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Mortality in the 21st century

A toolkit for robust modelling

Andy Harding and Matt Fletcher

Aon Hewitt

22 November 2016

Agenda

- Background
- Modelling challenges
- Modelling solutions
- Practical implementation

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Background

Base mortality analysis

- Purpose
  - Insurance (pricing, reserving, ongoing monitoring)
  - Pension plans (funding, accounting, risk settlement)
- Application
  - Mortality (protection)
  - Longevity (annuity – group and retail)
- Stakeholders
  - Policyholders, management and shareholders
  - Plan members, trustees and sponsoring company

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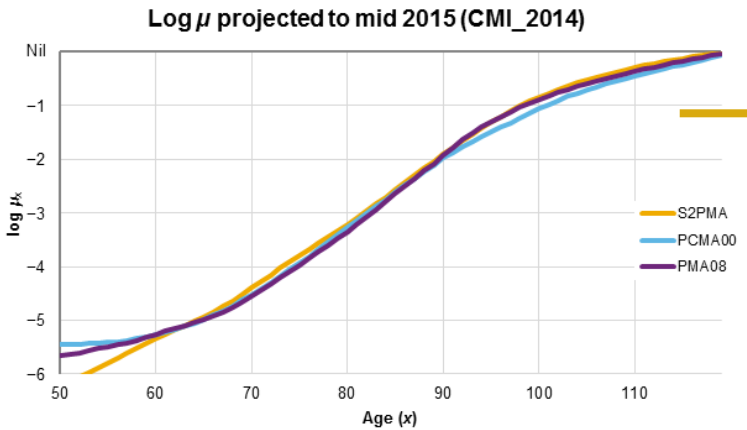
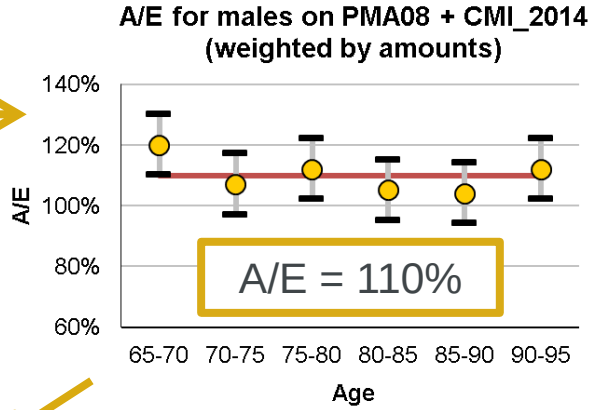
Simplistic approach

- Choose reference table e.g. PMA08 + CMI_2014
- Scale by A/E ratio (amounts-weighted)





Adopt mortality 110% of PMA08 + CMI_2014

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Materiality

- Mortality rate overestimated by just 1% …
- … e.g. q = 3.03% vs 3.00% …
- … means annuity PV underestimated by ~0.4%

i.e. £10m mis-pricing on £2.5bn portfolio

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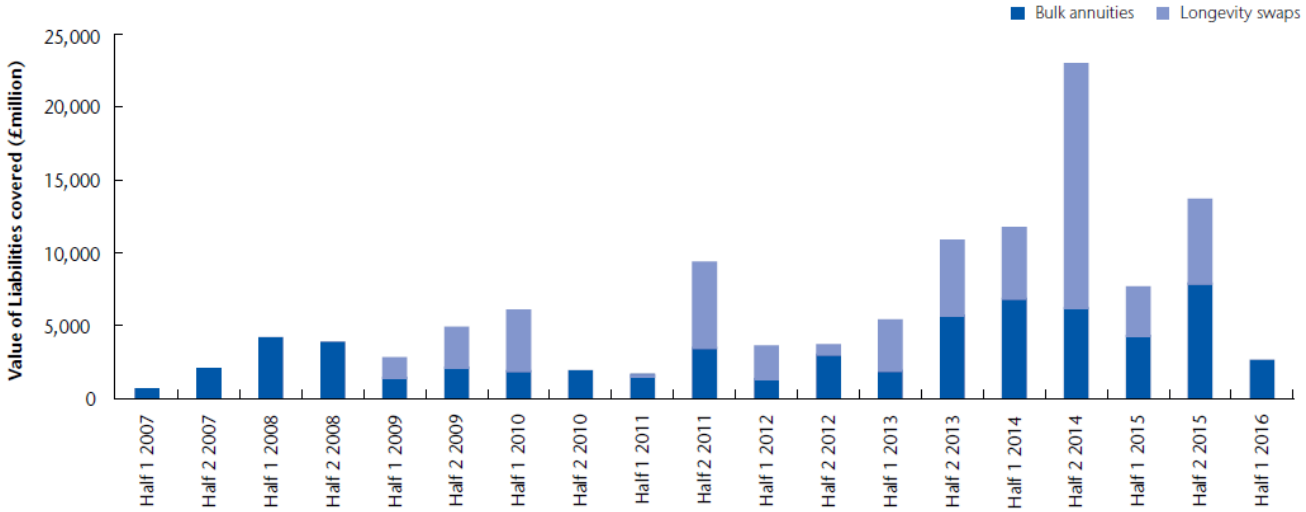
Growing sophistication – demand

- Market activity



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Growing sophistication – supply

- Availability of data
  - Electronic records
  - Postcodes, behaviour and health
- Credibility of data
  - Volume
  - Reliability
- Computational capacity

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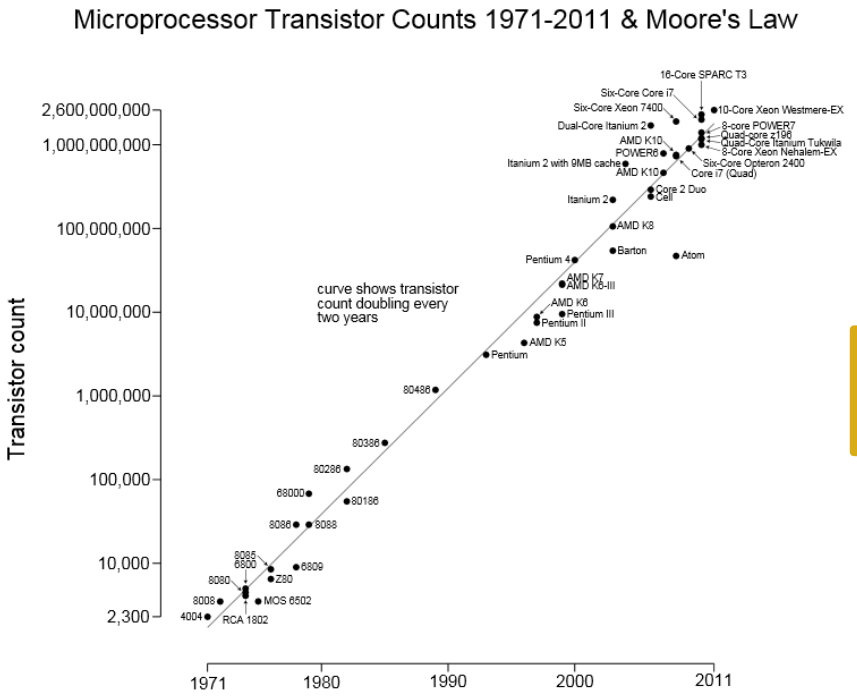
Growing sophistication – supply



Source: Wikipedia https://en.wikipedia.org/wiki/Moore%27s_law

Transistor count has doubled every 2 years

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Modelling challenges

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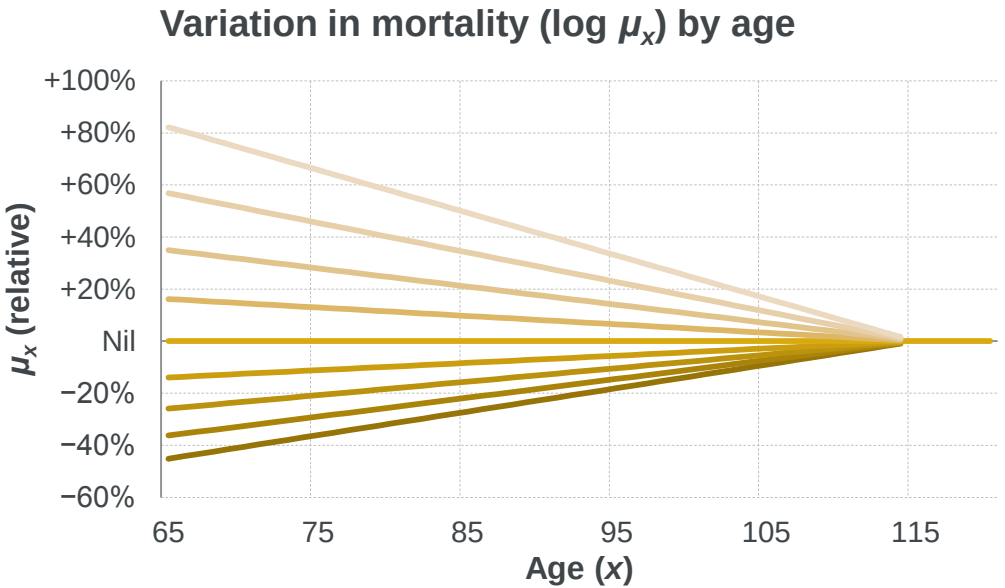
Heterogeneity

