Institute and Faculty of Actuaries

Modelling mortality by cause of death and socio-economic stratification: an analysis of mortality differentials in England

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Birmingham, September 16th 2014

Agenda

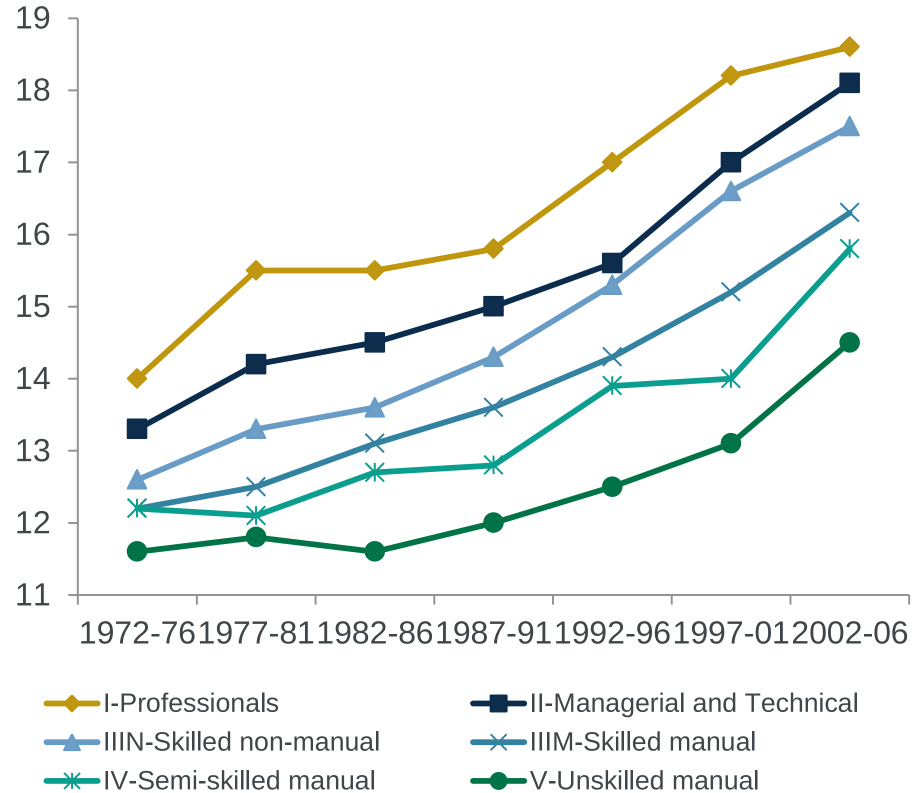
- Motivation
- Modelling mortality by cause of death (CoD)
- Modelling mortality by CoD and socio-economic stratification
- Case study: Mortality by deprivation in England
- Conclusions

Motivation

Socio-economic differences in mortality

- Well-documented relationship between mortality and socioeconomic variables
  - Education
  - Income
  - Occupation
  - Deprivation

Male life expectancy at age 65 by social class -England and Wales



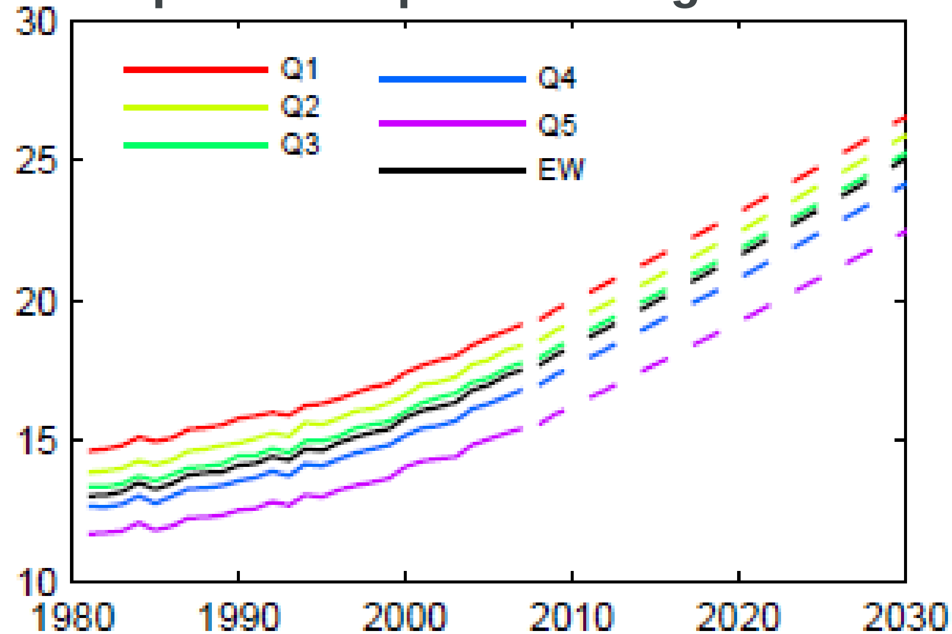
Source: ONS Longitudinal Study

Motivation

Socio-economic differences in mortality

- Well-documented relationship between mortality and socioeconomic variables
  - Education
  - Income
  - Occupation
  - Deprivation

Male life expectancy at age 65 by deprivation quintile - England

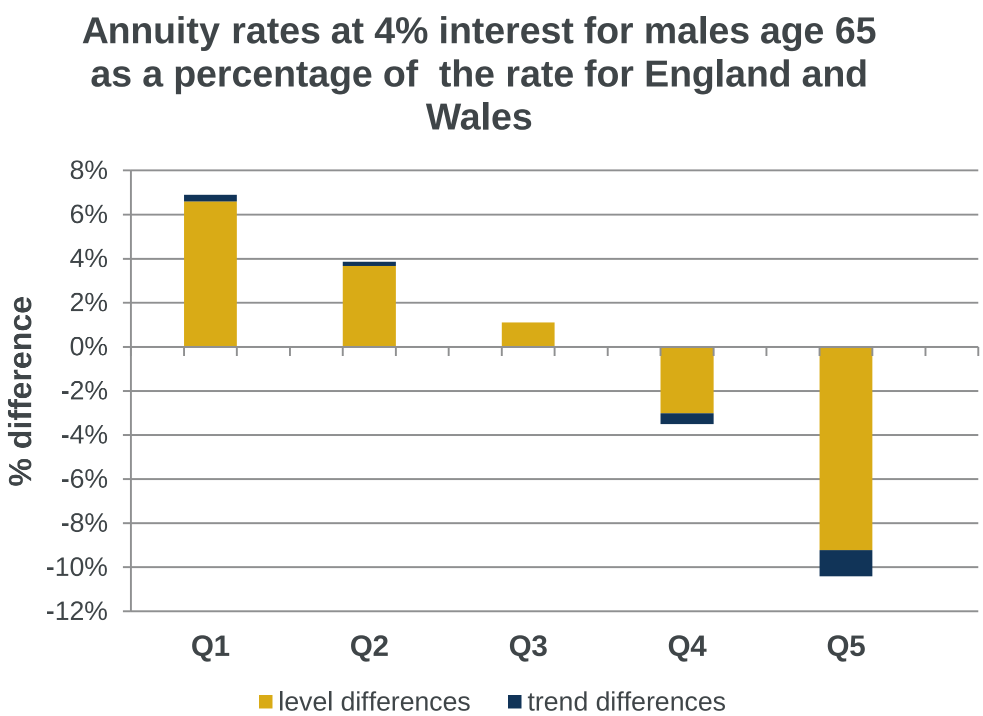


Source: Villegas and Haberman (2014)

Motivation

Socio-economic differences in mortality

- Important implications on social and financial planning
  - Public policy for tackling inequalities
  - Social security design
  - Annuity reserving and pricing
  - Longevity risk management



Source: Villegas and Haberman (2014)

Motivation
Cause-specific mortality

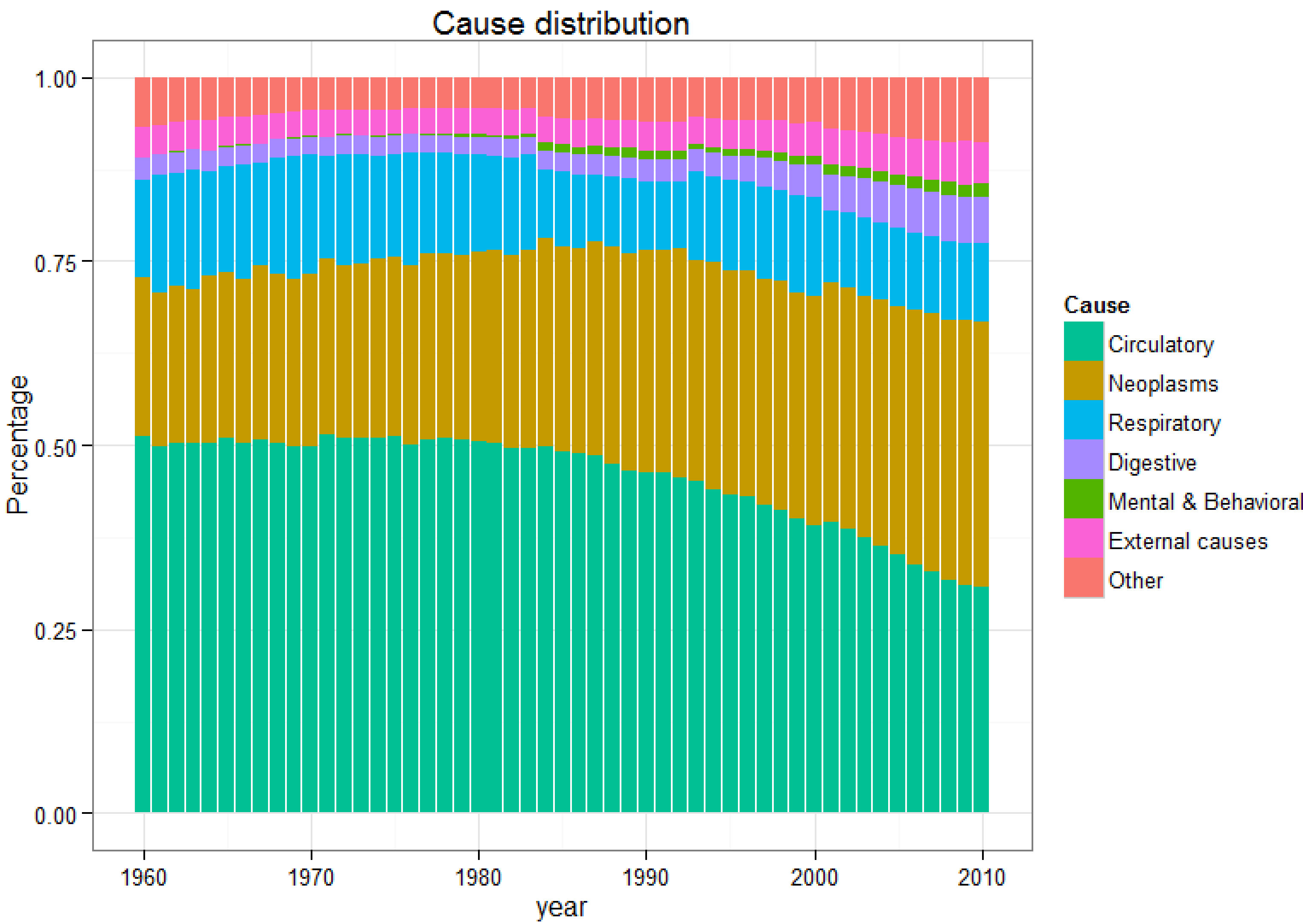
- Inform the assumptions underlying overall mortality projections

- Shed light on the drivers of
  - Mortality change
  - Mortality differentials

- Forecasts of cause-specific mortality required for many purposes
  - E.g Estimation of health care needs and costs

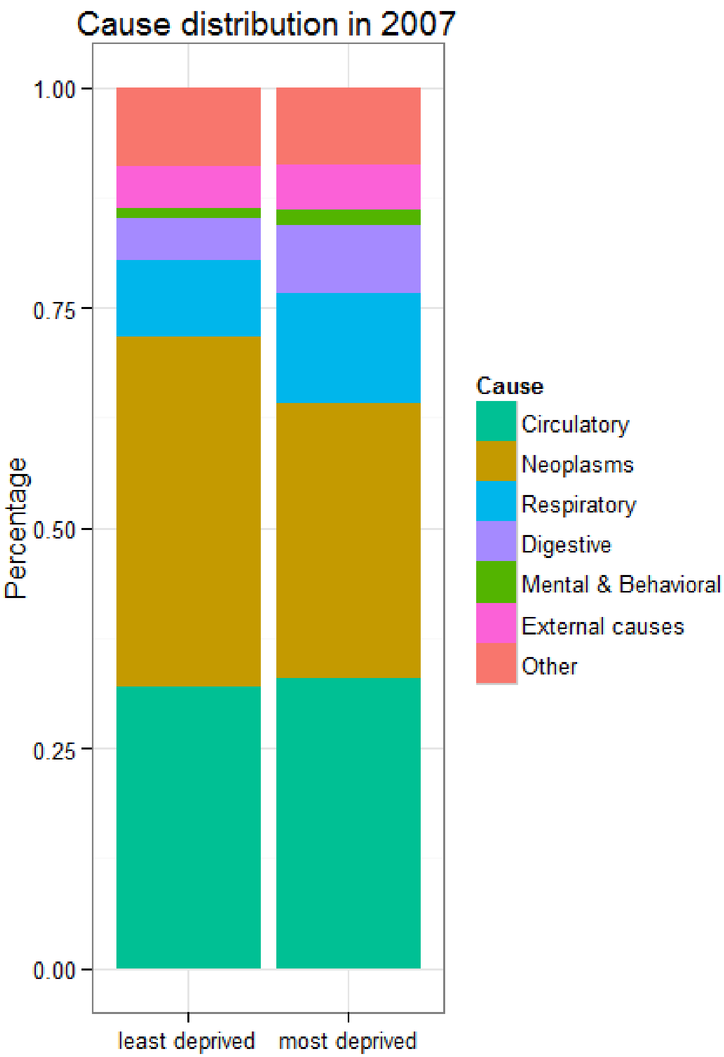
Causes of mortality in England and Wales

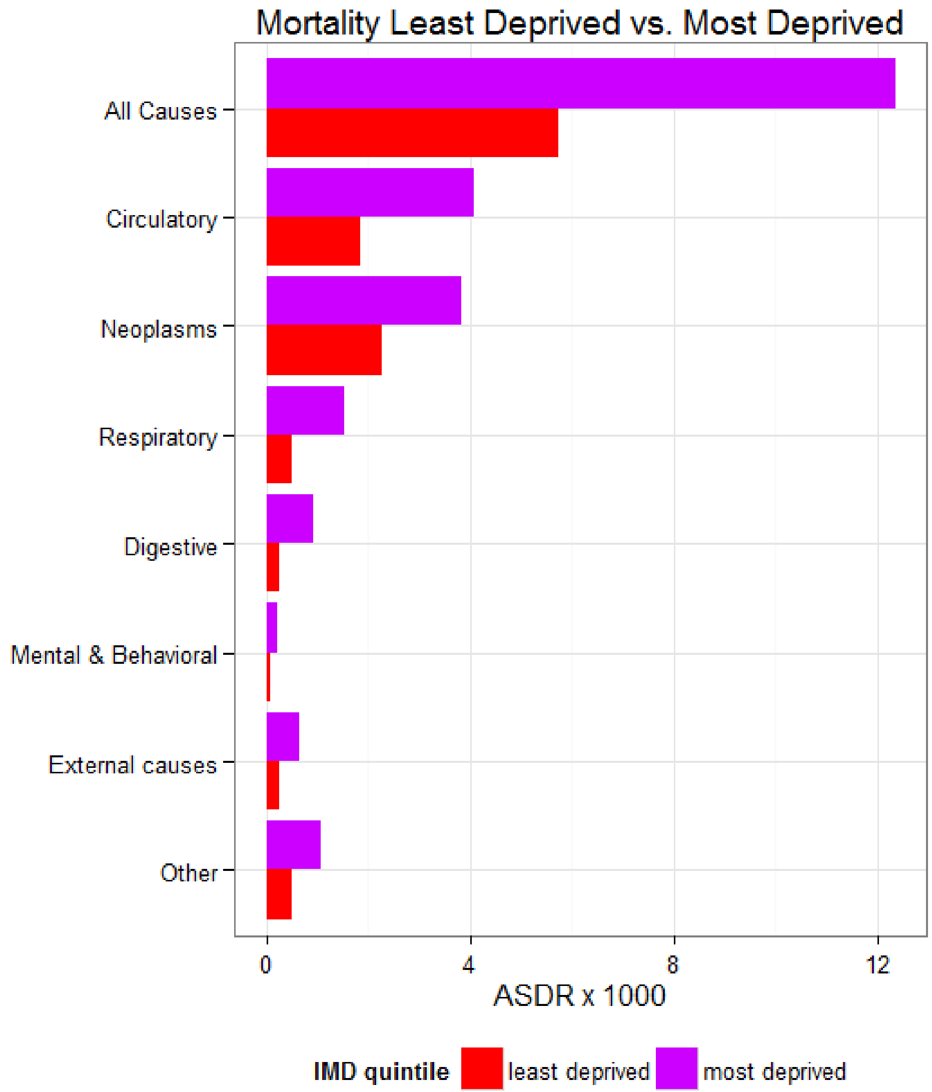
Causes distribution in time (ASDR males age 25-84)



