insurance Sectors

**Period when the underpinning research was undertaken:** 2013-2016

**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: |
|---|---|---|
| Andrew Cairns | Professor | 1992-date |

**Period when the claimed impact occurred:** 2014-2020

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

## 1. Summary of the impact

The 2011 UK census revealed issues with the accuracy of the underlying population data that were of considerable concern to the pensions and life insurance sectors. This led directly to the work of Cairns et al. (2016), who developed methods for identifying anomalies in national population and mortality data.

The work has impacted on institutions in the UK, US and France. Results of the research have enabled insurers to reduce prices for the transfer of pension liabilities, saving UK pension funds between GBP330,000,000 and GBP1,000,000,000. It has persuaded actuaries to revise the mortality tables that they use for pricing and reserving including changes in the methodology underpinning the UK actuaries' Continuous Mortality Investigation (CMI) mortality projection tables.

## 2. Underpinning research

The 2011 census revisions to England & Wales (E&W) population estimates by the Office for National Statistics (ONS) drew attention to the possibility that there are widespread issues in how population data are measured and reported in many countries. Cairns (Maxwell Institute) along with Blake (City University) and Dowd (Durham) were approached by the [text removed for publication] to investigate these issues further and propose how to correct anomalies in population and mortality data.

This collaboration led to the paper by Cairns et al. (2016) [3.1] (hereafter CBDK after the four authors) who highlighted potential anomalies in English and Welsh (E&W) population data and how these data are used in the calculation of mortality rates. A key discovery was that an uneven pattern of births within a given calendar year is a major cause of anomalies in population and *exposures* data decades later. The term *exposures* refers to the *average* population at a given age over the whole of a calendar year, but, in many countries such as E&W, exposures are approximated by the corresponding mid-year population estimate: and it is this approximation that can lead to significant errors in published *death rates* (deaths divided by exposures). Different countries or agencies might derive population estimates and exposures in different ways. But, however they do this, the estimated exposures will be subject to potentially significant errors, unless they take into account any significant irregular patterns in monthly or quarterly births data.

As one example, in the competitive life annuity market, profit margins tend to be quite small. Consequently, a 1% error, say, in the price of an annuity due to errors in the exposures data could lead to a 25% error in anticipated profits. [3.1] identified two cohorts in E&W with errors that exceed 1%.

The researchers developed a range of methodologies to help identify specific errors in population, exposures and deaths data:

- graphical diagnostics providing a powerful model-free toolkit for identifying anomalies in the form of *signature plots*;
- a Bayesian framework enabling the size of these anomalies to be quantified and corrected;
- two-dimensional diagnostics enabling the detection of small systematic errors in exposures and deaths of less than 1%.

Using these methodologies, [3.1] showed that ONS population data do contain significant anomalies of up to 9% in both mid-year population estimates and exposures that need correction.

The researchers [3.1], additionally, developed the cohort–births–deaths exposures methodology which can be used to explain many of the bigger errors. The first component was the *convexity adjustment ratio* which can be used to explain how persistent cohort-related errors arise when exposures are equated to mid-year population estimates. The second component was a methodology for deriving improved mid-year population estimates in census years from census data. Other anomalies were identified but only partially explained by the cohort-births-deaths methodology. Significantly, postcensal population estimates were demonstrated in the paper to magnify anomalies (e.g. *phantoms*) arising in census years.

In addition, anomalies were identified that are due to potential small biases in the reported age at death, and use of the Kannisto–Thatcher high-age methodology, resulting in a discontinuity at age 90 years.

Finally, [3.1] developed a holistic approach, not reliant on births data, to estimate and correct errors in population data.

Collectively, these errors can make substantial differences, particularly in respect of cohorts that are still sufficiently large to have a significant financial effect, e.g. the impact of anomalies in the 1947 cohort on pension liabilities.

The same types of errors – with possible variants – are now known to apply to other countries: some similar to E&W in deriving their population data from periodic (typically decadal) censuses. As one example, data for France (see [5.8]) share similar characteristics and reveal similar anomalies to those for E&W.

Cairns led the mathematical and statistical work in the paper.

## 3. References to the research

[3.1] Cairns, A.J.G., Blake, D., Dowd, K., and Kessler, A.R. (2016) Phantoms Never Die: Living with Unreliable Population Data. *Journal of the Royal Statistical Society, Series A,* 179: 975-1005. DOI: 10.1111/rssa.12159

## 4. Details of the impact

### Beneficiaries and Types of Impact

The results of this research are being used by or have had an impact on companies and institutions in the UK, US and France: [text removed for publication]; the Continuous Mortality Investigation of the Institute and Faculty of Actuaries (CMI); actuarial consultancies advising insurers and pension funds; UK pension funds; insurers and reinsurers; the Office for National Statistics (ONS). CBDK [3.1] has impacted on: professional practice; published mortality tables; pricing of billions of pounds of longevity transactions, with a documented/verifiable pathway to impact in each case.

### Pathway to impact

The authors' original and longer report was completed in December 2013, and was followed by a series of presentations by Cairns and co-authors to key stakeholders to kickstart generation of impact from the research. Presentations included US practitioners (New York), the US Social Security Administration (Baltimore), United Nations Population Directorate (New York), members of the Continuous Mortality Investigation (London), mortality experts at the Office for National Statistics (Titchfield), actuaries' Life Conference (Birmingham), and the International Mortality and Longevity Symposium (Birmingham).