- Change in profile
- Intrinsic PV impact
- Age shape



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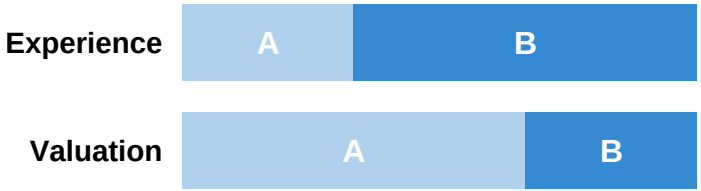
Heterogeneity – change in profile

- Population to be valued may have different profile to experience data



- Real-life example
  - Longevity transaction – 2 business units, distinct characteristics
  - Longer-lived business unit represented
    - 67% of the portfolio to be valued…
    - … but only 33% of the experience data
  - Simple A/E would have understated PV by 3%

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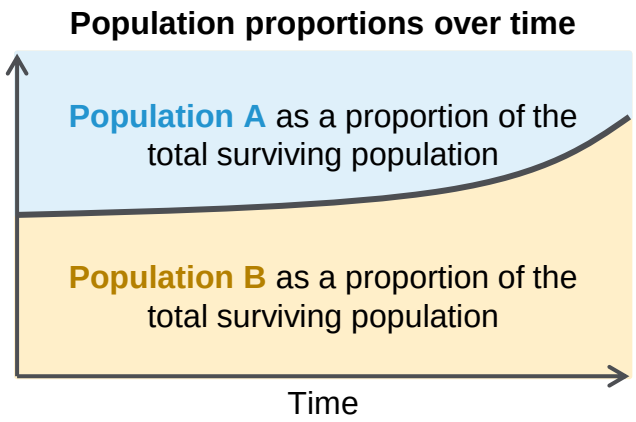
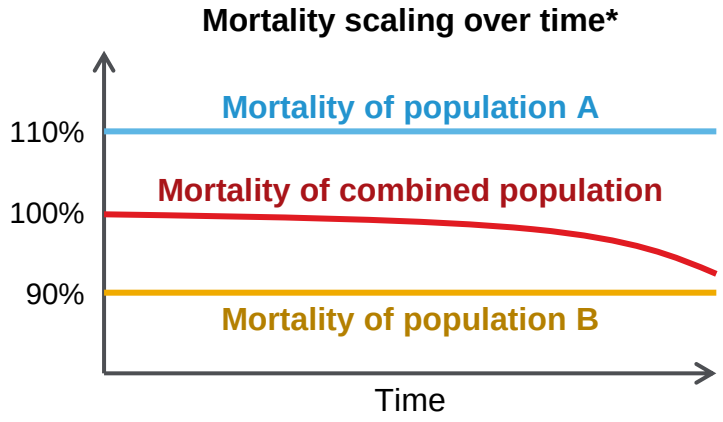
Heterogeneity – intrinsic PV impact

- A/E is a recent snapshot of mortality…
- … but PV is a forward-looking measure





* We have ignored mortality convergence by age in order to simplify the presentation

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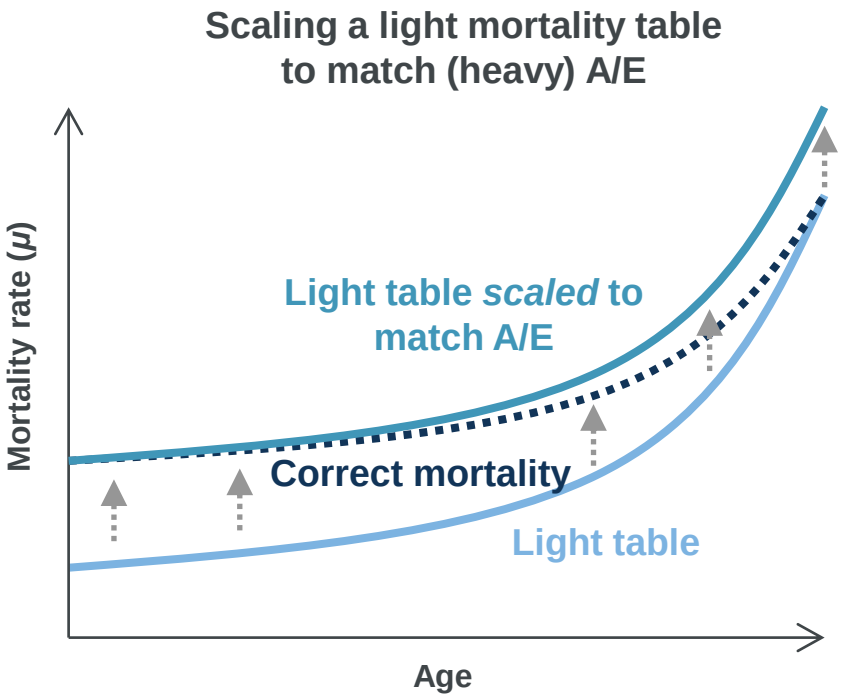
Heterogeneity – age shape



If you scale a **light table** to match A/E (which is typically weighted towards lower ages than the liabilities) then you may *understate* liabilities because the mortality shape of the **scaled table** is wrong. (The correct shape is the **dotted line**.)

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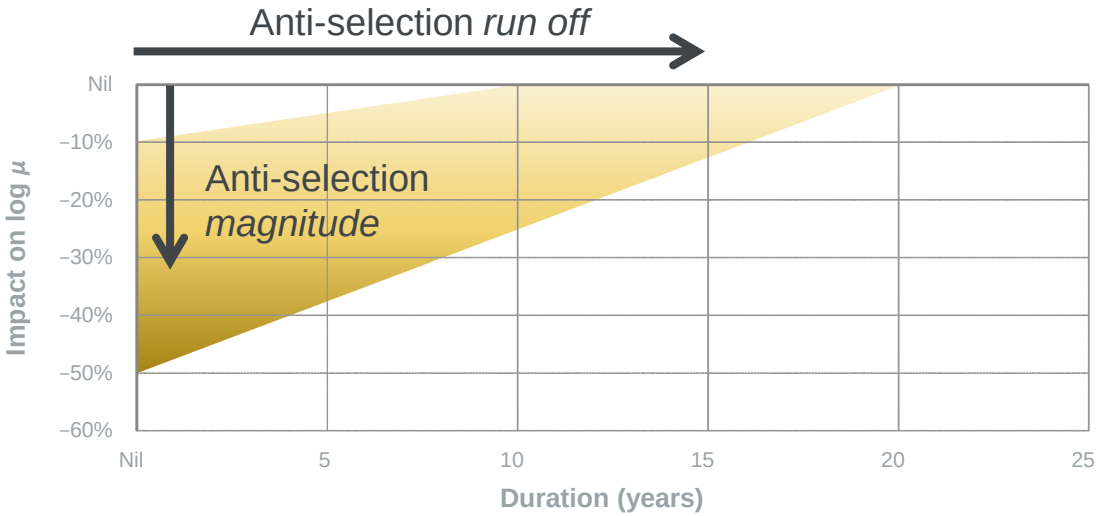
Anti-selection

- Annuity purchase selects for mortality characteristics
- Impact depends heavily on book



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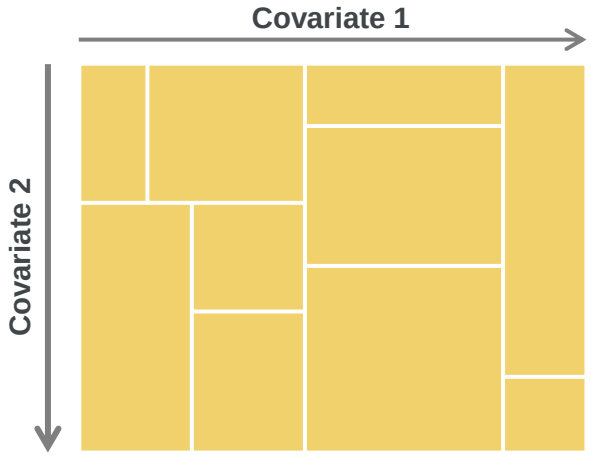
Covariates

- Discrete
  - Sections (exec, staff, works)
  - Product / retirement type
  - Sales channel
- Continuous
  - Benefit amount
  - High-resolution socio-economic profiling
- Co-graduation – e.g. ill-health impact across sections
- Risk of data-mining