Causes of mortality in England

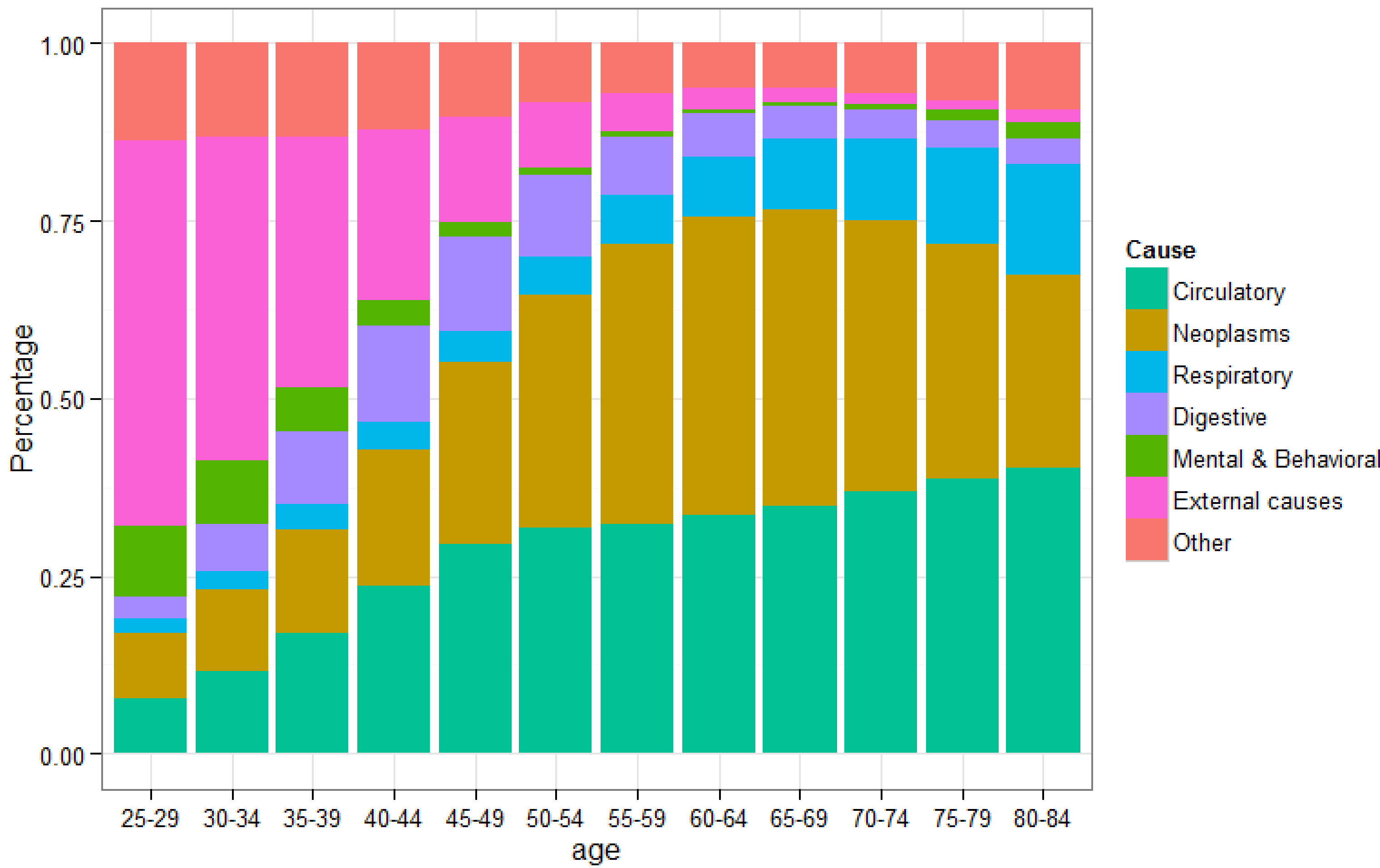
Variation by deprivation quintile (ASDR males age 25-84)





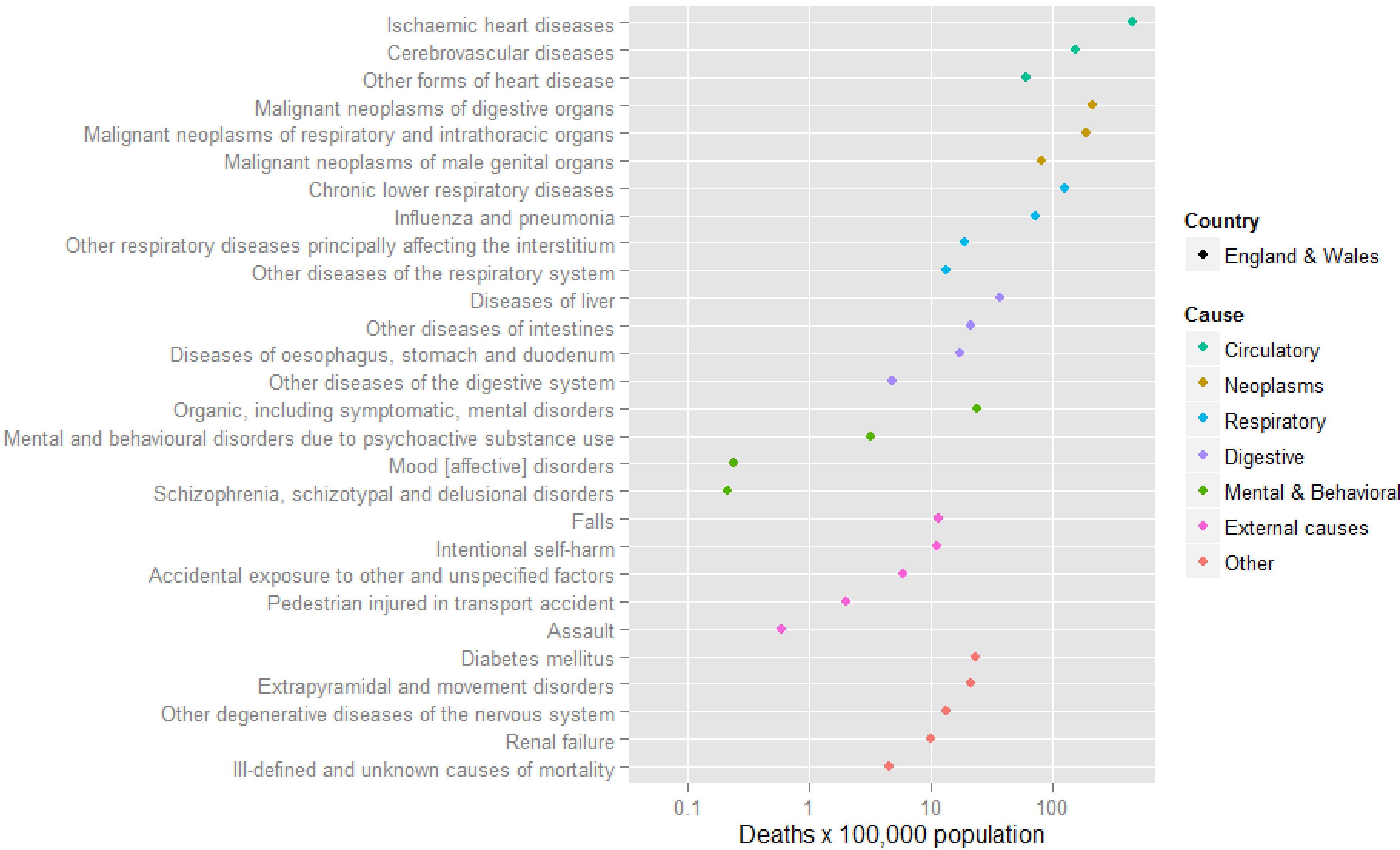
Causes of mortality in England and Wales

Causes distribution by age (males 2001-2010)



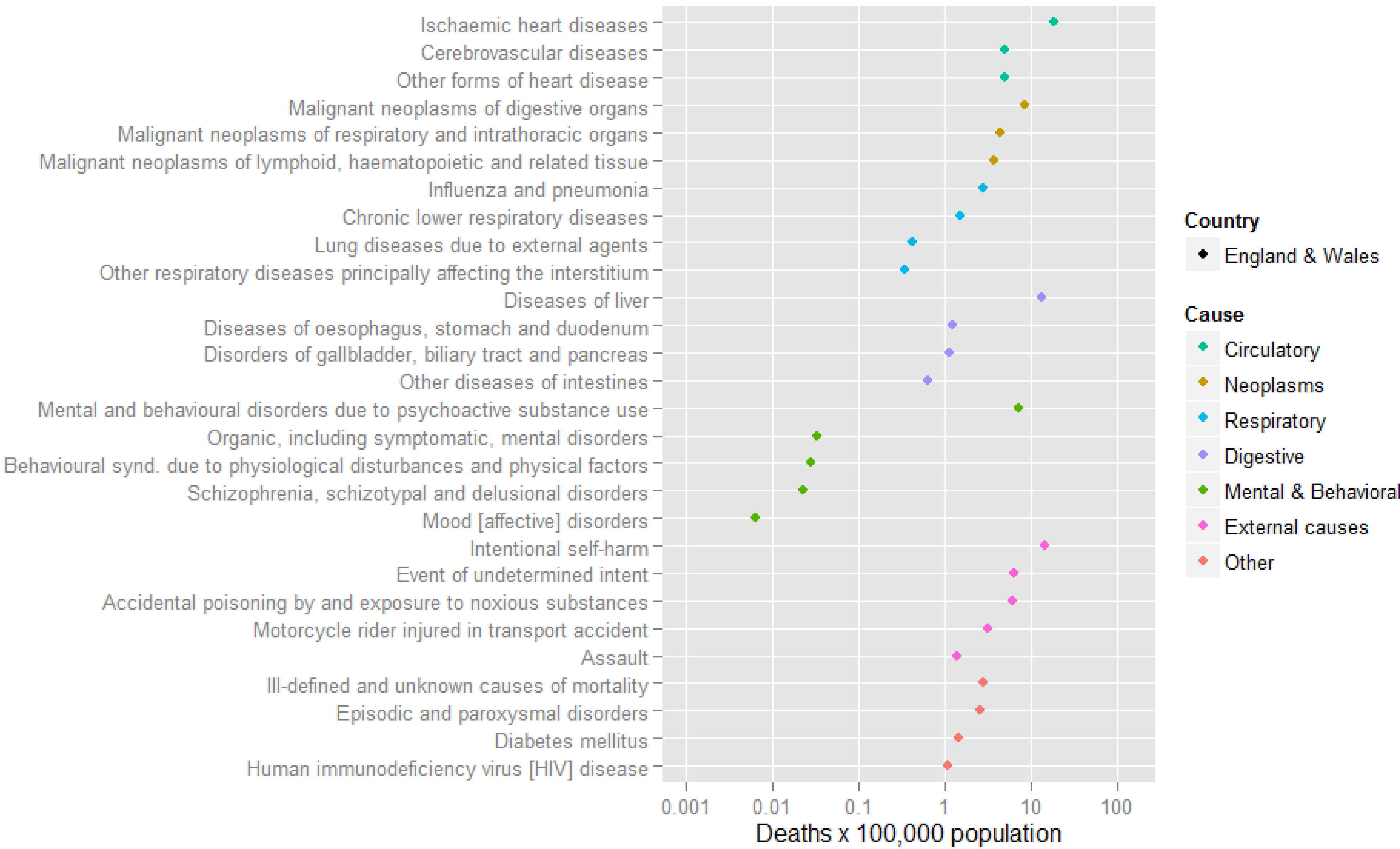
Causes of mortality in England and Wales

Main causes for males aged 50-84 (2001-2010)



Causes of mortality in England and Wales

Main causes for males aged 25-49 (2001-2010)



Modelling mortality by cause of death

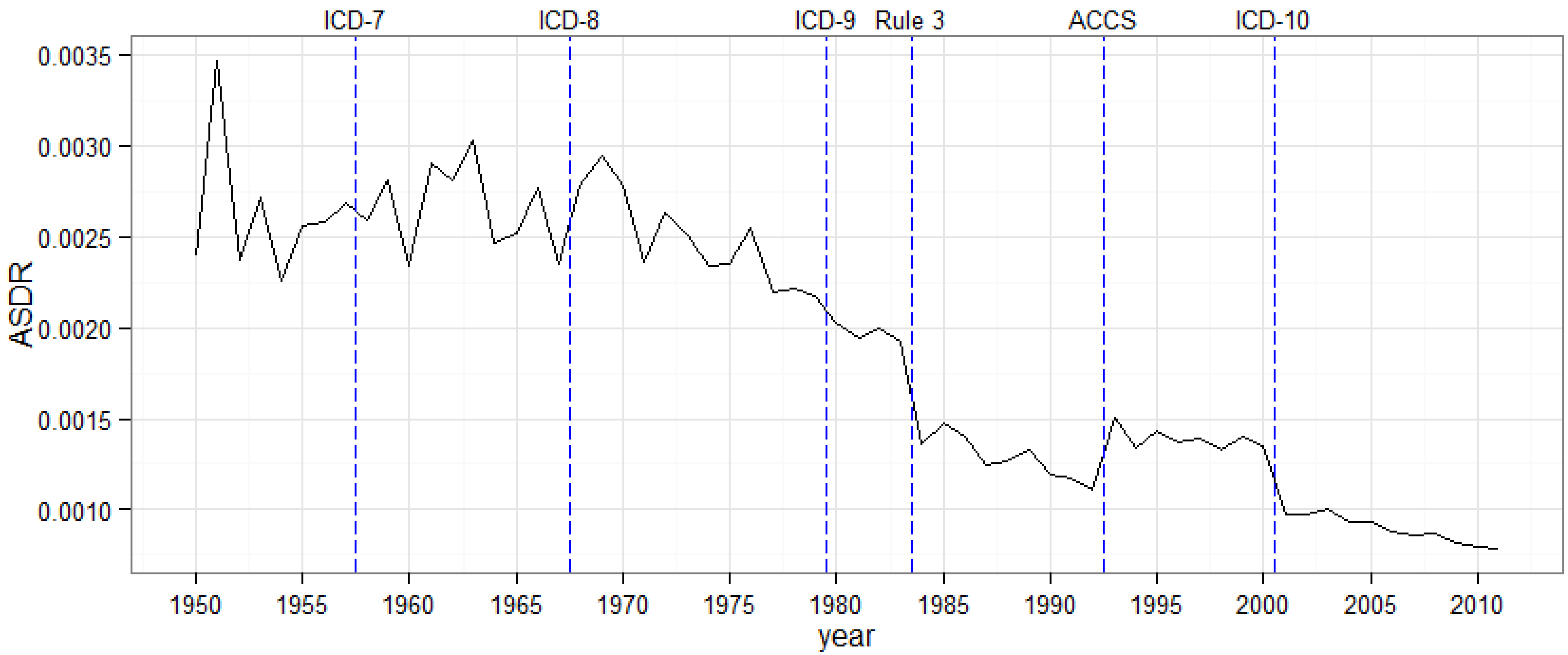
Challenges

- Correlation between causes
  - Same risk factor can affect several causes (e.g. smoking and some cancers and heart diseases)
  - Reduction in the relative importance of one cause can lead to further improvements on other causes
- Increase in dimensionality induced by the disaggregation
  - The same modelling methods might not be appropriate for all causes
  - Major empirical exercise
- Changes in classification of causes of death difficult the analysis of trends