**[text removed for publication]**

The impetus for CBDK originated from [text removed for publication] who were concerned about the accuracy of ONS population data. The results in CBDK gave [text removed for publication] the confidence to revise their mortality tables and reduce prices. Since publication of the paper, [text removed for publication] have used the results in all of their UK transactions. [text removed for publication] supporting letter [5.1] states: "*As a direct result of this study, my team revised [their] mortality tables … [and] have reduced the price charged by [text removed for publication] by nearly 1%*". She continues to note that [text removed for publication] I have executed transactions worth [text removed for publication] since 2016, resulting in savings to UK pension funds and insurers of approximately [text removed for publication]. "*Moreover, we believe that the entire market has taken these revised tables into account … [with] estimated savings … nearing £1 billion.*"

**Office for National Statistics**

The ONS conducted a methodological review in 2016 of official high-age population estimates. One of the key drivers for the review was CBDK [3.1]. (See ONS, 2016, page 4; [5.2].)

**Continuous Mortality Investigation (CMI)**

The CMI conducts mortality investigations on behalf of the UK actuarial profession and produces mortality tables and forecasts of mortality improvements that are extensively used by UK pension funds and insurers when they value their liabilities.

Methods and results in CBDK have been used extensively in two key work streams (mortality projections and high-age mortality) of the CMI that are clearly documented in the CMI working paper (WP) series.

CMI Working Paper 91 (WP-91) [5.3] (pages 4, 5, 11, 56, 57) and its successors concern the CMI's approach to projecting mortality improvements. These require use of a table of historical mortality rates. The results of CBDK convinced the CMI that anomalies could have a material impact on mortality projections and so, inspired by CBDK, they developed a simplified method to adjust for anomalies. The CMI's flagship projection tool itself [5.4] gives users the choice of whether or not to use the adjusted or unadjusted population data, but use of the adjusted data is the default.

A further impact of CBDK on the work of the CMI is evidenced in WP-100 [5.5] (pages 3, 13, 15, 18, 19, 39-49, 73-78 including references to "CBDK" diagnostics). This documents the CMI's work to improvements in single age mortality rates at very high ages, and makes extensive use of the CBDK diagnostic tools 1, 2A and 2B. [5.5] builds on the conclusions of CBDK that the ONS data have a small discontinuity at age 90, and developed their own methodology to correct this.

The CMI projections model, including its high age methodology are used extensively by life insurance and pensions actuaries in setting best estimate mortality improvement assumptions (e.g. see the USS 2018 Valuation [5.6], page 12). These assumptions impact on the valuation of trillions of pounds of insurance and pension liabilities. A decrease of only 0.1% *per annum* (quite common in recent years) to the mortality improvement rate in CMI_2018 will take tens of billions off these liabilities.

**[text removed for publication]**

[text removed for publication] is among the world's largest providers of actuarial services. Their supporting letter [5.7] [text removed for publication discusses the impact CBDK has had internally and how it has impacted on their clients.

- The work of CBDK *"initiated more than four years of research in [text removed for publication]"*;
- Work with a major client, [text removed for publication], led the client *"to update its own mortality tables, …. leading to a change in [their] capital calculation modelling."*
- CBDK more generally has had a strong impact on consulting, including increased awareness of data quality issues, and, through CBDK-inspired adjustments to data, have

had a significant impact on the calibration of stochastic mortality models: calibrations that have an impact on regulatory capital requirements for insurers.

The supporting letter [5.7] also emphasizes the impact of CBDK on the Human Mortality Database (HMD) (a much-used source of mortality data by multinational insurers) which revised its exposures methodology in 2018.

**5. Sources to corroborate the impact**

[5.1] Letter of support [text removed for publication].

[5.2] Office for National Statistics (2016) *Accuracy of official high-age population estimates, in England and Wales: an evaluation.* https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/ageing/methodologies/accuracyofofficialhighagepopulationestimatesinenglandandwalesanevaluation

[5.3] UK Continuous Mortality Investigation (CMI), CMI Working Paper 91 (2016) CMI Mortality Projections Model consultation – technical paper, Mortality Projections Committee. https://www.actuaries.org.uk/system/files/field/document/CMI%20WP091%20v01%202016-08-31%20-%20CMI%20Model%20consultation%20technical%20paper_0.pdf

[5.4] CMI_2019 The CMI Mortality Projections Model; an Excel-based toolkit. Information describing the toolkit is available at https://www.actuaries.org.uk/learn-and-develop/continuous-mortality-investigation/cmi-working-papers/mortality-projections/cmi-working-paper-129.

[5.5] CMI Working Paper 100 (2017) *A second report on high age mortality,* High Age Mortality Working Party, with additional *Supplementary Technical Paper*. https://www.actuaries.org.uk/learn-and-develop/continuous-mortality-investigation/cmi-working-papers/other/cmi-working-paper-100

[5.6] Universities Superannuation Scheme (USS) Scheme funding report of the actuarial valuation of the universities superannuation scheme as at 31 March 2018 (Page 12). www.uss.co.uk/about-us/valuation-and-funding/2018-valuation

[5.7] Letter of Support [text removed for publication].

[5.8] [text removed for publication]