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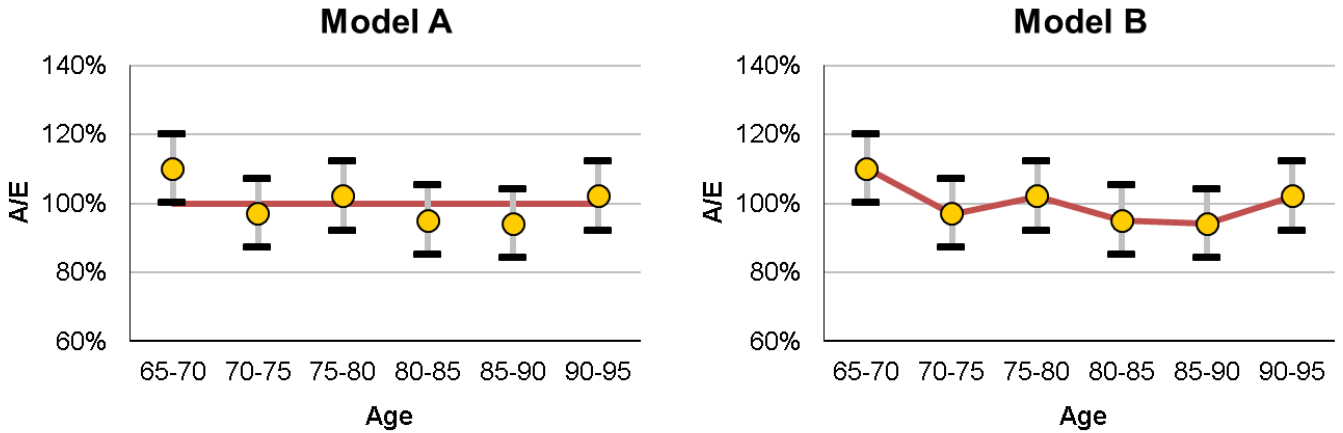
Model selection

- Statistical impact (beware overfitting)
- PV impact

Which is better?



What is 'better'?

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Modelling solutions

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Framework

- Proportional hazards model

$$\mu_{it}(\beta) = \mu^{Ref}{}_{it} \, exp(\beta^T \varphi_{it})$$

Reference table

Vector of factor weights (‘model parameters’)

Vector of covariates/rating factors

- This is an example of a *Generalised Linear Model*
- Advantages
  - Enormously flexible and tractable
  - Derivatives of log likelihood are trivial, so straightforward to fit
  - Mortality improvements can be built in (e.g. to the reference table)

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Fitting and diagnostics

- Maximise the log likelihood

$$LL = -E + A \log\mu$$

where

Death indicator

$$A = \sum_{i \in individuals} D_i$$

Date of death (random)

Mortality

$$E = \sum_{i \in individuals} \int_{v_i}^{T_i} \mu_{it} \, dt$$

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Fitting and diagnostics

- Maximise the log likelihood

$$LL = -E\omega + A\omega \log\mu$$

where

Death indicator

$$A\omega = \sum_{i \in individuals} D_i \omega_{iT_i}$$

Date of death (random)

Mortality

$$E\omega = \sum_{i \in individuals} \int_{v_i}^{T_i} \mu_{it}\, \omega_{it}\, dt$$

- Simple example

Flat scaling, i.e. mortality	$\mu_{it} = \alpha \mu^{Ref}{}_{it}$
Maximising *LL* leads to	$\alpha = A\omega / \left(E^{Ref}\omega\right)$
with 90% confidence ≈	$\pm 1.645 \sqrt{E\omega^2}/E\omega$

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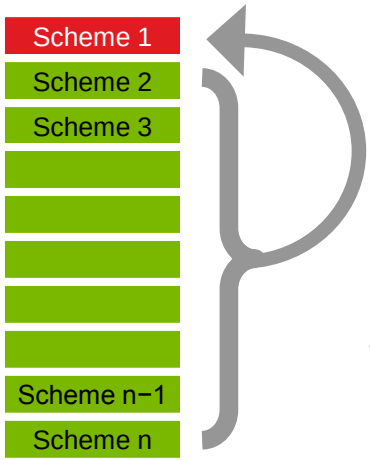
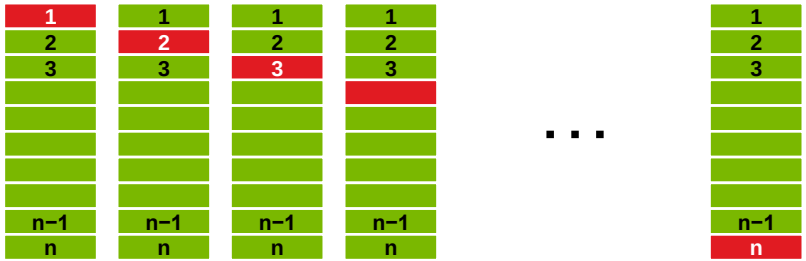
Model selection – cross-validation

- Tests actual *predictivity* across groups of interest
- But computationally onerous…
- … and not always possible to partition



Is this mortality…

…predicted by the model fitted to these schemes?



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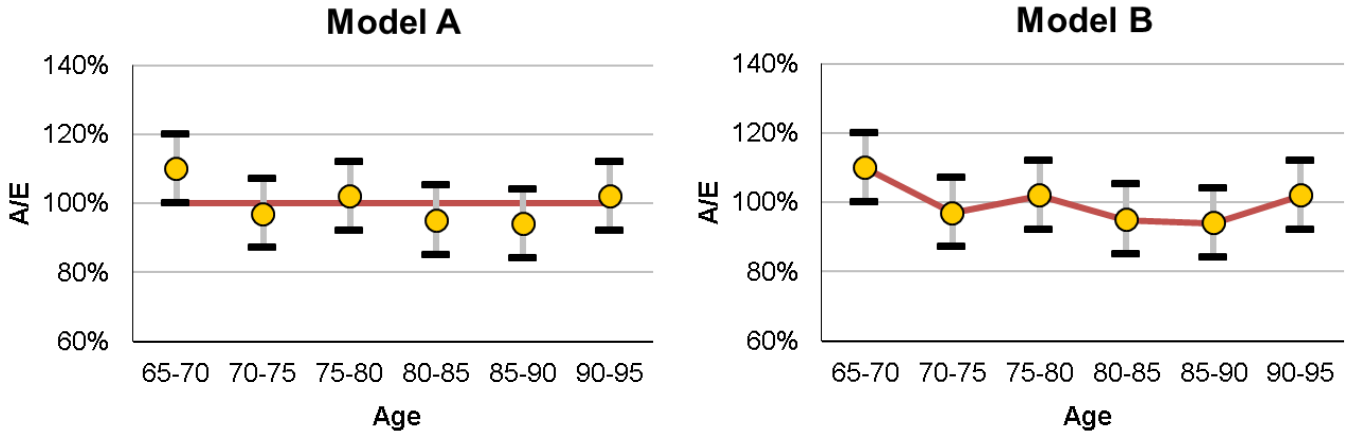
Model selection – information criteria

- Maximise log likelihood

$$LL = -E\omega + A\omega \log\mu$$

Which is better?



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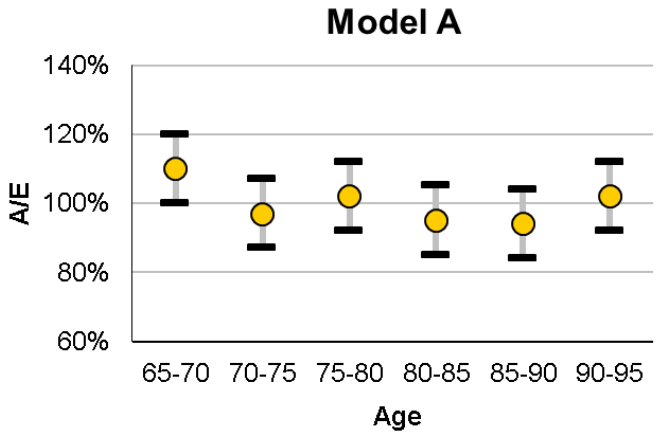