Modelling mortality by cause of death

Cause of death coding changes

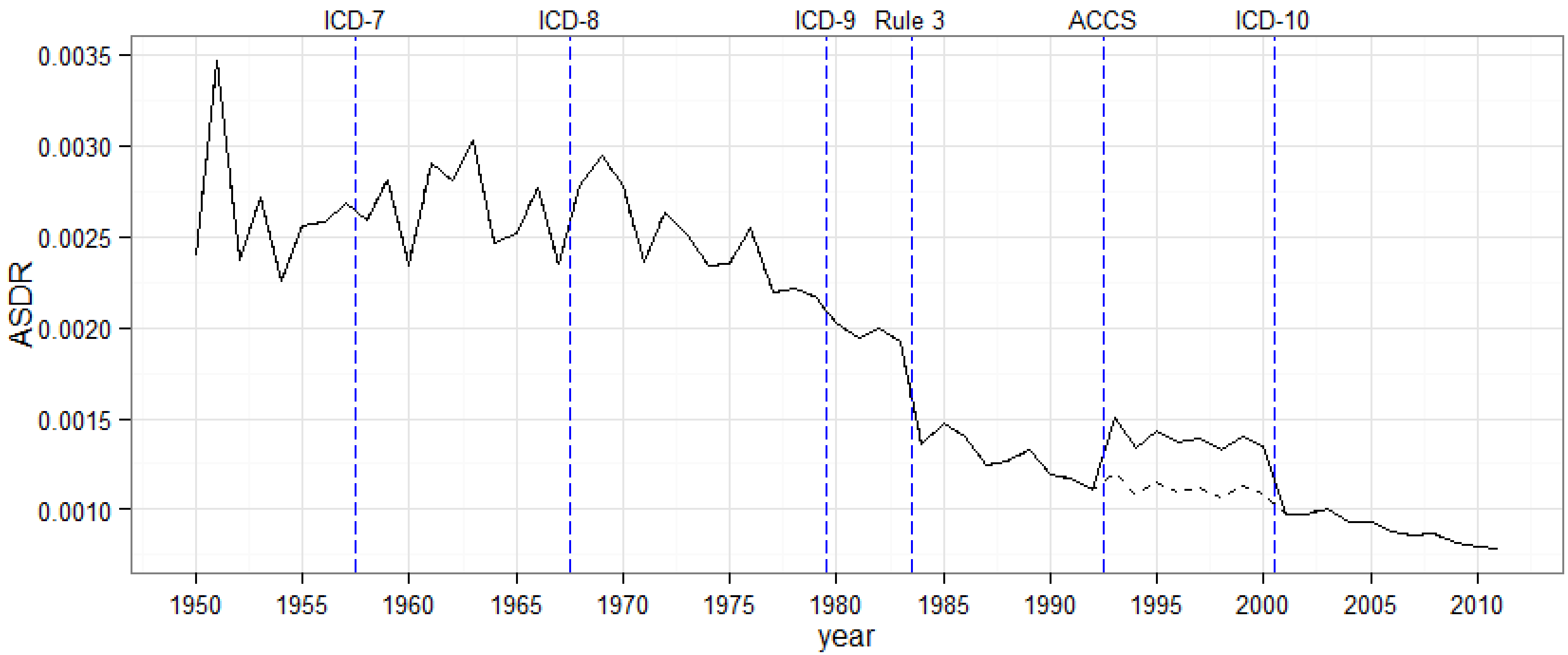
Age-standardised mortality rate for respiratory diseases (Male age 25-84 – England and Wales)



Modelling mortality by cause of death

Cause of death coding changes

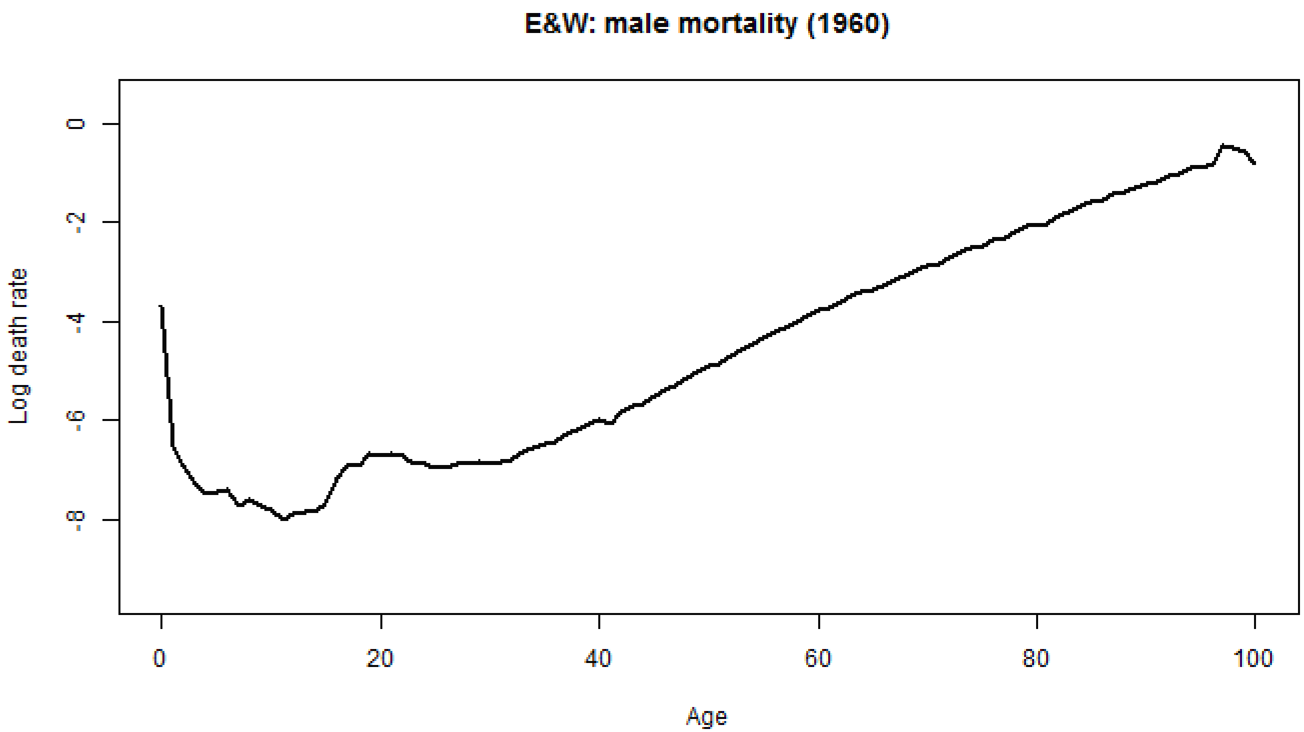
Age-standardised mortality rate for respiratory diseases (Male age 25-84 – England and Wales)



- Adjustment methods
  - Bridge coding and comparability ratios (e.g. ONS for ICD-9 to ICD10)
  - Statistical correction methods (e.g. Rey et al (2009), Park et al (2006))

Modelling mortality

Lee-Carter model



Modelling mortality
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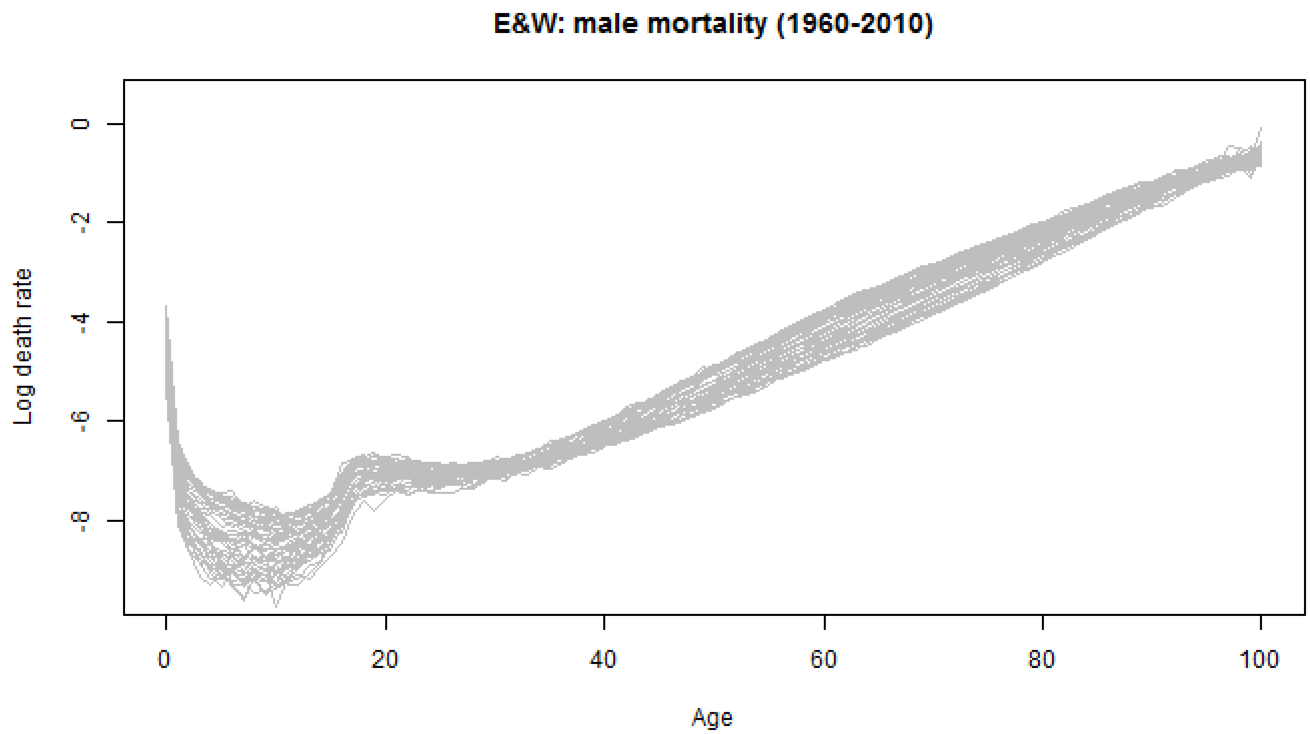
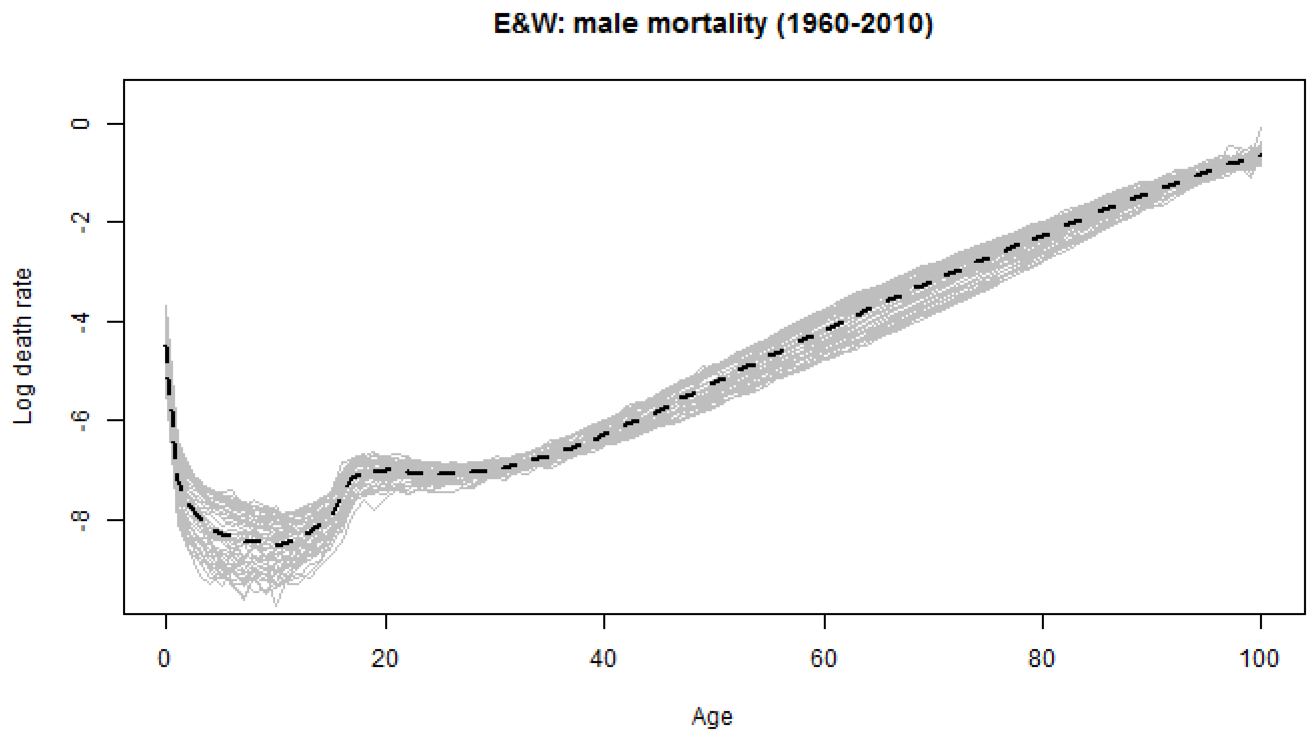


$$\log \mu_{xt} \quad =$$

Modelling mortality

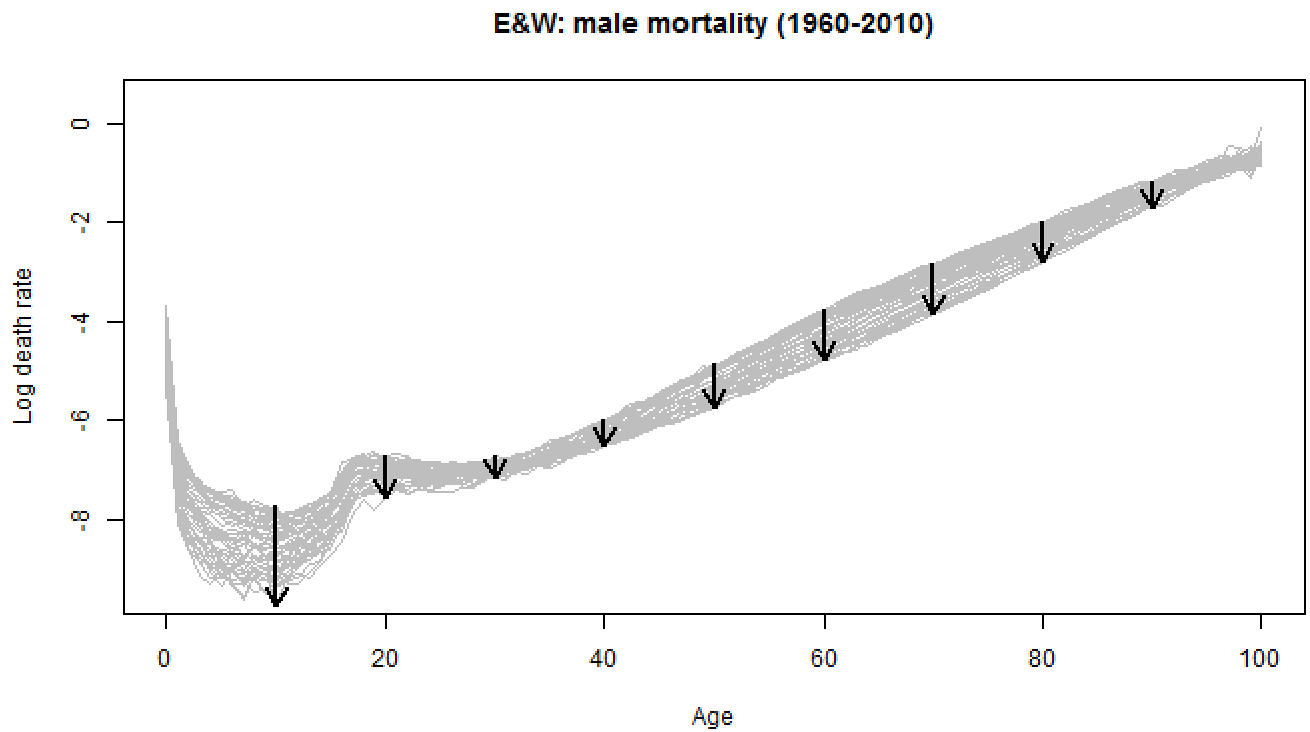
Lee-Carter model



$$\log \mu_{xt} = \alpha_x$$

Modelling mortality

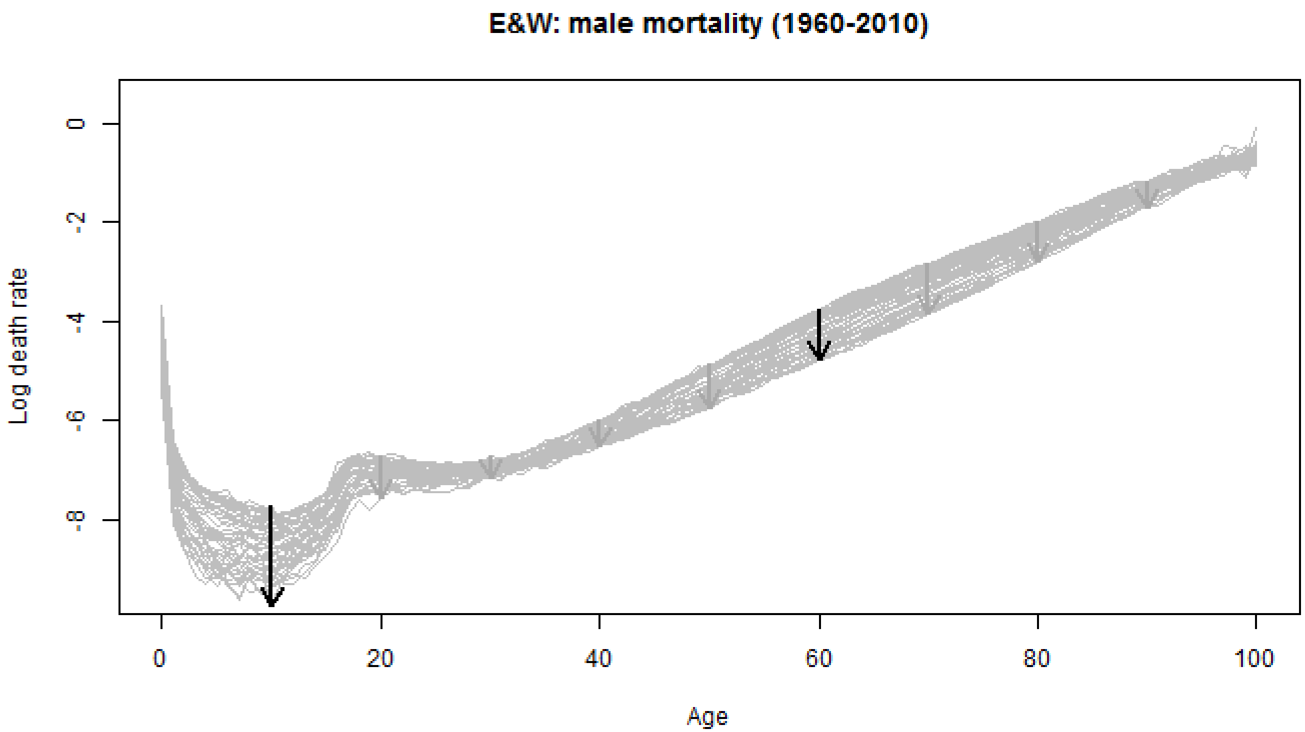
Lee-Carter model



$$\log \mu_{xt} = \alpha_x + \kappa_t$$

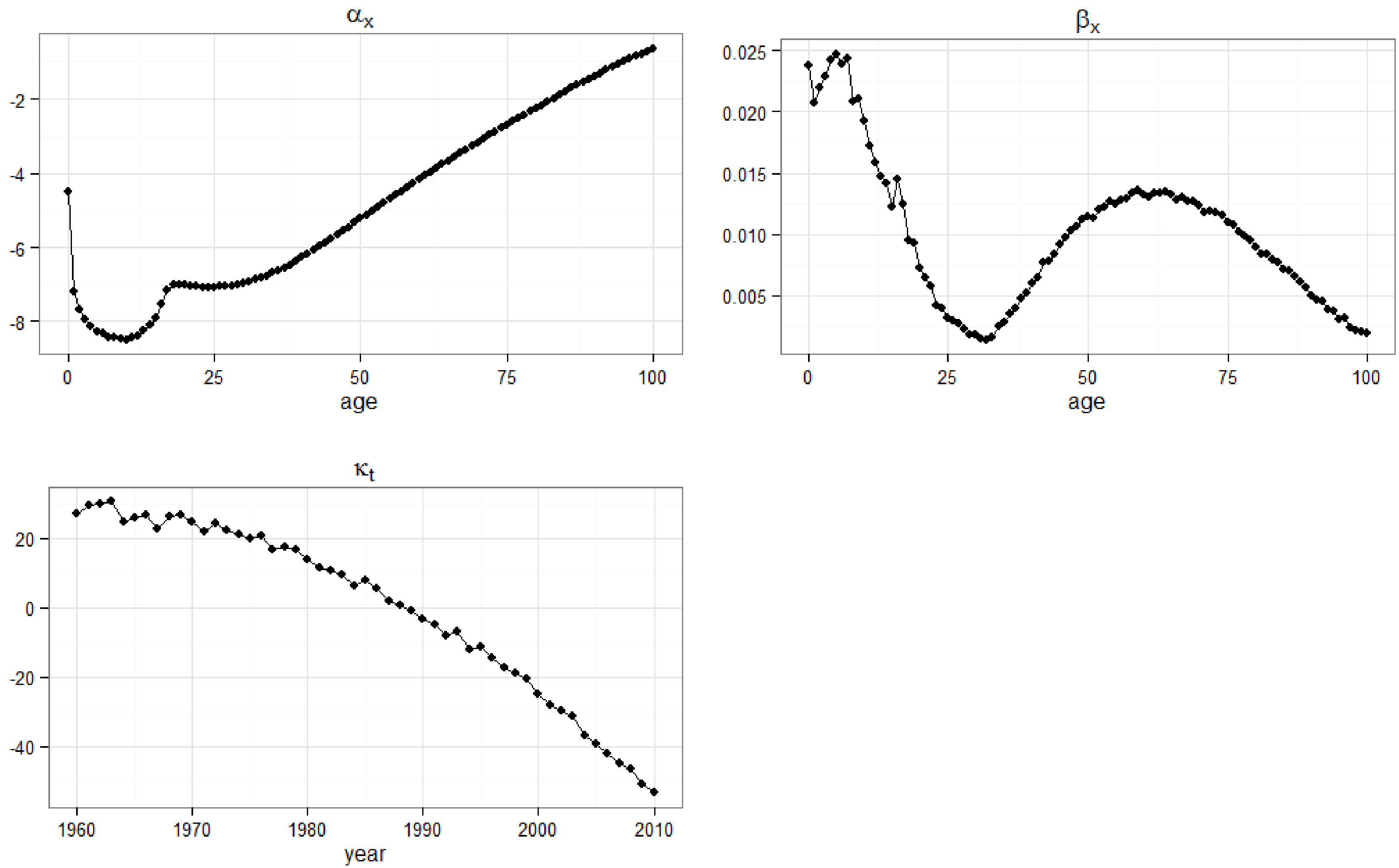
Modelling mortality

Lee-Carter model



$$\log \mu_{xt} = \alpha_x + \beta_x \kappa_t$$

Modelling mortality
Lee-Carter model



Modelling mortality by cause of death

Lee-Carter model with coding changes

$$\log \mu_{xt} = \alpha_x + \beta_x \kappa_t$$

Modelling mortality by cause of death

Lee-Carter model with coding changes

$$\log \mu_{xt} = \alpha_x + \beta_x \kappa_t$$

Age-specific mortality pattern

Age-modulating parameters

Overall time trend of mortality

Modelling mortality by cause of death

Lee-Carter model with coding changes

$$\log \mu_{xt} = \alpha_x + \beta_x \kappa_t$$

Age-specific mortality pattern

Age-modulating parameters

Overall time trend of mortality

Modelling mortality by cause of death

Lee-Carter model with coding changes

$$\log \mu_{xt} = \alpha_x + \beta_x \kappa_t + \sum_{i=1}^{h} \delta_x^{(i)} f^{(i)}(t)$$

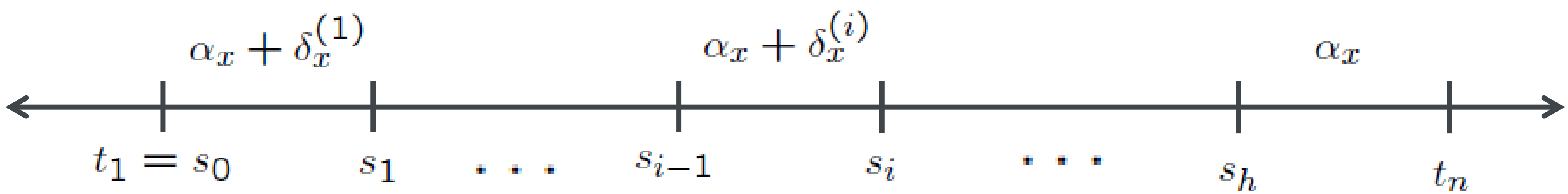
Age-specific mortality pattern

Age-modulating parameters

Overall time trend of mortality

Adjustment for coding changes

$$f^{(i)}(t) = \mathcal{I}_{\{s_{i-1} \leq t < s_i\}}$$



Modelling mortality by cause of death

Lee-Carter model with coding changes – Invariant transformations

$$\log \mu_{xt} = \alpha_x + \beta_x \kappa_t + \sum_{i=1}^{h} \delta_x^{(i)} f^{(i)}(t)$$

This specification is invariant to the following parameter transformations

Standard Lee-Carter transformations

$$\{\tilde{\alpha}_x, \tilde{\kappa}_t\} = \{\alpha_x + b_1 \beta_x, \kappa_t - b_1\}$$

$$\left\{\tilde{\beta}_x, \tilde{\kappa}_t\right\} = \left\{\frac{1}{b_2}\beta_x, b_2 \kappa_t\right\}$$

Modelling mortality by cause of death

Lee-Carter model with coding changes – Invariant transformations

$$\log \mu_{xt} = \alpha_x + \beta_x \kappa_t + \sum_{i=1}^{h} \delta_x^{(i)} f^{(i)}(t)$$

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Standard Lee-Carter transformations
$\{\tilde{\alpha}_x, \tilde{\kappa}_t\} = \{\alpha_x + b_1\beta_x, \kappa_t - b_1\}$ $\left\{\tilde{\beta}_x, \tilde{\kappa}_t\right\} = \left\{\frac{1}{b_2}\beta_x, b_2\kappa_t\right\}$
New transformations
$\left\{\tilde{\delta}_x^{(i)}, \tilde{\kappa}_t\right\} = \left\{\delta_x^{(i)} + a_i\beta_x, \kappa_t - a_i f^{(i)}(t)\right\} \quad i = 1, \ldots, h$

Modelling mortality by cause of death

Lee-Carter model with coding changes – Identifiability constraints

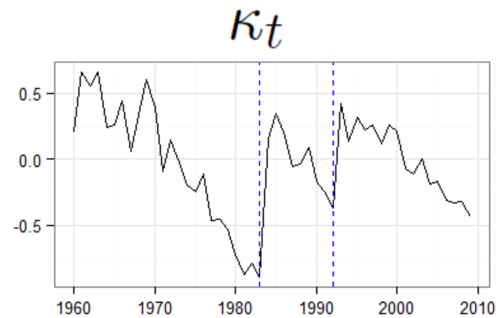
Standard Lee-Carter

Make the last year in the data the reference
$\{\tilde{\alpha}_x, \tilde{\kappa}_t\} = \{\alpha_x + b_1\beta_x, \kappa_t - b_1\} \longrightarrow \kappa_{t_n} = 0$
Normalise the age gradient
$\{\tilde{\beta}_x, \tilde{\kappa}_t\} = \left\{\frac{1}{b_2}\beta_x, b_2\kappa_t\right\} \longrightarrow \sum_x \beta_x = 1$

Modelling mortality by cause of death

Lee-Carter model with coding changes – Identifiability constraints

$$\left\{\tilde{\delta}_x^{(i)}, \tilde{\kappa}_t\right\} = \left\{\delta_x^{(i)} + a_i\beta_x, \kappa_t - a_i f^{(i)}(t)\right\}$$

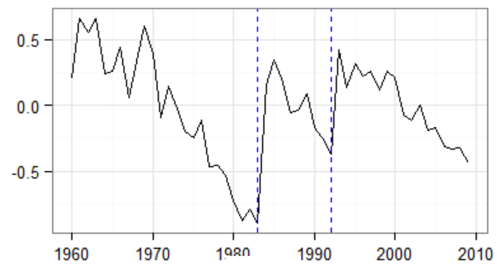


Modelling mortality by cause of death

Lee-Carter model with coding changes – Identifiability constraints

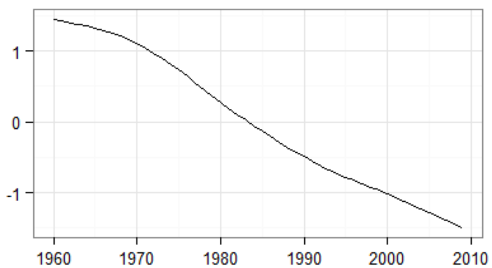
$$\left\{\tilde{\delta}_x^{(i)}, \tilde{\kappa}_t\right\} = \left\{\delta_x^{(i)} + a_i\beta_x, \kappa_t - a_i f^{(i)}(t)\right\}$$

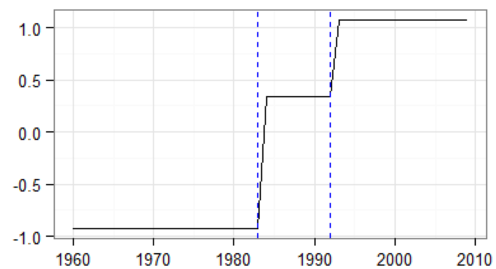
$$\kappa_t$$

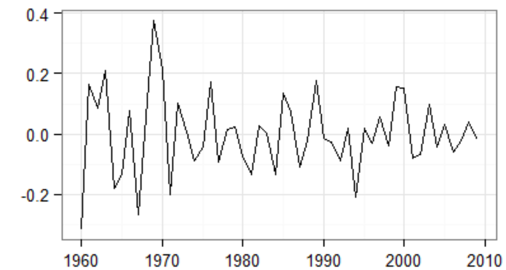


$$=$$

$$g(t) \quad + \quad \sum_{i=1}^{h} a_i f^{(i)}(t) \quad + \quad \epsilon_t$$





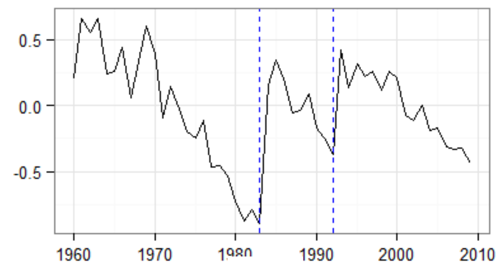


Modelling mortality by cause of death

Lee-Carter model with coding changes – Identifiability constraints

$$\left\{\tilde{\delta}_x^{(i)}, \tilde{\kappa}_t\right\} = \left\{\delta_x^{(i)} + a_i\beta_x, \kappa_t - a_i f^{(i)}(t)\right\}$$

κ_t



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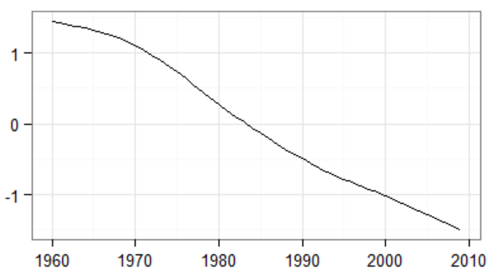
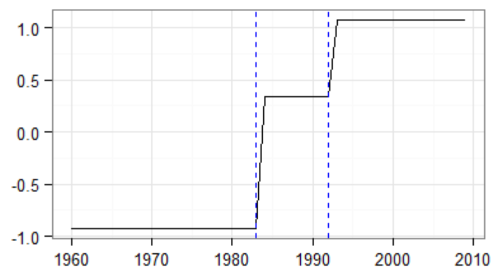
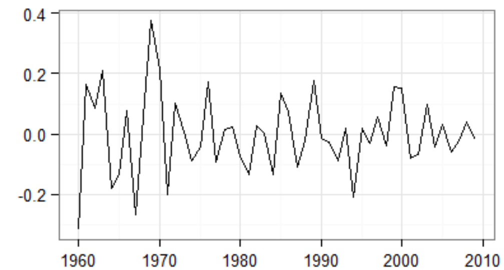
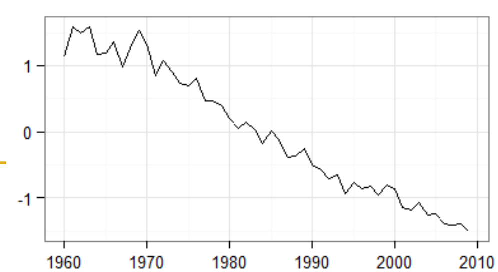