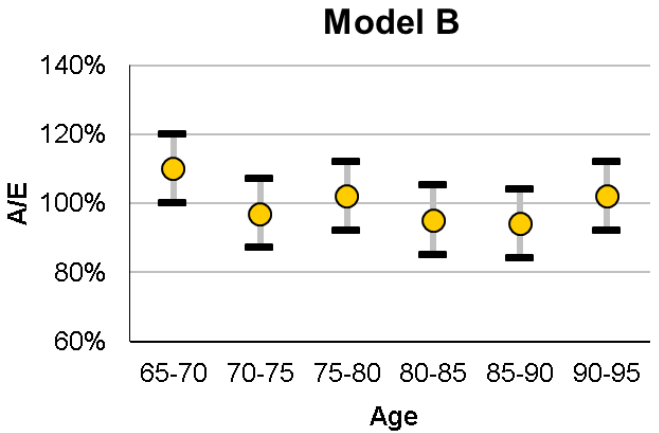

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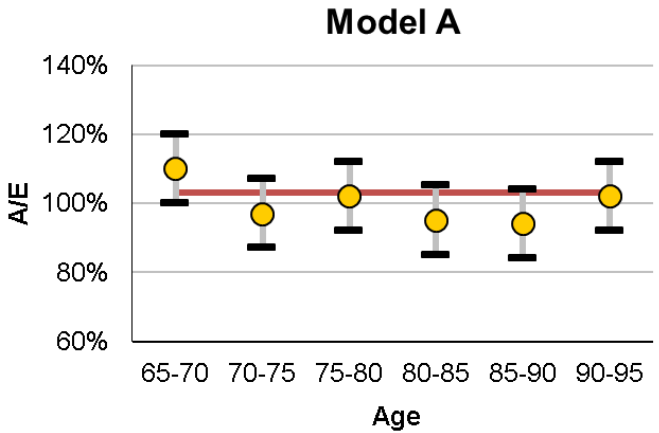

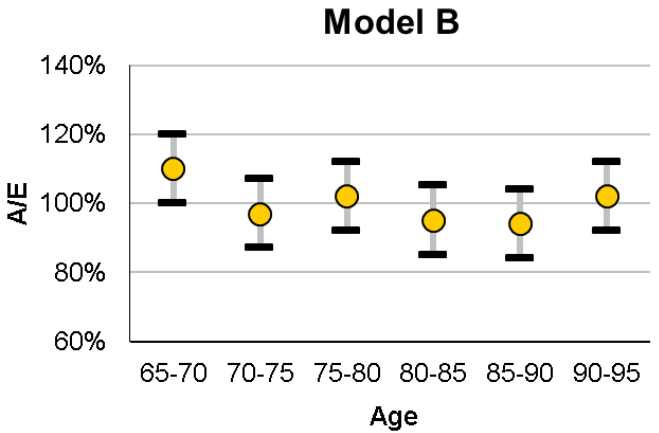

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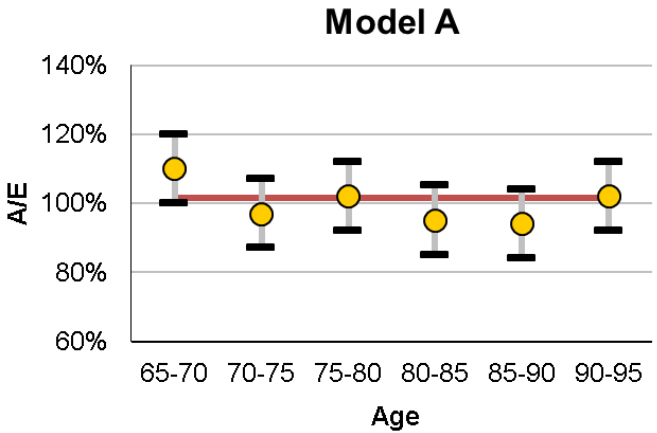

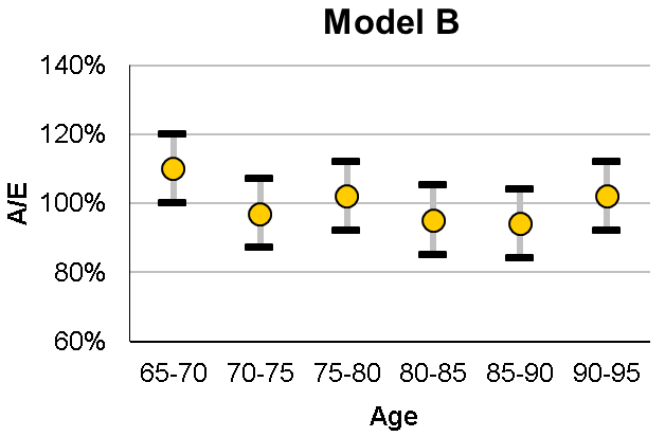

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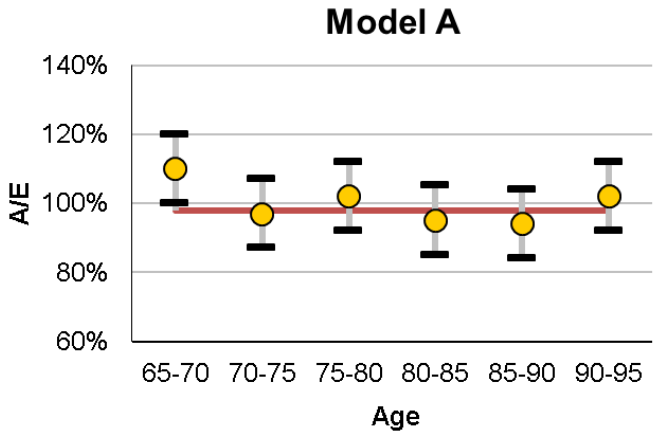

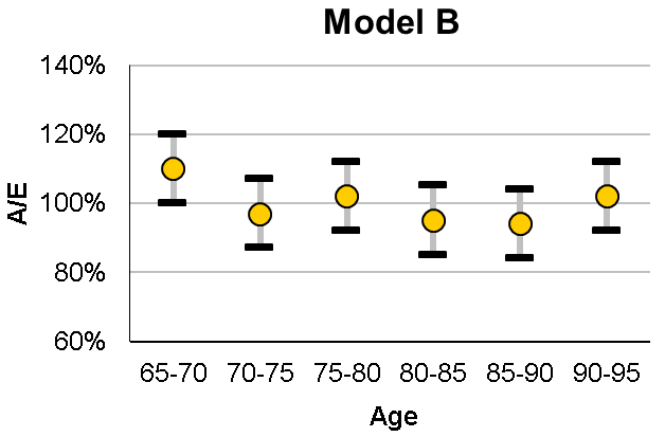

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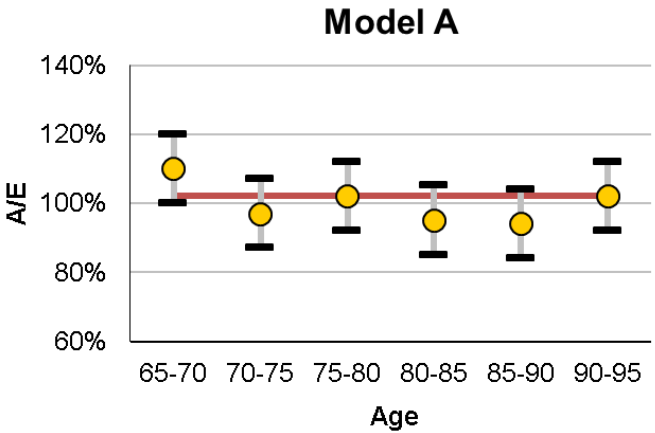

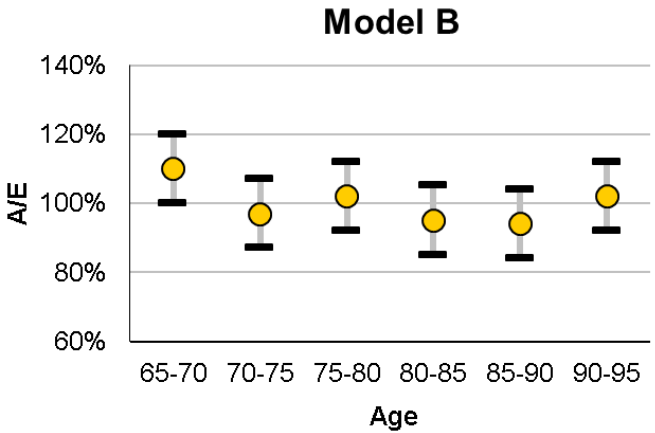

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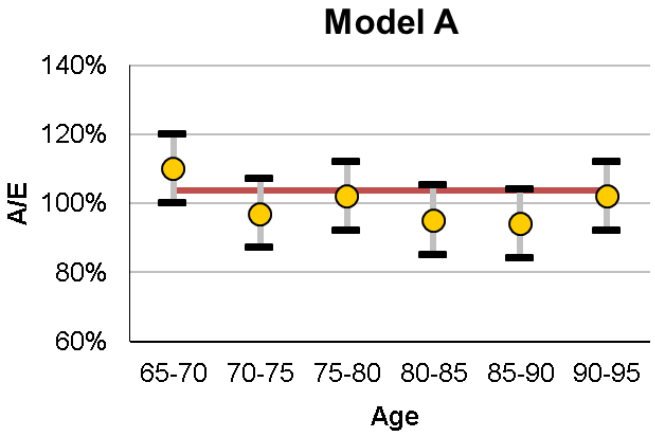