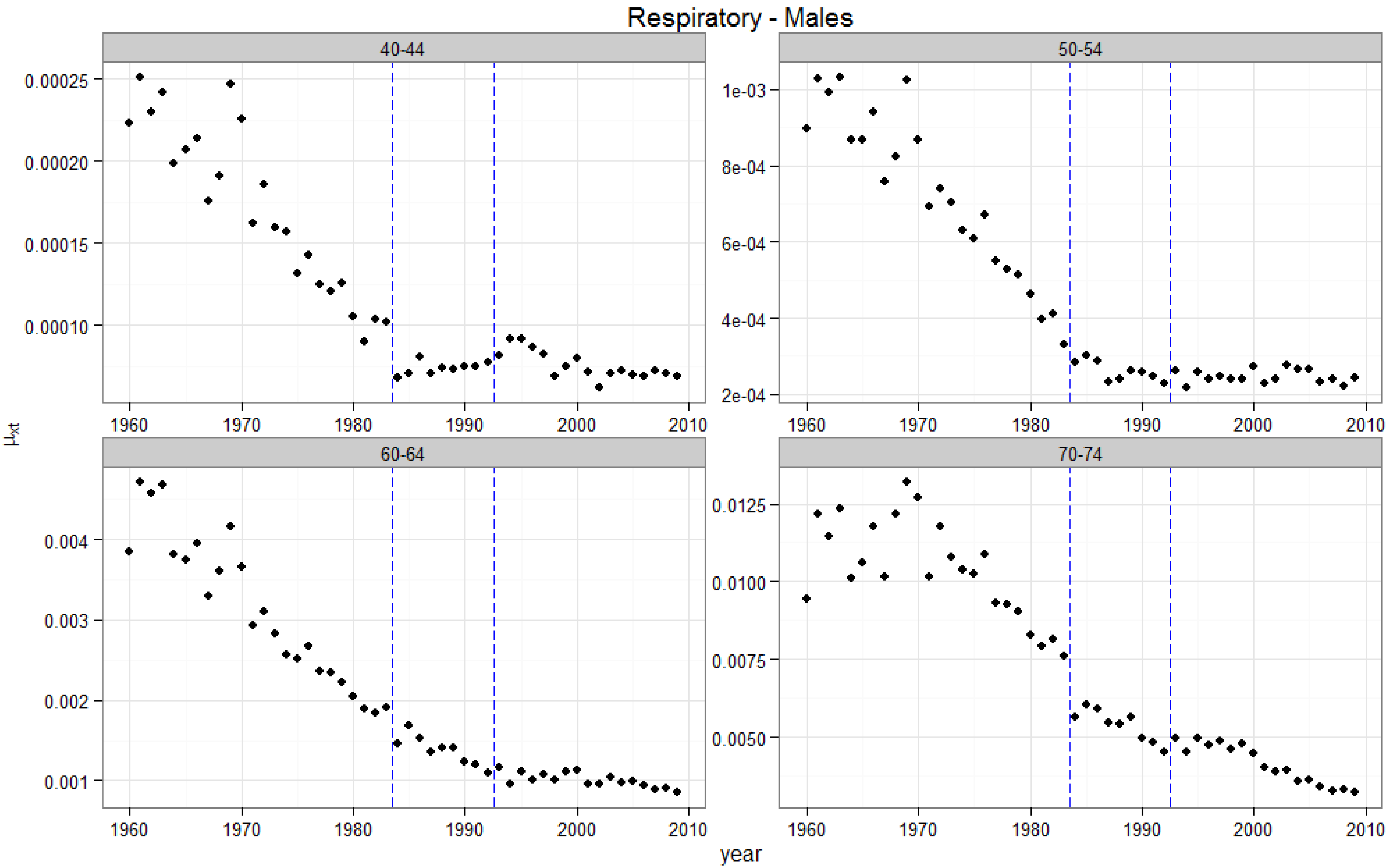


$$g(t) + \epsilon_t = \tilde{\kappa}_t = \kappa_t - \sum_{i=1}^{h} a_i f^{(i)}(t)$$



Modelling mortality by cause of death

Lee-Carter model with coding changes – Example



Modelling mortality by cause of death

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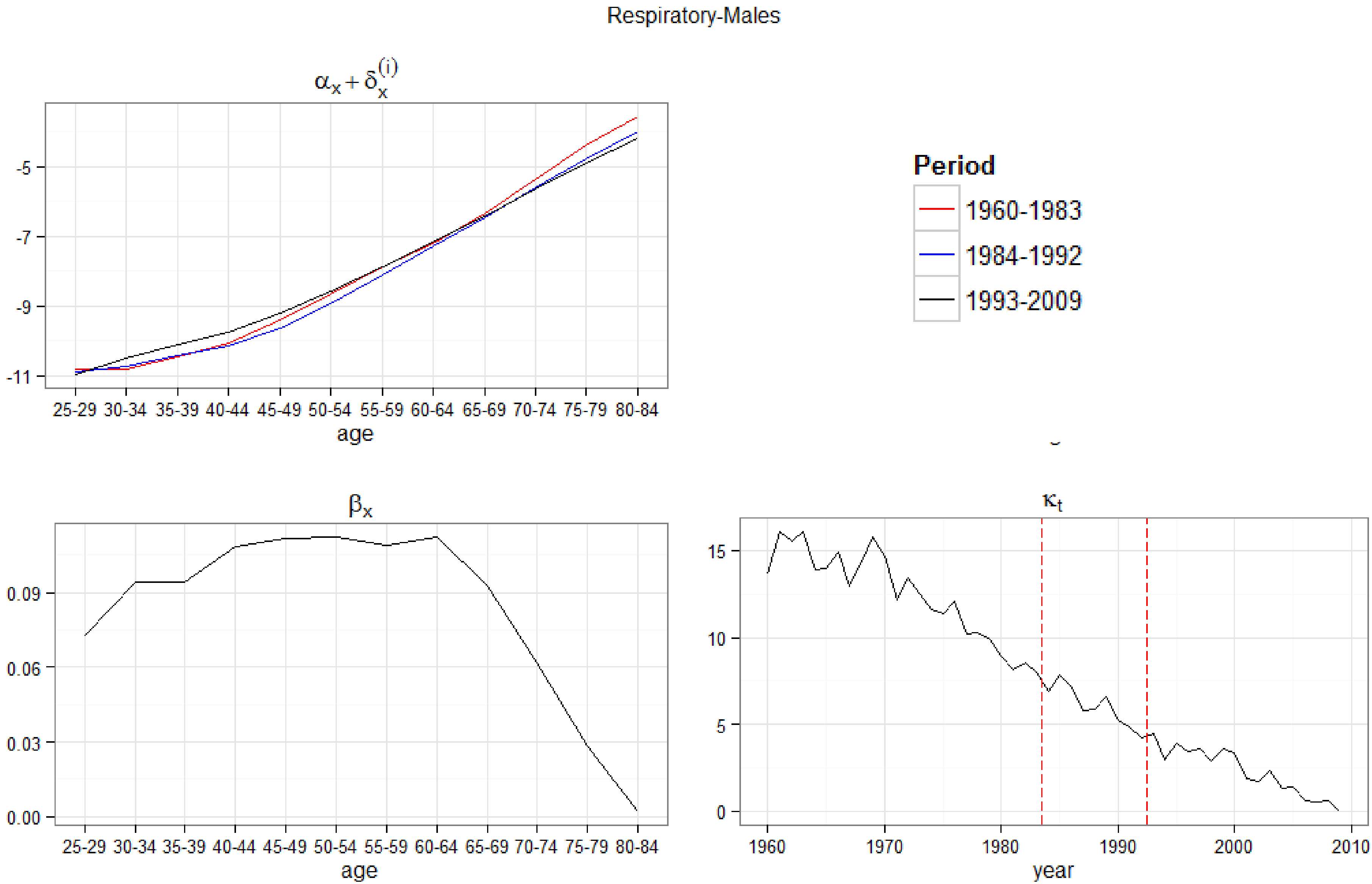

Modelling mortality by cause of death

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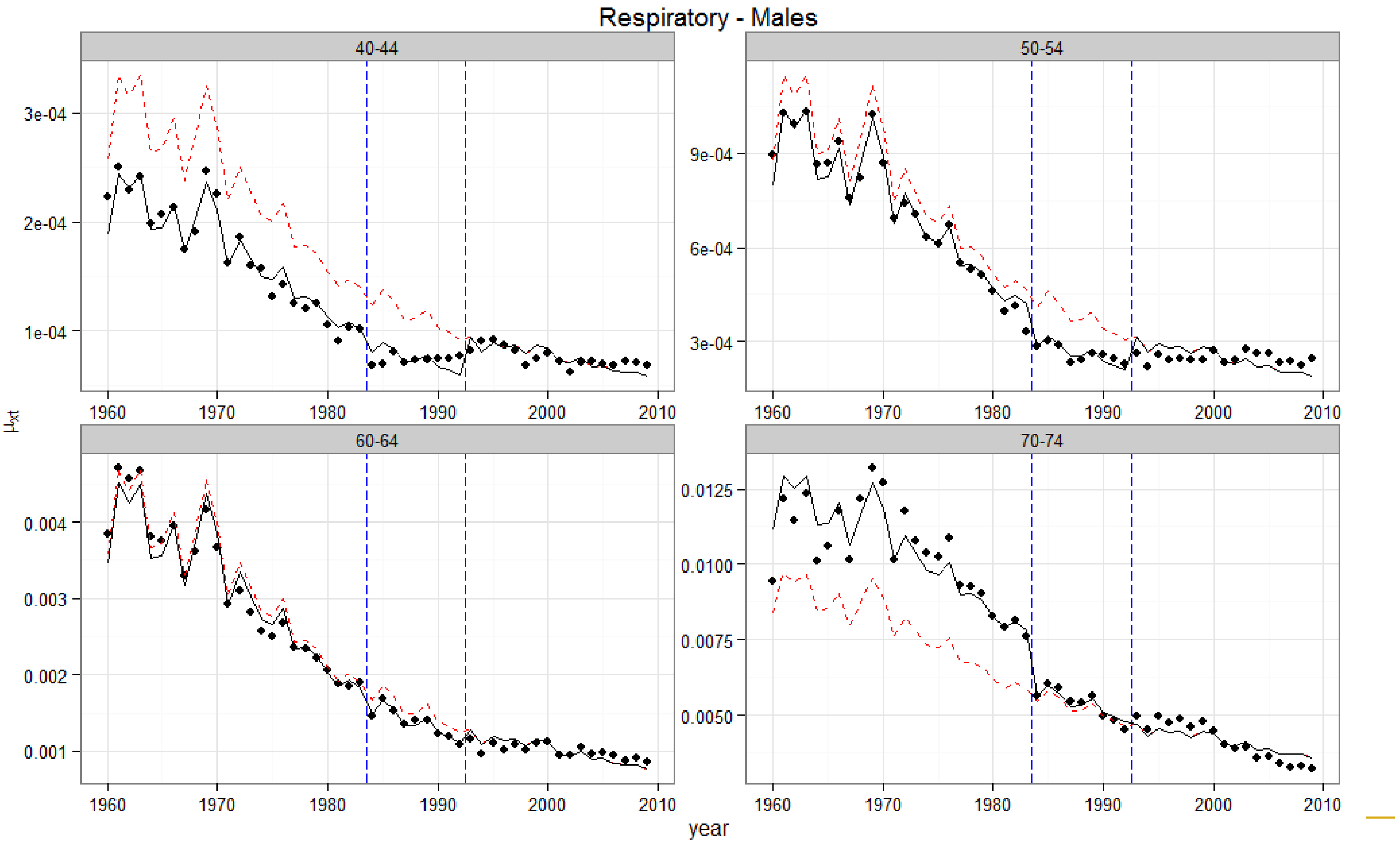

Modelling by CoD and socio-economic stratification

Three-way Lee-Carter model (Russolillo et al, 2011)

$$\log \mu^{c}_{xtg} = \alpha^{c}_{x} \qquad + \beta^{c}_{x} \quad \kappa^{c}_{t} + \sum_{i=1}^{h} \delta^{c,(i)}_{x} f^{(i)}(t)$$

Modelling by CoD and socio-economic stratification

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$$\log \mu^{c}_{xtg} = \alpha^{c}_{x} + \alpha^{c}_{xg} + \beta^{c}_{x} \quad \kappa^{c}_{t} + \sum_{i=1}^{h} \delta^{c,(i)}_{x} f^{(i)}(t)$$

Level differentials

Modelling by CoD and socio-economic stratification

Three-way Lee-Carter model (Russolillo et al, 2011)

$$\log \mu_{xtg}^{c} = \alpha_x^c + \underbrace{\alpha_{xg}^c}_{\text{Level differentials}} + \underbrace{\beta_x^c \lambda_g^c}_{\text{Improvement differentials}} \kappa_t^c + \sum_{i=1}^{h} \delta_x^{c,(i)} f^{(i)}(t)$$

Level differentials

Improvement differentials

Modelling by CoD and socio-economic stratification

Three-way Lee-Carter model

$$\log \mu_{xtg}^{c} = \alpha_x^c + \alpha_{xg}^c + \beta_x^c \lambda_g^c \kappa_t^c + \sum_{i=1}^{h} \delta_x^{c,(i)} f^{(i)}(t)$$

- Estimate the model parameters using a two stage estimation procedure with a reference population
  - National population data available for longer periods of time than socio-economic disaggregated data
  - More precise estimation of the long-run mortality trend
  - Coherency with the national mortality trend
- Stage 1:
  - Estimate $\alpha_x^c, \beta_x^c, \kappa_t^c, \delta_x^{c,(i)}$ using the reference population data
- Stage 1I:
  - Estimate $\alpha_{xg}^c, \lambda_g^c$ conditional on $\alpha_x^c, \beta_x^c, \kappa_t^c, \delta_x^{c,(i)}$

Case study: Mortality by deprivation in England
Application data

Subpopulation data

- England population disaggregated by deprivation quintile using the 2007 version of the English Index of Multiple Deprivation (IMD 2007)
- Ages: 25-29,30-34,…,80-84
- Period: 1981-2007

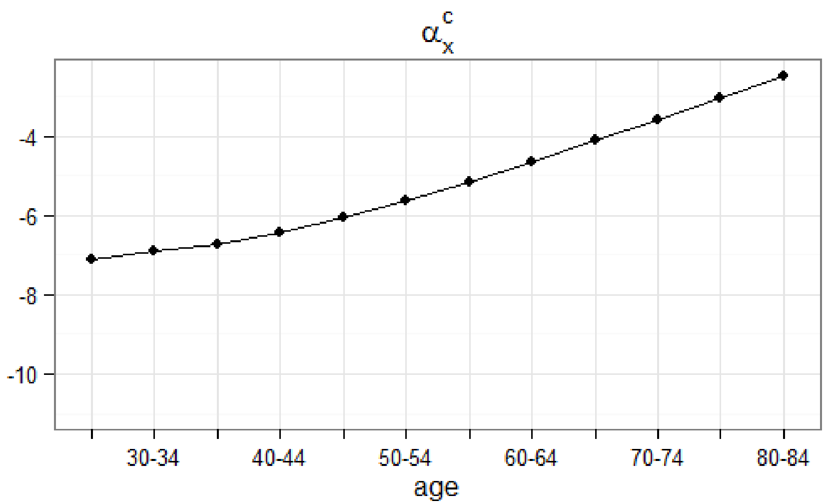
Reference population data

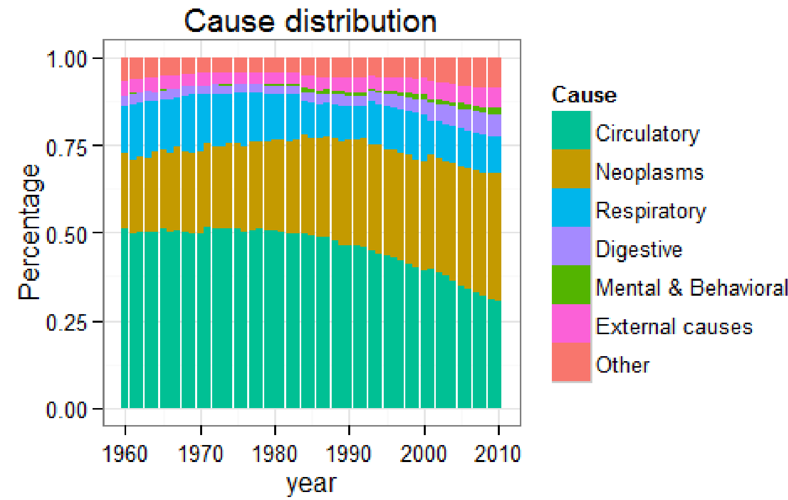
- England and Wales population
- Ages: 25-29,30-34,…,80-84
- Period: 1960-2009

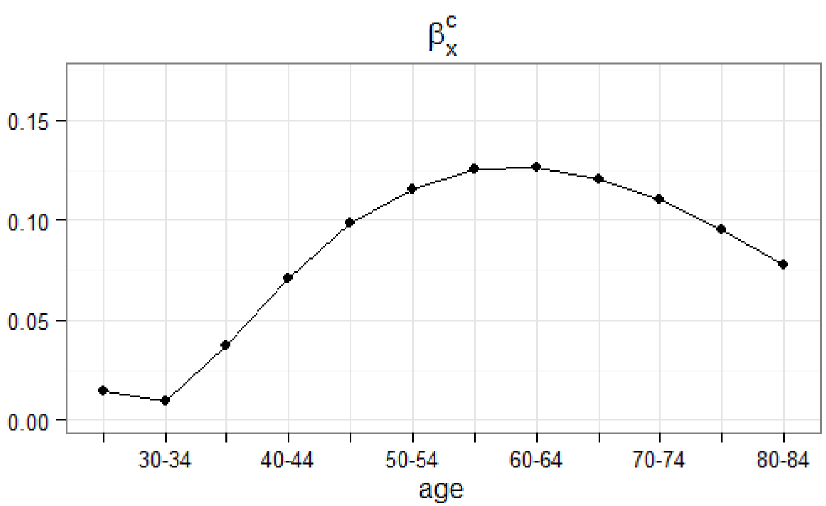
Case study: Mortality by deprivation in England

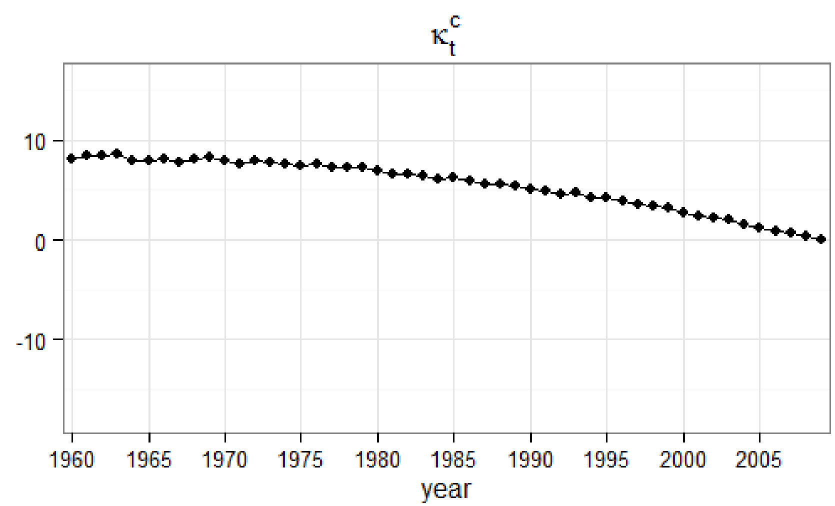
England and Wales Male population parameters

$$\log \mu^c_{xtg} = \alpha^c_x + \alpha^c_{xg} + \beta^c_x \lambda^c_g \kappa^c_t + \sum_{i=1}^{h} \delta^{c,(i)}_x f^{(i)}(t)$$









Case study: Mortality by deprivation in England

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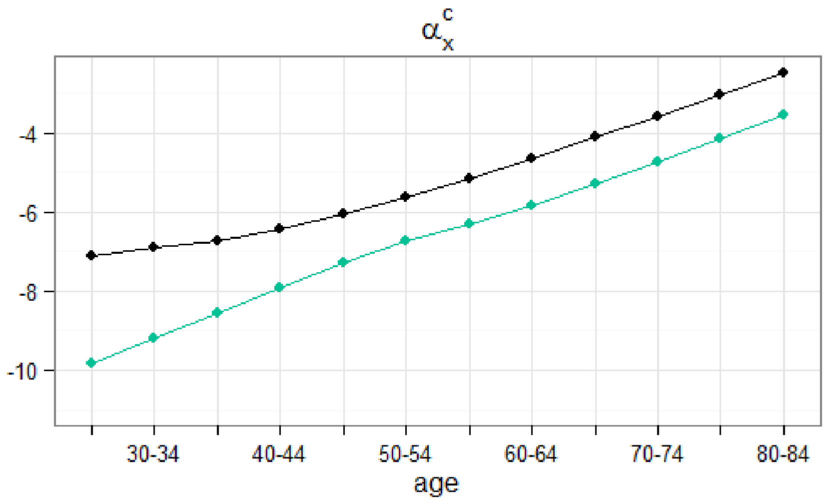

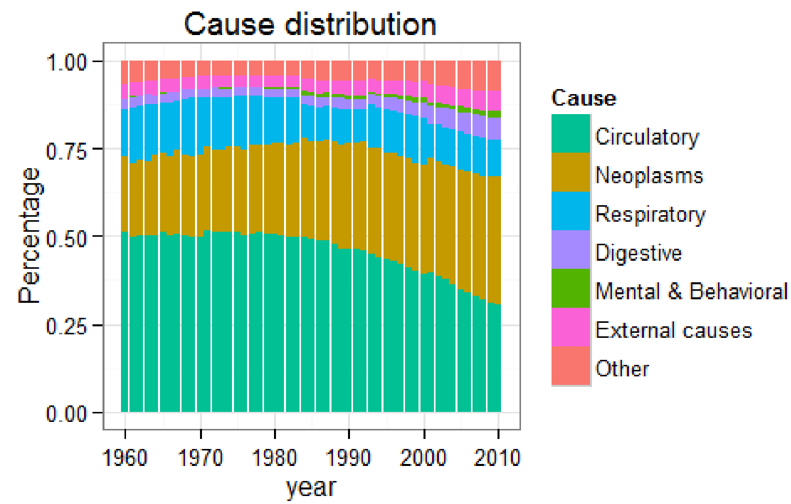

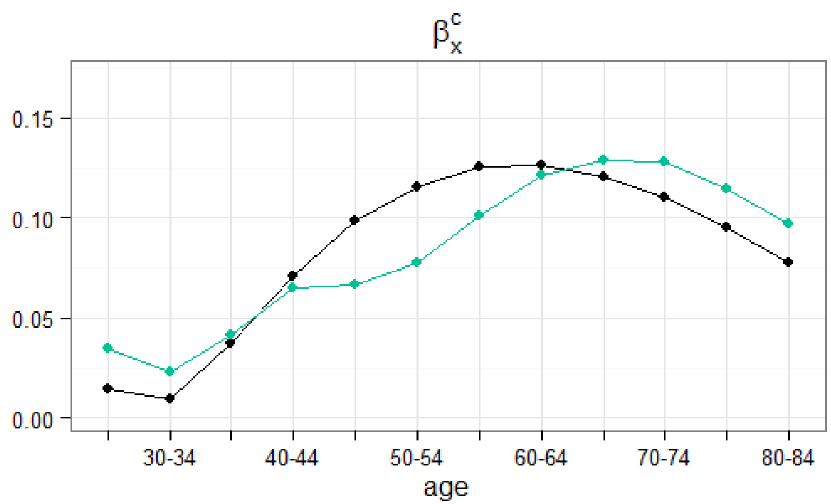

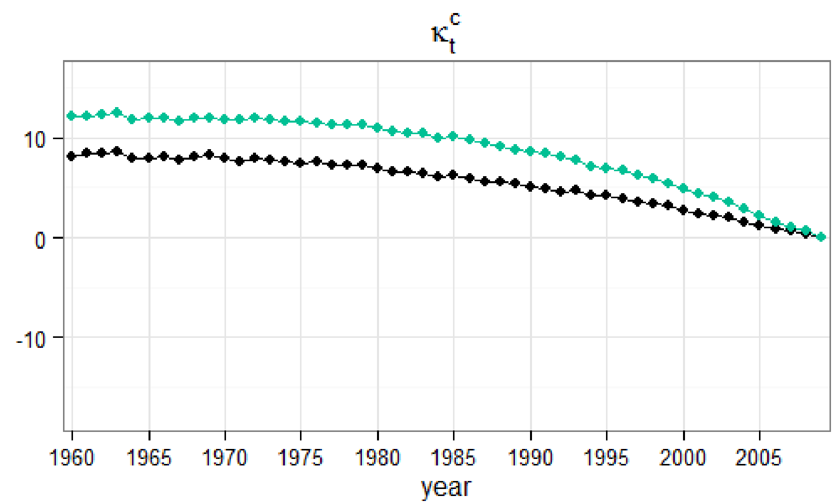

Case study: Mortality by deprivation in England

England and Wales Male population parameters

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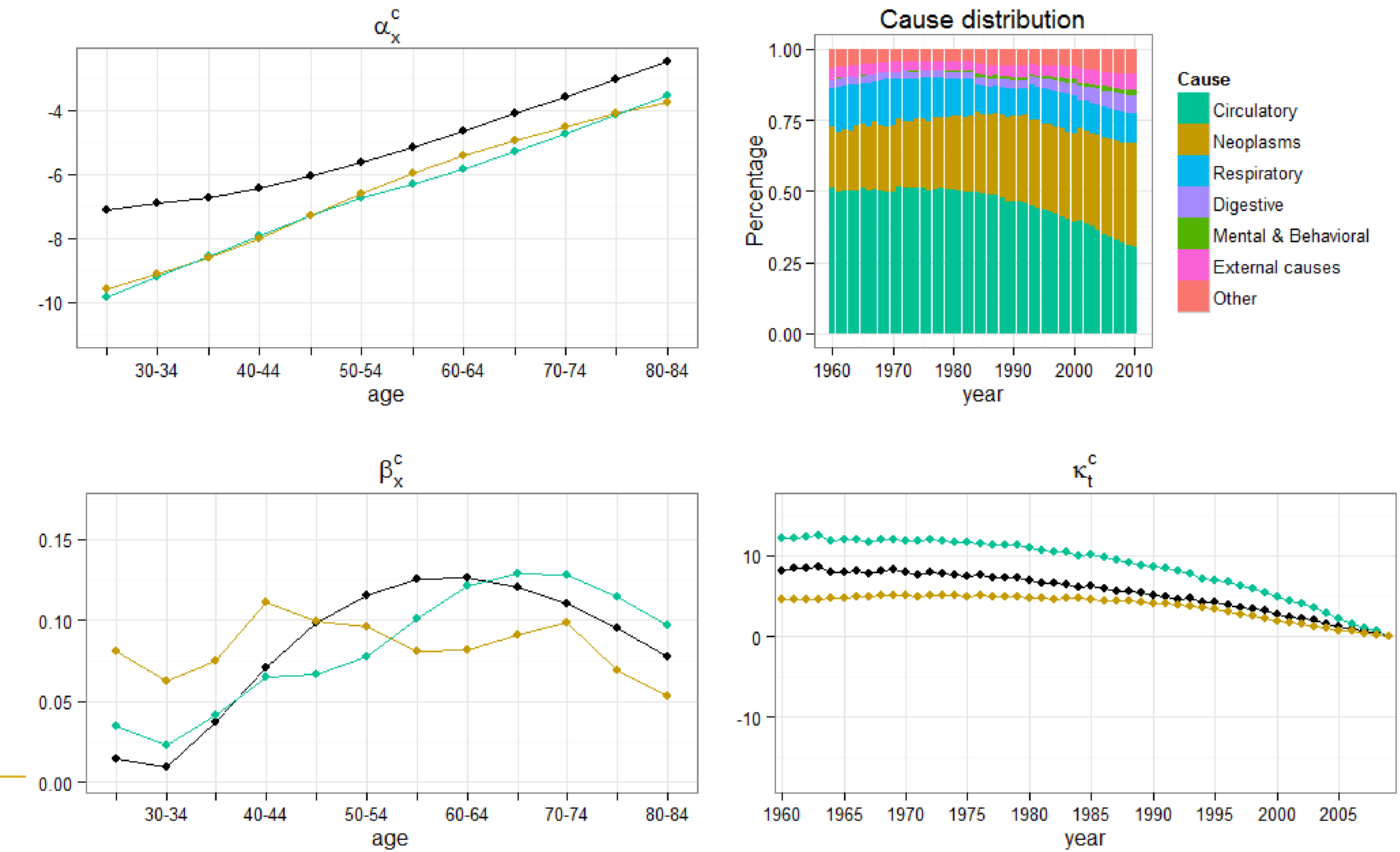

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England and Wales Male population parameters

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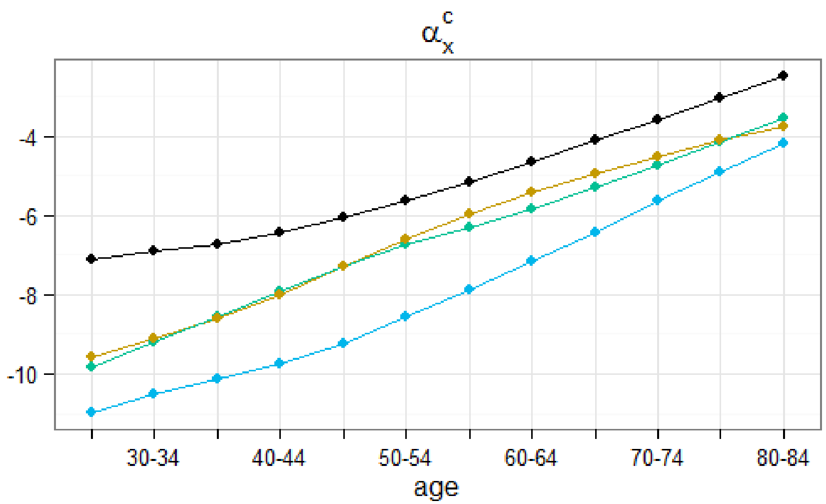