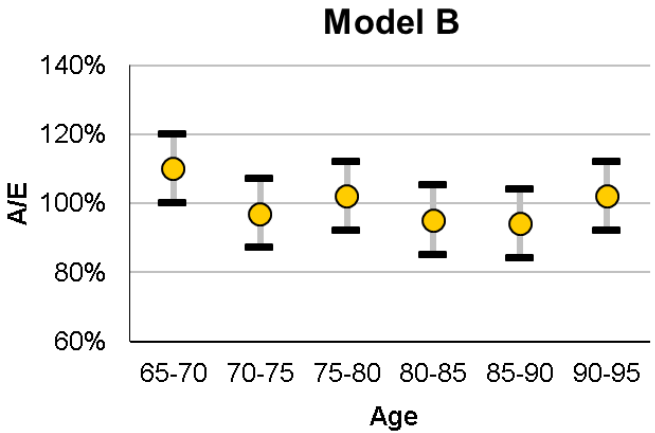

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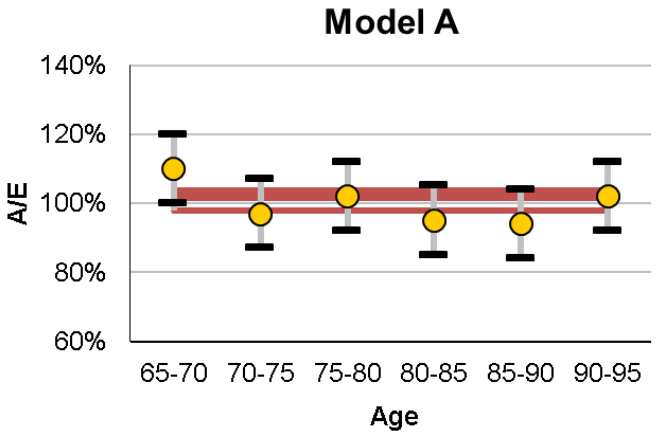

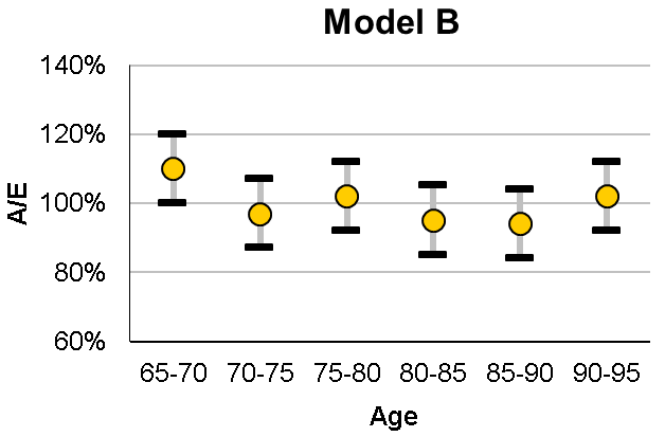

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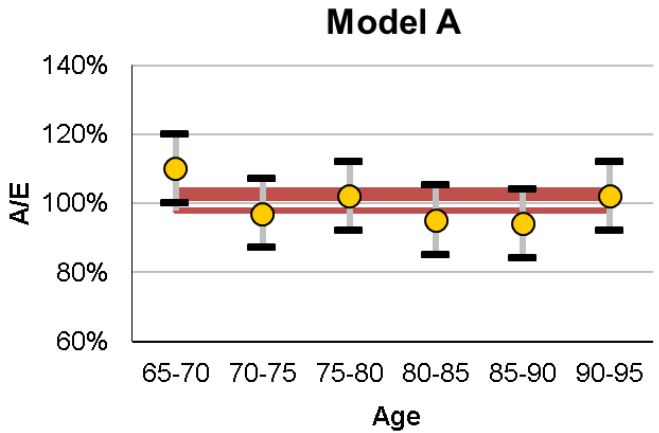

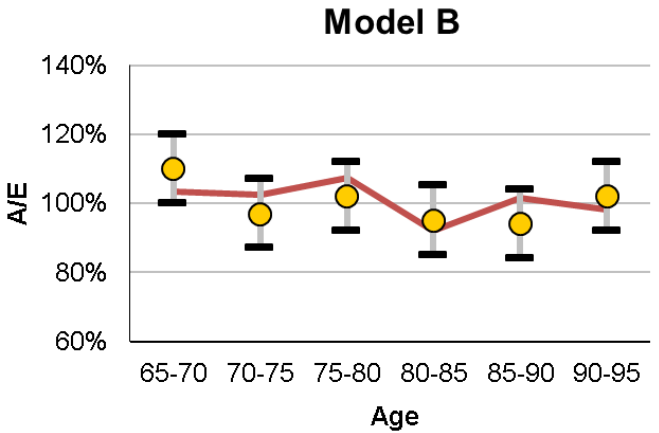

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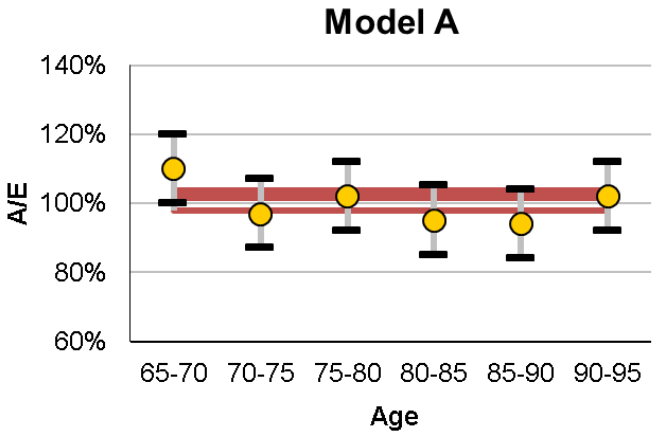

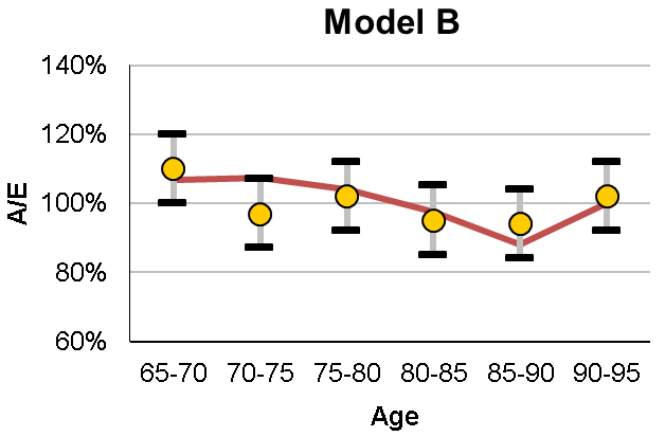

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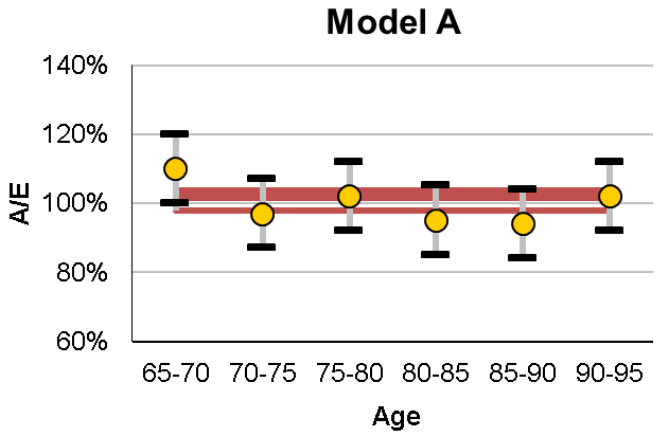

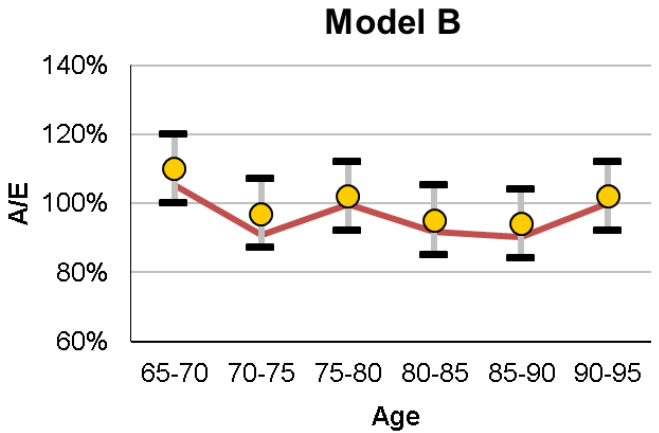

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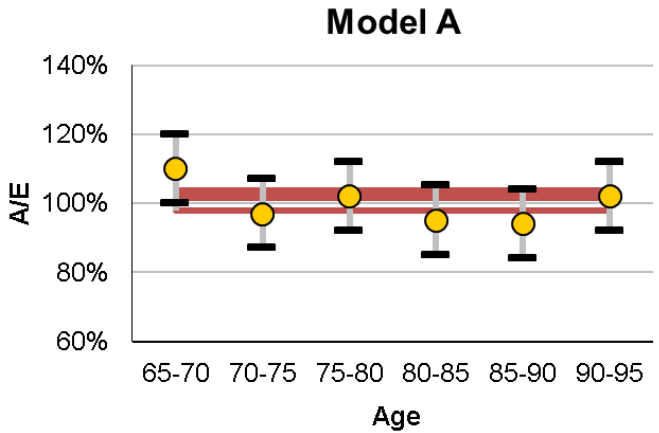