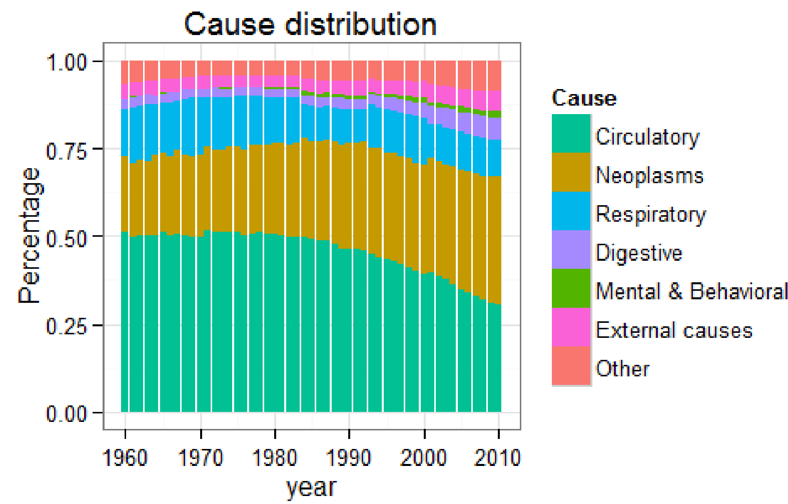

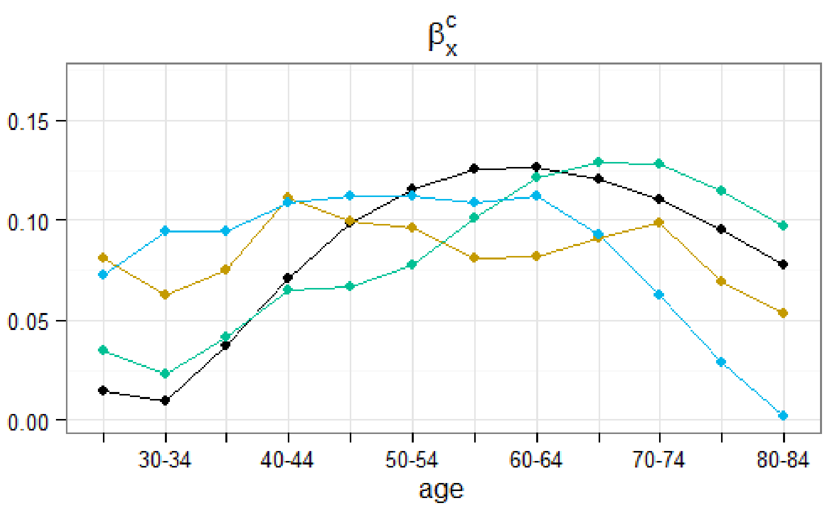

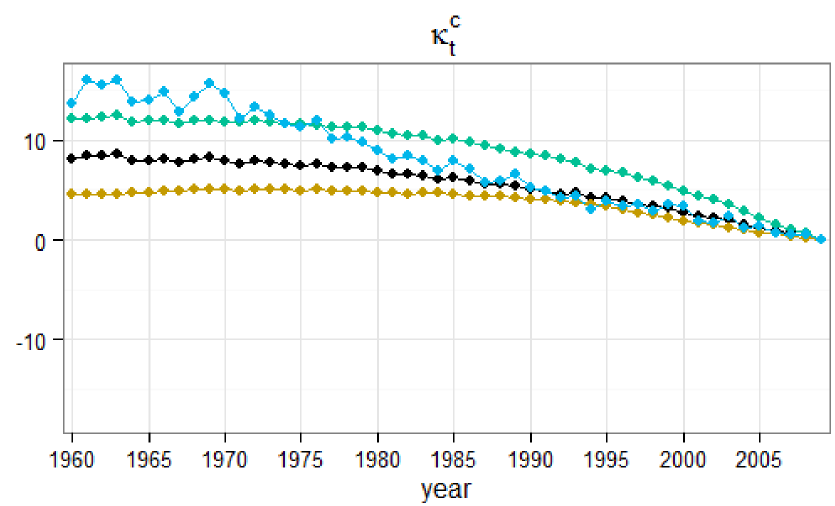

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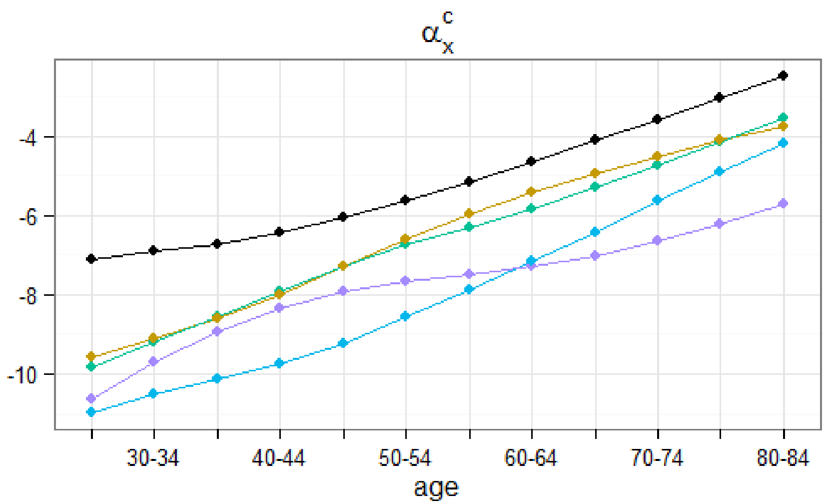
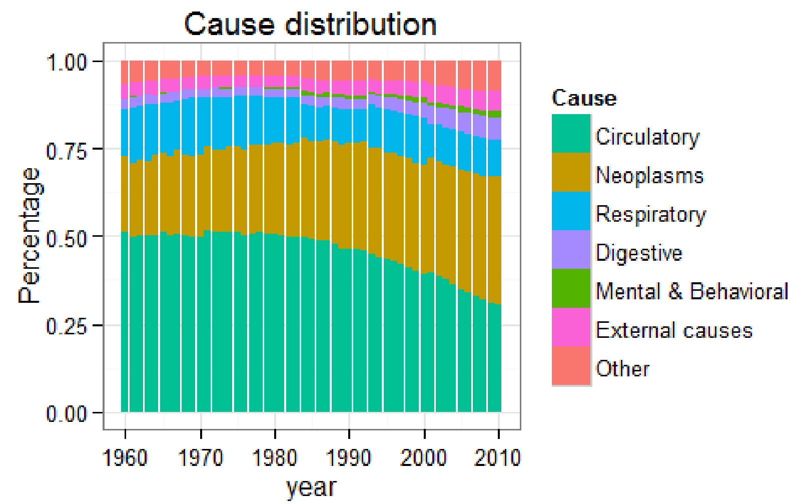
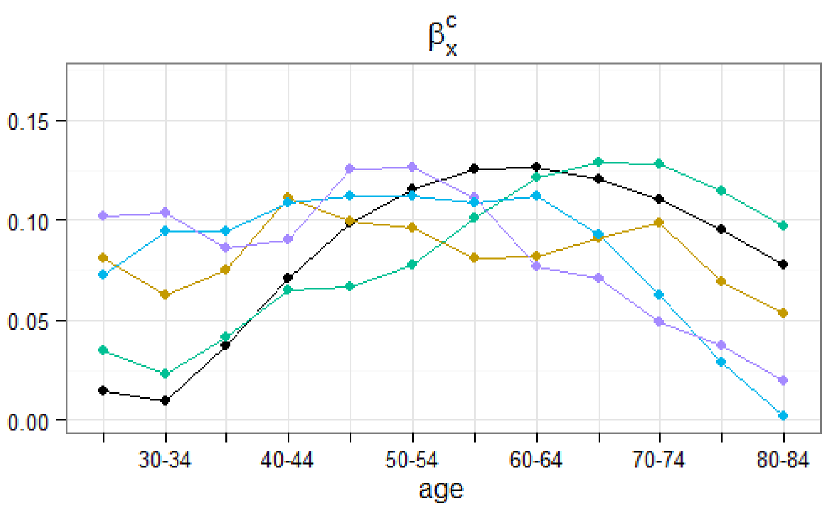
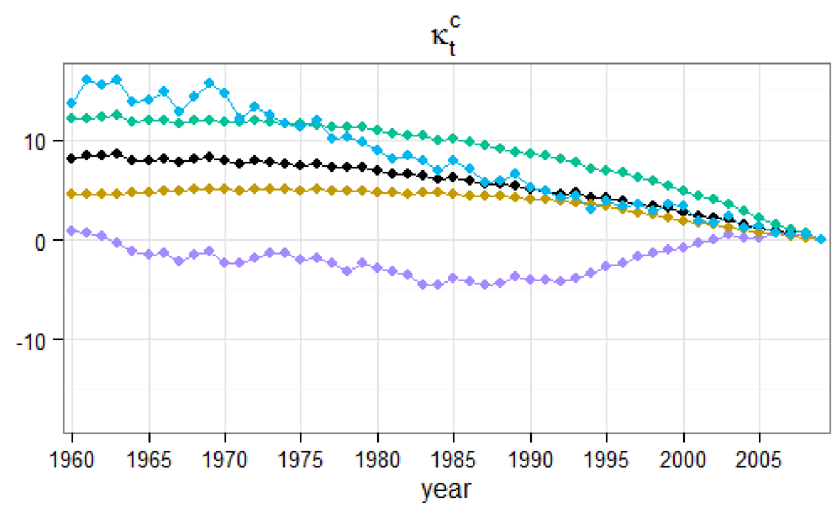




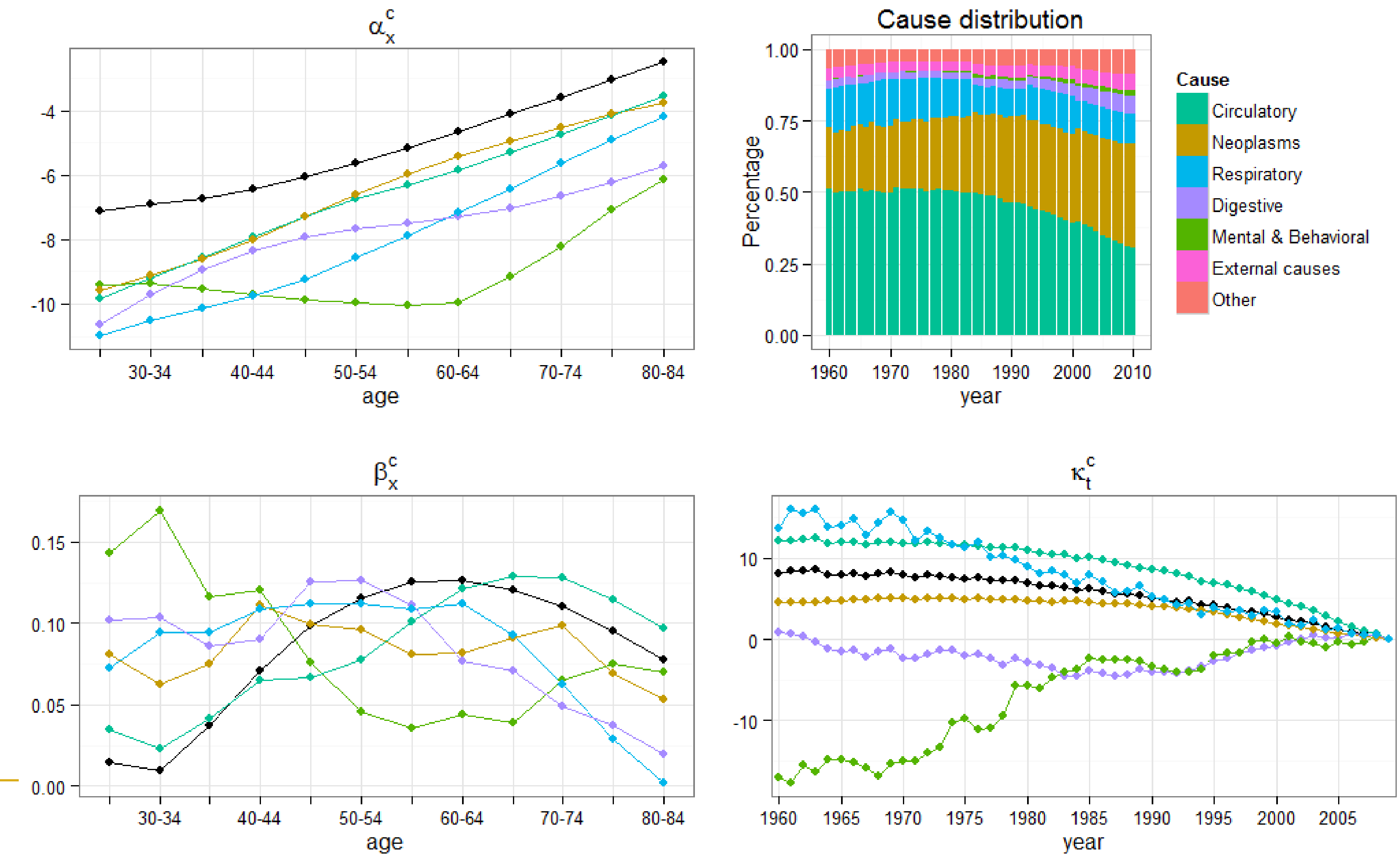




Case study: Mortality by deprivation in England

England and Wales Male population parameters

$$\log \mu^c_{xtg} = \alpha^c_x + \alpha^c_{xg} + \beta^c_x \lambda^c_g \kappa^c_t + \sum_{i=1}^{h} \delta^{c,(i)}_x f^{(i)}(t)$$



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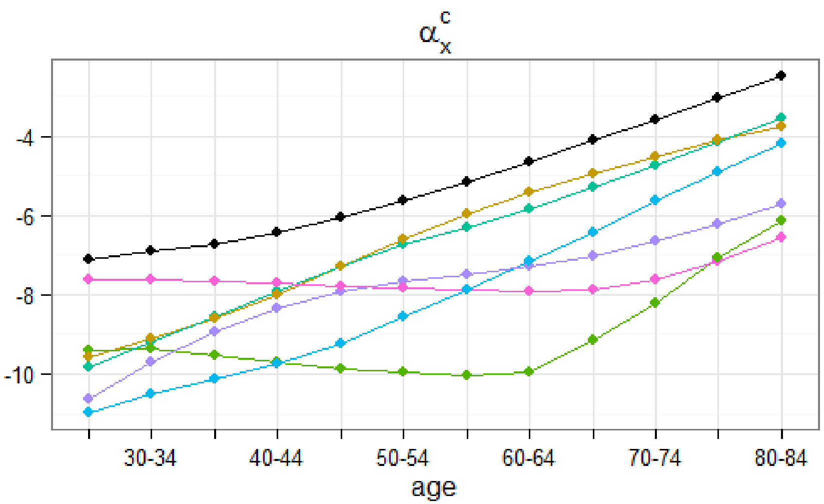