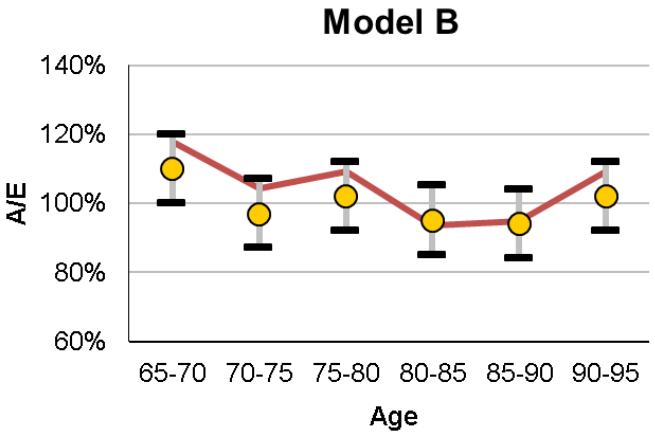

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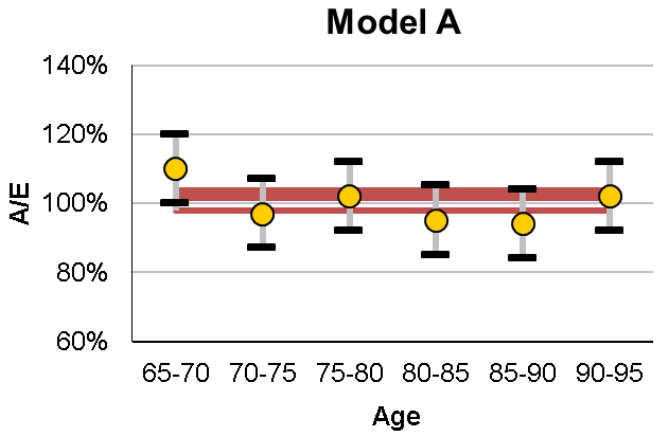

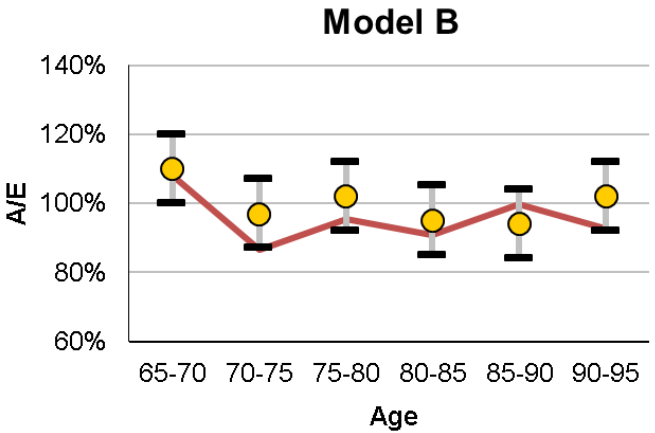

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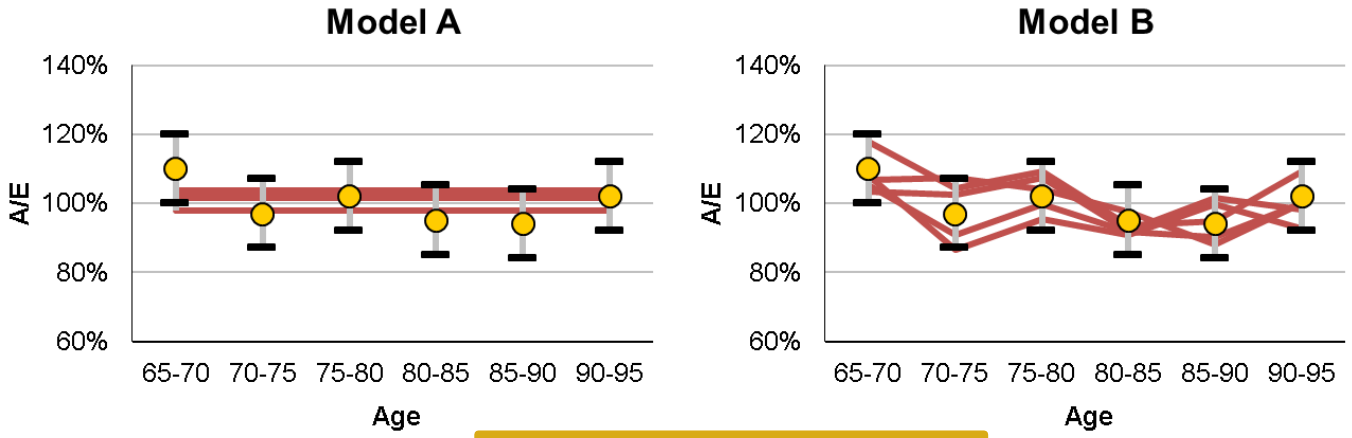
Model selection – information criteria

- Maximise log likelihood $LL = -E\omega + A\omega \log\mu$

Which is better?



Bias-variance tradeoff

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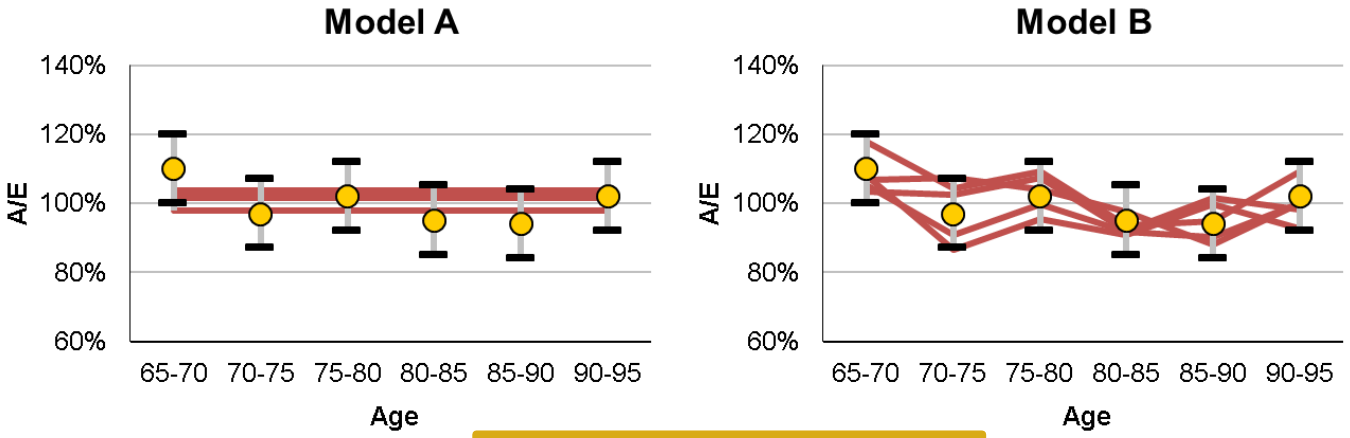
Model selection – information criteria

- Maximise *penalised* log likelihood $LLP = LL - Penalty$

Which is better?



Bias-variance tradeoff

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Model selection – information criteria

- What is ‘better’?
- AIC: *Out-of-sample predictivity*
- Aim to maximise: $\boldsymbol{E}_{X_1}\boldsymbol{E}_{X_2}(LL(X_2 \mid \hat{\beta}(X_1))$
- Leads to: $LLP = LL - k$

  where k is the no. of parameters
- Need to adjust for amounts-weighting and overdispersion
- Asymptotically equivalent to cross-validation…

  … BUT only if samples are unbiased!

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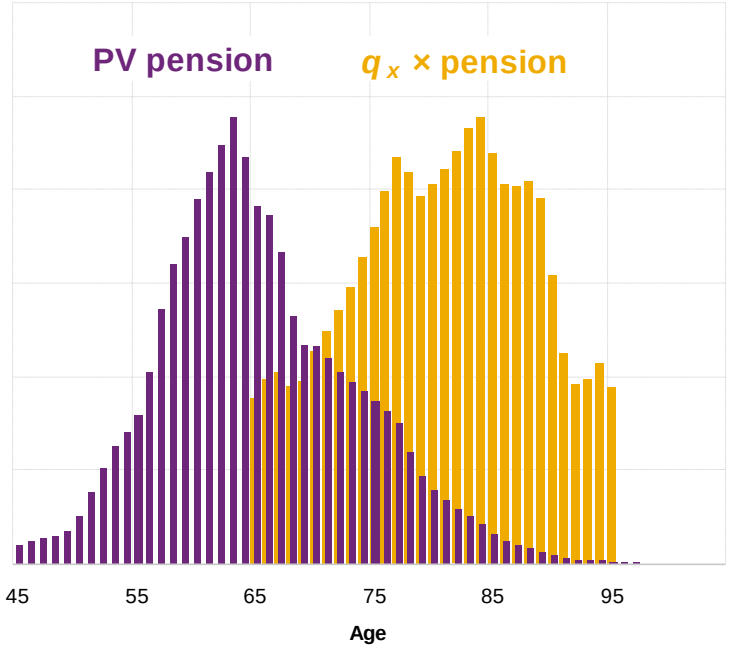
PV equivalence

- A/E scaling
  - implies a simplistic model
  - weights to the wrong population
- Better to
  - choose a sensible model
  - fit parameters:
    - point estimates
    - (co)variance
  - apply fitted model to give PV impact
- Can re-express as PV-equivalent q-scaling



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Example

- Candidate models for annuity portfolio
- LLP based on amounts-weighted AIC (overdispersion 3)

Fitting results for each model

Model	Penalised log likelihood (relative to best; Ω=3)	Log likelihood (relative to best; Ω=3)	Penalty	Number of covariates	Normalised penalised log likelihood (relative to best; Ω=3)	PV impact
Model A	−125,218	−178,968	42,788	2	−6.1	−0.12%
Model B	−135,554	−178,335	53,758	3	−6.6	−0.14%
Model C	−99,708	−153,360	42,886	2	−4.9	nil
Model D	−112,087	−153,107	55,519	3	−5.5	−0.03%
Model E	nil	nil	96,539	4	nil	+0.39%
Model F	−7,699	10,838	115,076	6	−0.4	+0.41%

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Practical implementation

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Key features

- Safe
- Flexible
- Efficient

- Need flexible type-safe object-oriented programming environment

- Object-oriented programming (OOP)
  - Class – object template
  - Fields, properties and methods

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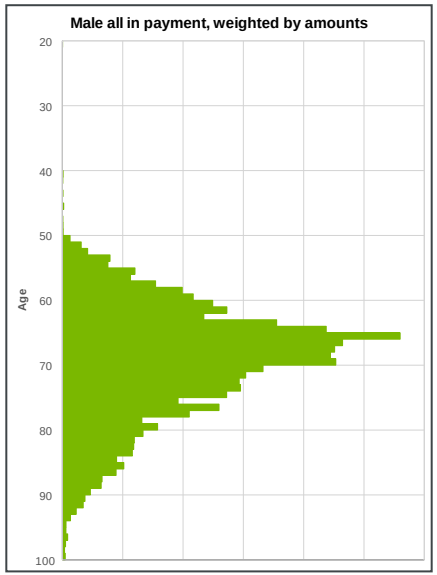
Simple example

Valuation data summary for male annuitants

Group	Total pension (£'000 p.a.)
15-25	54
25-35	0
35-45	25
45-55	2,145
55-65	20,164
65-75	26,341
75-85	19,889
85-95	6,373
95-105	343
Total	**75,347**




```
Member[] members = ReadMemberData(file);
double sumPension65_75 = 0.0;
double sumPension75_85 = 0.0;
foreach (var m in members)
{
   if (m.Age >= 65 && m.Age < 75)
   {
      if (m.Sex == "M") { sumPension65_75 += m.Pension; }
   }
   if (m.Age >= 75 && m.Age < 85)
   {
      if (m.Sex == "M") { sumPension75_85 += m.Pension; }
   }
}
```

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Safe

- DRY (Don’t Repeat Yourself)

```
Member[] members = ReadMemberData(file);
double sumPension65_75 = 0.0;
double sumPension75_85 = 0.0;
foreach (var m in members)
{
    if (m.Age >= 65 && m.Age < 75)
    {
        if (m.Sex == "M") { sumPension65_75 += m.Pension; }
    }
    if (m.Age >= 75 && m.Age < 85)
    {
        if (m.Sex == "M") { sumPension75_85 += m.Pension; }
    }
}
```

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Safe

- DRY (Don't Repeat Yourself)

```
Member[] members = ReadMemberData(file);
int ageStart = 65;
int ageStep = 10;
int groupCount = 2;
var sumByGroup = new double[groupCount];
foreach (var m in members)
{
   int ageLow = ageStart;
   for (int i = 0; i < groupCount ; ++i)
   {
      if (m.Age >= ageLow && m.Age < ageLow + ageStep)
      {
         if (m.Sex == "M") { sumByGroup[i] += m.Pension; }
      }
      ageLow += ageStep;
   }
}
```

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Safe

- DRY (Don’t Repeat Yourself)
- Type safety

```
Member[] members = ReadMemberData(file);
int ageStart = 65;
int ageStep = 10;
int groupCount = 2;
var sumByGroup = new double[groupCount];
foreach (var m in members)
{
   int ageLow = ageStart;
   for (int i = 0; i < groupCount ; ++i)
   {
      if (m.Age >= ageLow && m.Age < ageLow + ageStep)
      {
         if (m.Sex == "M") { sumByGroup[i] += m.Pension; }
      }
      ageLow += ageStep;
   }
}
```

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Safe

- DRY (Don't Repeat Yourself)
- Type safety

```
Member[] members = ReadMemberData(file);
int ageStart = 65;
int ageStep = 10;
int groupCount = 2;
var sumByGroup = new double[groupCount];
foreach (var m in members)
{
   int ageLow = ageStart;
   for (int i = 0; i < groupCount ; ++i)
   {
      if (m.Age >= ageLow && m.Age < ageLow + ageStep)
      {
         if (m.Sex == Sex.Male) { sumByGroup[i] += m.Pension; }
      }
      ageLow += ageStep;
   }
}
```

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Safe

- DRY (Don’t Repeat Yourself)
- Type safety
- Time safety

```
Member[] members = ReadMemberData(file);
int ageStart = 65;
int ageStep = 10;
int groupCount = 2;
var sumByGroup = new double[groupCount];
foreach (var m in members)
{
   int ageLow = ageStart;
   for (int i = 0; i < groupCount ; ++i)
   {
      if (m.Age >= ageLow && m.Age < ageLow + ageStep)
      {
         if (m.Sex == Sex.Male) { sumByGroup[i] += m.Pension; }
      }
      ageLow += ageStep;
   }
}
```

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Safe

- DRY (Don't Repeat Yourself)
- Type safety
- Time safety

```
Member[] members = ReadMemberData(file);
var asAtDate = Time.BeginDay(2016, 12, 1);
var ageStart = TimeDiff.FromYears(65);
var ageStep = TimeDiff.FromYears(10);
int groupCount = 2;
var sumByGroup = new double[groupCount];
foreach (var m in members)
{
   var ageLow = ageStart;
   for (int i = 0; i < groupCount; ++i)
   {
      var age = asAtDate - m.BirthDate;
      if (age >= ageLow && age < ageLow + ageStep)
      {
         if (m.Sex == Sex.Male) { sumByGroup[i] += m.Pension; }
      }
      ageLow += ageStep;
   }
}
```

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Safe

- DRY (Don't Repeat Yourself)
- Type safety
- Time safety
- Immutability

```
Member[] members = ReadMemberData(file);
var asAtDate = Time.BeginDay(2016, 12, 1);
var ageStart = TimeDiff.FromYears(65);
var ageStep = TimeDiff.FromYears(10);
int groupCount = 2;
var sumByGroup = new double[groupCount];
foreach (var m in members)
{
   var ageLow = ageStart;
   for (int i = 0; i < groupCount; ++i)
   {
      var age = asAtDate - m.BirthDate;
      if (age >= ageLow && age < ageLow + ageStep)
      {
         if (m.Sex == Sex.Male) { sumByGroup[i] += m.Pension; }
      }
      ageLow += ageStep;
   }
}
```

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Safe

- DRY (Don't Repeat Yourself)
- Type safety
- Time safety
- Immutability

```
MemberData memberData = ReadMemberData(file);
var asAtDate = Time.BeginDay(2016, 12, 1);
var ageStart = TimeDiff.FromYears(65);
var ageStep = TimeDiff.FromYears(10);
int groupCount = 2;
var sumByGroup = new double[groupCount];
foreach (var m in memberData)
{
   var ageLow = ageStart;
   for (int i = 0; i < groupCount; ++i)
   {
      var age = asAtDate - m.BirthDate;
      if (age >= ageLow && age < ageLow + ageStep)
      {
         if (m.Sex == Sex.Male) { sumByGroup[i] += m.Pension; }
      }
      ageLow += ageStep;
   }
}
```

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Flexible

- Modular programming

```
MemberData memberData = ReadMemberData(file);
var asAtDate = Time.BeginDay(2016, 12, 1);
var ageStart = TimeDiff.FromYears(65);
var ageStep = TimeDiff.FromYears(10);
int groupCount = 2;
var sumByGroup = new double[groupCount];
foreach (var m in memberData)
{
   var ageLow = ageStart;
   for (int i = 0; i < groupCount; ++i)
   {
      var age = asAtDate - m.BirthDate;
      if (age >= ageLow && age < ageLow + ageStep)
      {
         if (m.Sex == Sex.Male) { sumByGroup[i] += m.Pension; }
      }
      ageLow += ageStep;
   }
}
```

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Flexible

- Modular programming

```
MemberData memberData = ReadMemberData(file);
var asAtDate = Time.BeginDay(2016, 12, 1);
var ageStart = TimeDiff.FromYears(65);
var ageStep = TimeDiff.FromYears(10);
int groupCount = 2;
Document.AddPenTable(memberData, asAtDate, Sex.Male,
    ageStart, ageStep, groupCount);
```

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Flexible

- Modular programming

```
MemberData memberData = ReadMemberData(file);
var asAtDate = Time.BeginDay(2016, 12, 1);
var ageStart = TimeDiff.FromYears(65);
var ageStep = TimeDiff.FromYears(10);
int groupCount = 2;
Document.AddPenTable(memberData, asAtDate, Sex.Male,
    ageStart, ageStep, groupCount);
```

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Flexible

- Modular programming

```
MemberData memberData = ReadMemberData(file);
var asAtDate = Time.BeginDay(2016, 12, 1);
var ageStart = TimeDiff.FromYears(65);
var ageStep = TimeDiff.FromYears(10);
int groupCount = 2;
Document.AddTable(memberData, asAtDate, Sex.Male,
    ageStart, ageStep, groupCount, m => m.Pension);
```

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Flexible

- Modular programming

```
MemberData memberData = ReadMemberData(file);
var asAtDate = Time.BeginDay(2016, 12, 1);
var ageStart = TimeDiff.FromYears(65);
var ageStep = TimeDiff.FromYears(10);
int groupCount = 2;
Document.AddTable(memberData, asAtDate, Sex.Male,
    ageStart, ageStep, groupCount, m => 1.0);
```

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Flexible

- Modular programming

```
MemberData memberData = ReadMemberData(file);
var asAtDate = Time.BeginDay(2016, 12, 1);
var ageStart = TimeDiff.FromYears(65);
var ageStep = TimeDiff.FromYears(10);
int groupCount = 2;
foreach (var sex in new[] { Sex.Male, Sex.Female })
{
    foreach (var weight in weights)
    {
        Document.AddTable(memberData, asAtDate, sex,
            ageStart, ageStep, groupCount, weight);
    }
}
```

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Flexible

- Modular programming
- Alternative file formats

```
MemberData memberData = ReadMemberData(file);
var asAtDate = Time.BeginDay(2016, 12, 1);
var ageStart = TimeDiff.FromYears(65);
var ageStep = TimeDiff.FromYears(10);
int groupCount = 2;
foreach (var sex in new[] { Sex.Male, Sex.Female })
{
   foreach (var weight in weights)
   {
      Document.AddTable(memberData, asAtDate, sex,
         ageStart, ageStep, groupCount, weight);
   }
}
```

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Flexible

- Modular programming
- Alternative file formats

```
MemberData memberData = ReadMemberData(file, Format.Xlsx);
var asAtDate = Time.BeginDay(2016, 12, 1);
var ageStart = TimeDiff.FromYears(65);
var ageStep = TimeDiff.FromYears(10);
int groupCount = 2;
foreach (var sex in new[] { Sex.Male, Sex.Female })
{
   foreach (var weight in weights)
   {
      Document.AddTable(memberData, asAtDate, sex,
         ageStart, ageStep, groupCount, weight);
   }
}
```

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Flexible

- Modular programming
- Alternative file formats

```
MemberData memberData = ReadMemberData(file, Format.Accdb);
var asAtDate = Time.BeginDay(2016, 12, 1);
var ageStart = TimeDiff.FromYears(65);
var ageStep = TimeDiff.FromYears(10);
int groupCount = 2;
foreach (var sex in new[] { Sex.Male, Sex.Female })
{
   foreach (var weight in weights)
   {
      Document.AddTable(memberData, asAtDate, sex,
         ageStart, ageStep, groupCount, weight);
   }
}
```

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Flexible

- Modular programming
- Alternative file formats

```
MemberData memberData = ReadMemberData(file, Format.Txt);
var asAtDate = Time.BeginDay(2016, 12, 1);
var ageStart = TimeDiff.FromYears(65);
var ageStep = TimeDiff.FromYears(10);
int groupCount = 2;
foreach (var sex in new[] { Sex.Male, Sex.Female })
{
   foreach (var weight in weights)
   {
      Document.AddTable(memberData, asAtDate, sex,
         ageStart, ageStep, groupCount, weight);
   }
}
```

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Flexible

- Modular programming
- Alternative file formats

```
MemberData memberData = ReadMemberData(file, Format.Csv);
var asAtDate = Time.BeginDay(2016, 12, 1);
var ageStart = TimeDiff.FromYears(65);
var ageStep = TimeDiff.FromYears(10);
int groupCount = 2;
foreach (var sex in new[] { Sex.Male, Sex.Female })
{
   foreach (var weight in weights)
   {
      Document.AddTable(memberData, asAtDate, sex,
         ageStart, ageStep, groupCount, weight);
   }
}
```

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Efficient

- Data compression
- Parallel processing

```
MemberData memberData = ReadMemberData(file, Format.Csv);
var asAtDate = Time.BeginDay(2016, 12, 1);
var ageStart = TimeDiff.FromYears(65);
var ageStep = TimeDiff.FromYears(10);
int groupCount = 2;
foreach (var sex in new[] { Sex.Male, Sex.Female })
{
   foreach (var weight in weights)
   {
      Document.AddTable(memberData, asAtDate, sex,
         ageStart, ageStep, groupCount, weight);
   }
}
```

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Efficient

- Data compression
- Parallel processing

```
MemberData memberData = ReadMemberData(file, Format.Csv);
var asAtDate = Time.BeginDay(2016, 12, 1);
var ageStart = TimeDiff.FromYears(65);
var ageStep = TimeDiff.FromYears(10);
int groupCount = 2;
foreach (var sex in new[] { Sex.Male, Sex.Female })
{
    Parallel.For(0, weights.Length, i =>
    {
        var weight = weights[i];
        Document.AddTable(memberData, asAtDate, sex
            , ageStart, ageStep, groupCount, weight);
    });
}
```

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Efficient

- Data compression
- Parallel processing

```
MemberData memberData = ReadMemberData(file, Format.Csv);
var asAtDate = Time.BeginDay(2016, 12, 1);
var ageStart = TimeDiff.FromYears(65);
var ageStep = TimeDiff.FromYears(10);
int groupCount = 2;
foreach (var sex in new[] { Sex.Male, Sex.Female })
{
    Parallel.For(0, weights.Length, i =>
    {
        var weight = weights[i];
        Document.AddTable(memberData, asAtDate, sex
            , ageStart, ageStep, groupCount, weight);
    });
}
```

Institute and Faculty of Actuaries

Efficient

- Data compression
- Parallel processing

```
MemberData memberData = ReadMemberData(file, Format.Csv);
var asAtDate = Time.BeginDay(2016, 12, 1);
var ageStart = TimeDiff.FromYears(65);
var ageStep = TimeDiff.FromYears(10);
int groupCount = 2;
foreach (var sex in new[] { Sex.Male, Sex.Female })
{
   var tables = new Table[weights.Length];
   Parallel.For(0, weights.Length, i =>
   {
      var weight = weights[i];
      tables[i] = CreateTable(memberData, asAtDate, sex
         , ageStart, ageStep, groupCount, weight);
   });
   for (int i = 0; i < weights.Length; ++i)
   {
      Document.Add(tables[i]);
   }
}
```

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Recap

22 November 2016

Recap

- Background
- Modelling challenges
- Modelling solutions
- Practical implementation

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Questions

Comments

Expressions of individual views by members of the Institute and Faculty of Actuaries and its staff are encouraged.

The views expressed in this presentation are those of the presenter.

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