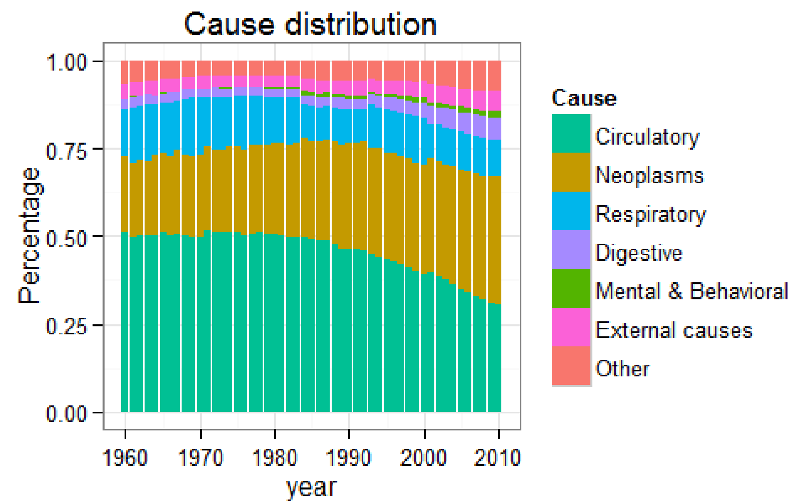

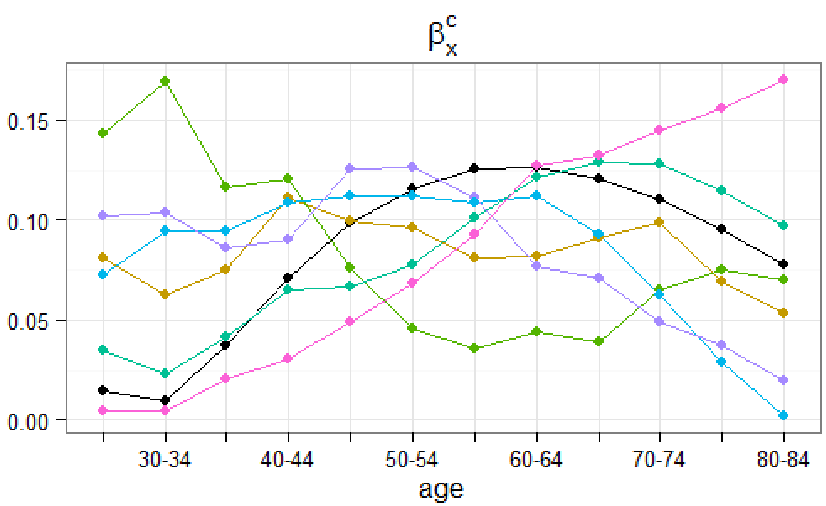

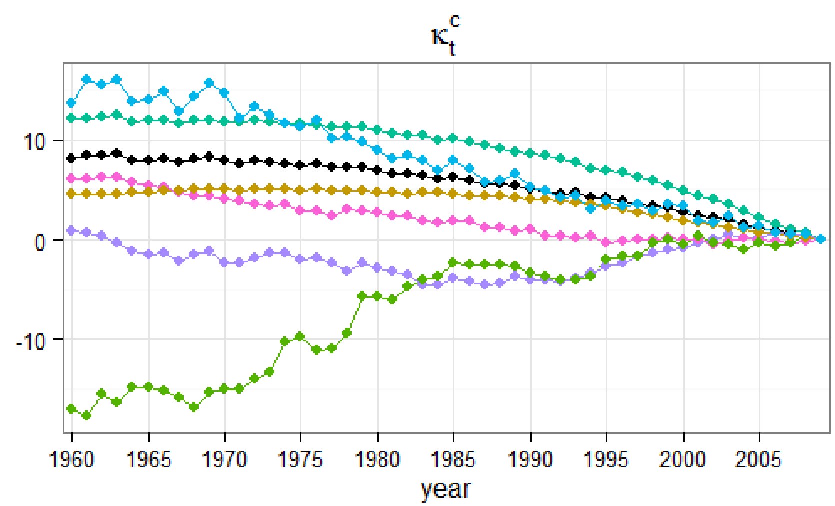

Case study: Mortality by deprivation in England

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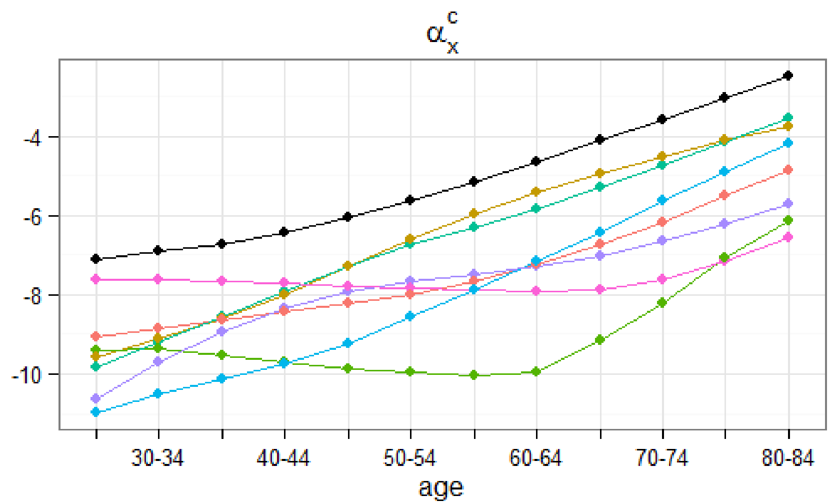
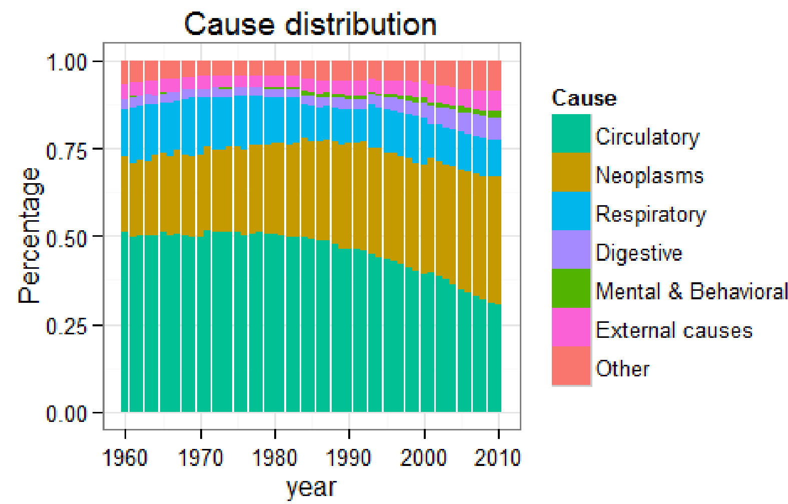
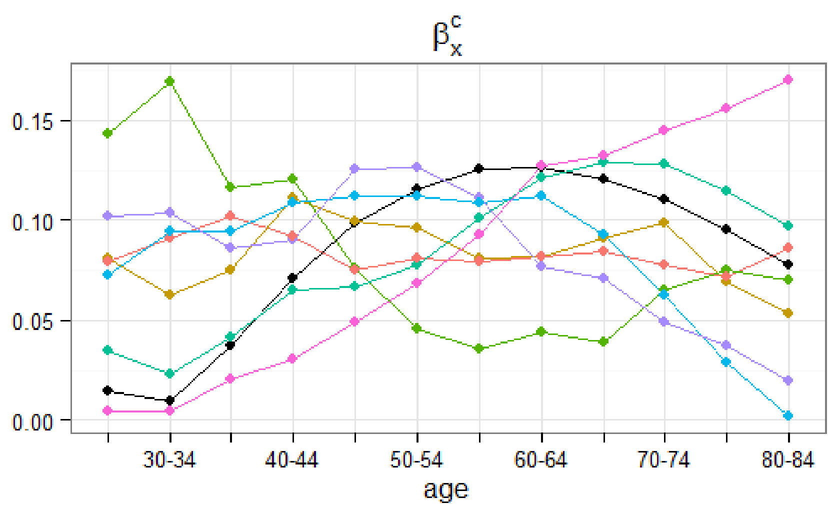
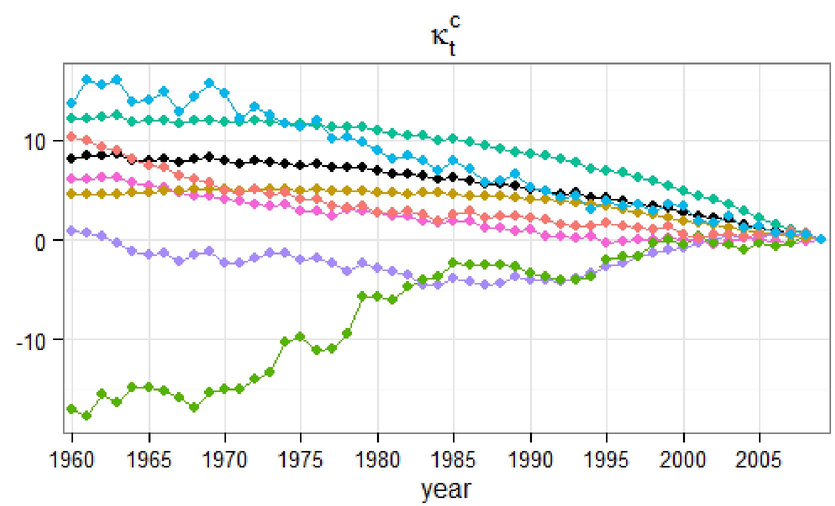




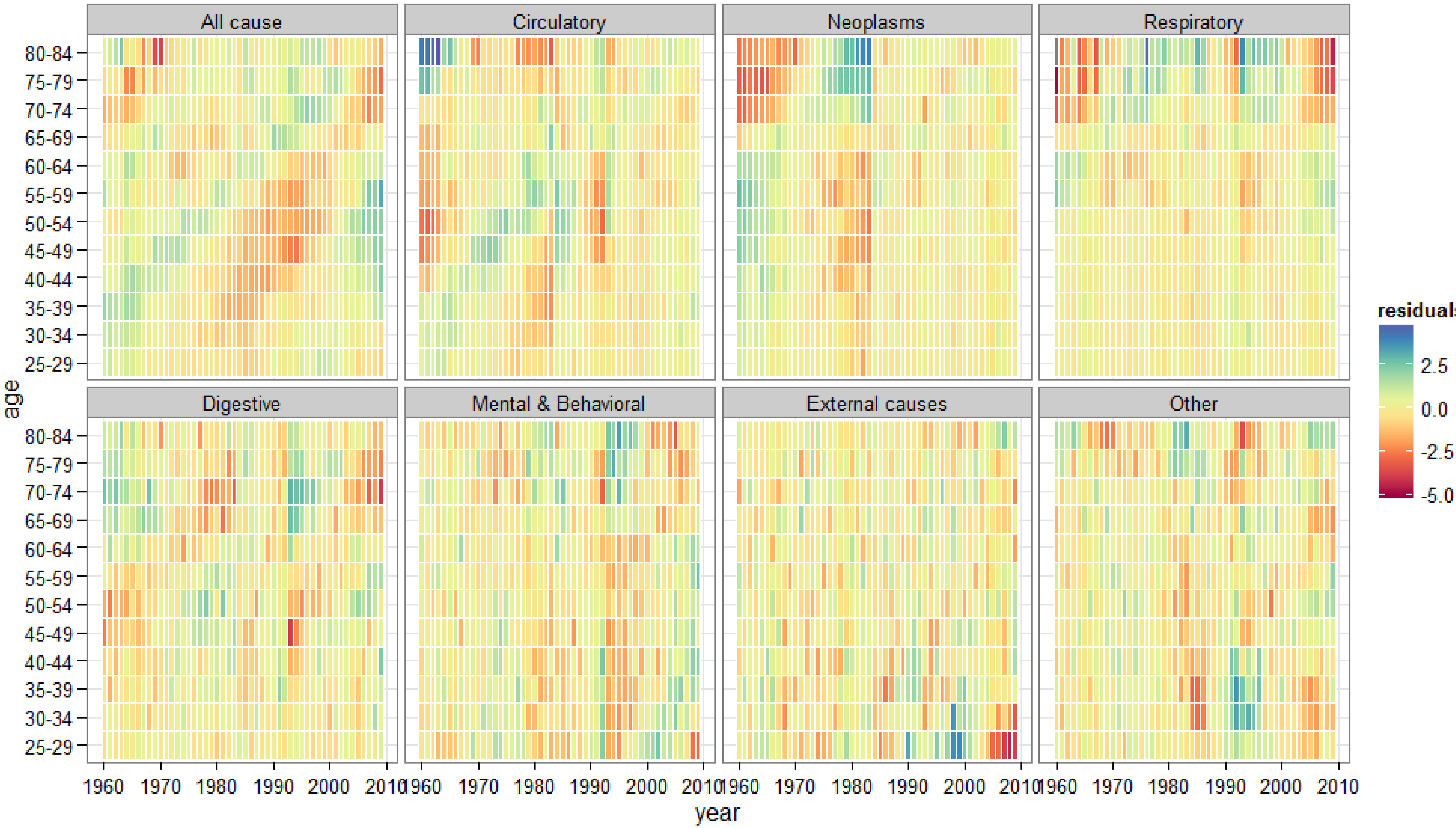




Case study: Mortality by deprivation in England

England and Wales Male population - Residuals

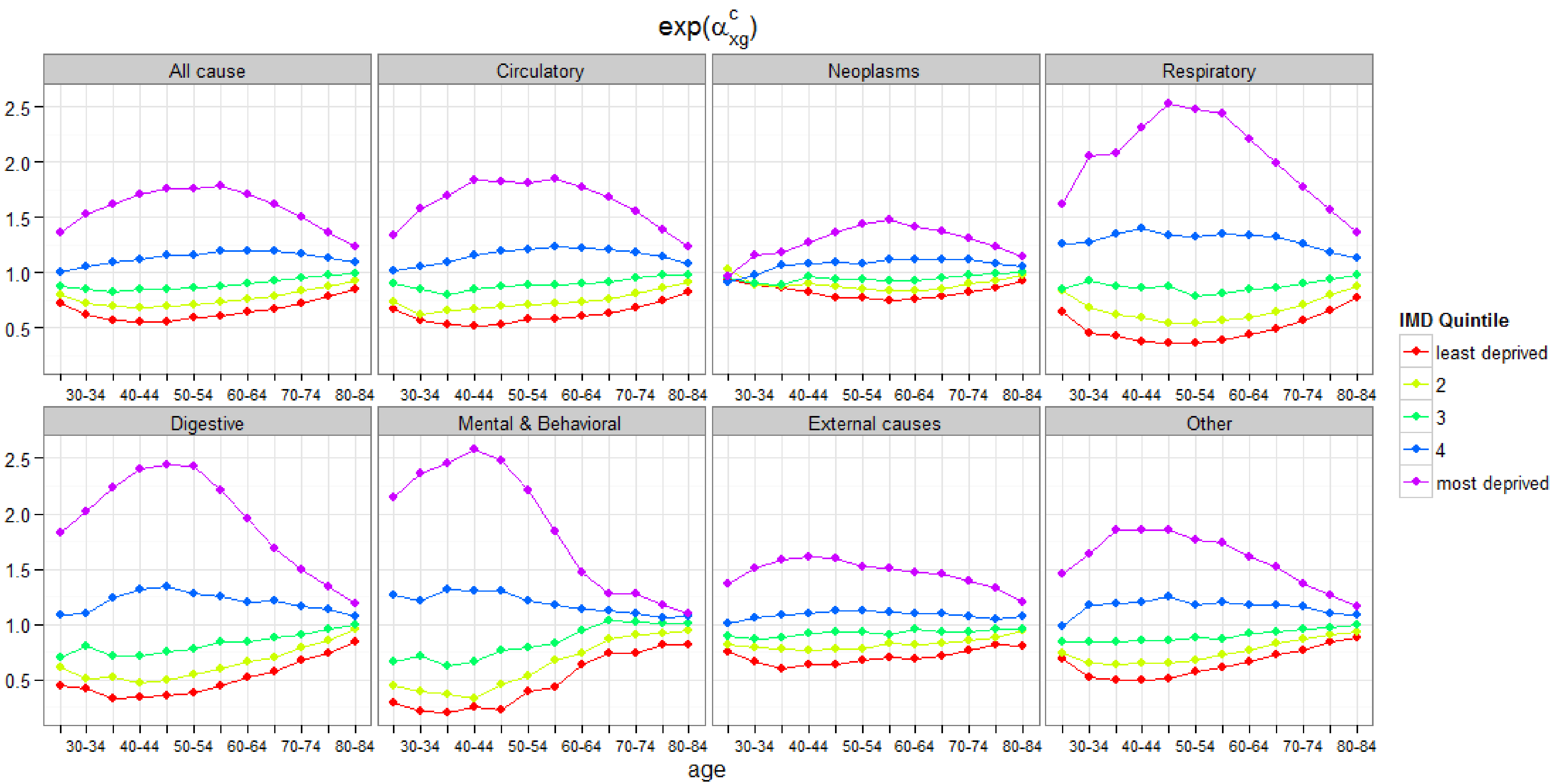
$$\log \mu_{xtg}^c = \alpha_x^c + \alpha_{xg}^c + \beta_x^c \lambda_g^c \kappa_t^c + \sum_{i=1}^{h} \delta_x^{c,(i)} f^{(i)}(t)$$



Case study: Mortality by deprivation in England

Level differences by deprivation quintile (Males)

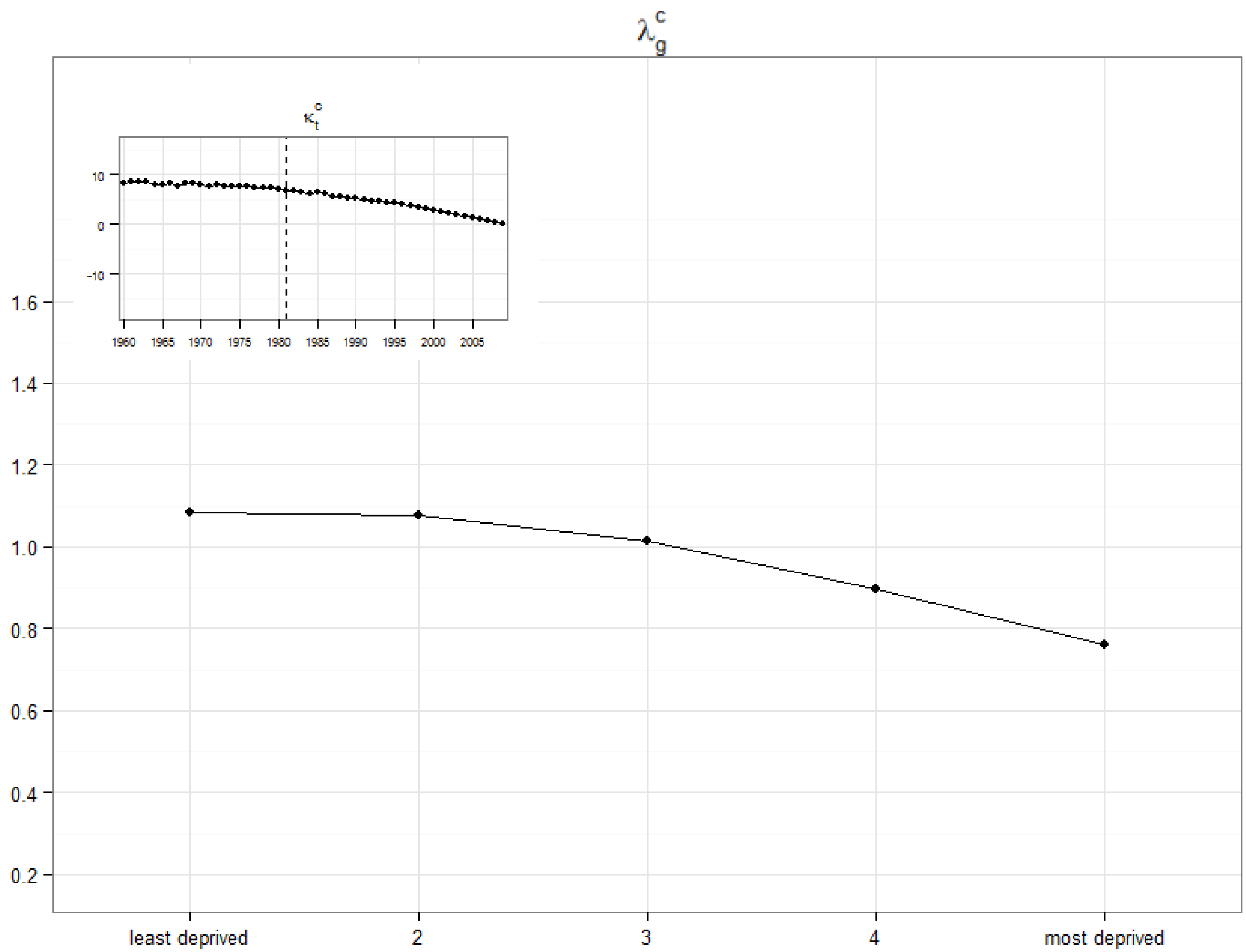
$$\log \mu_{xtg}^{c} = \alpha_x^c + \alpha_{xg}^c + \beta_x^c \lambda_g^c \kappa_t^c + \sum_{i=1}^{h} \delta_x^{c,(i)} f^{(i)}(t)$$



Case study: Mortality by deprivation in England

Trend differences by deprivation quintile (Males)

$$\log \mu_{xtg}^{c} = \alpha_x^c + \alpha_{xg}^c + \beta_x^c \lambda_g^c \kappa_t^c + \sum^{h} \delta_x^{c,(i)} f^{(i)}(t)$$



Cause	Average annual Improvement*
All cause	1.99%
Circulatory	
Neoplasms	
Respiratory	
Digestive	
Mental & Behavioral	
External causes	
Other	

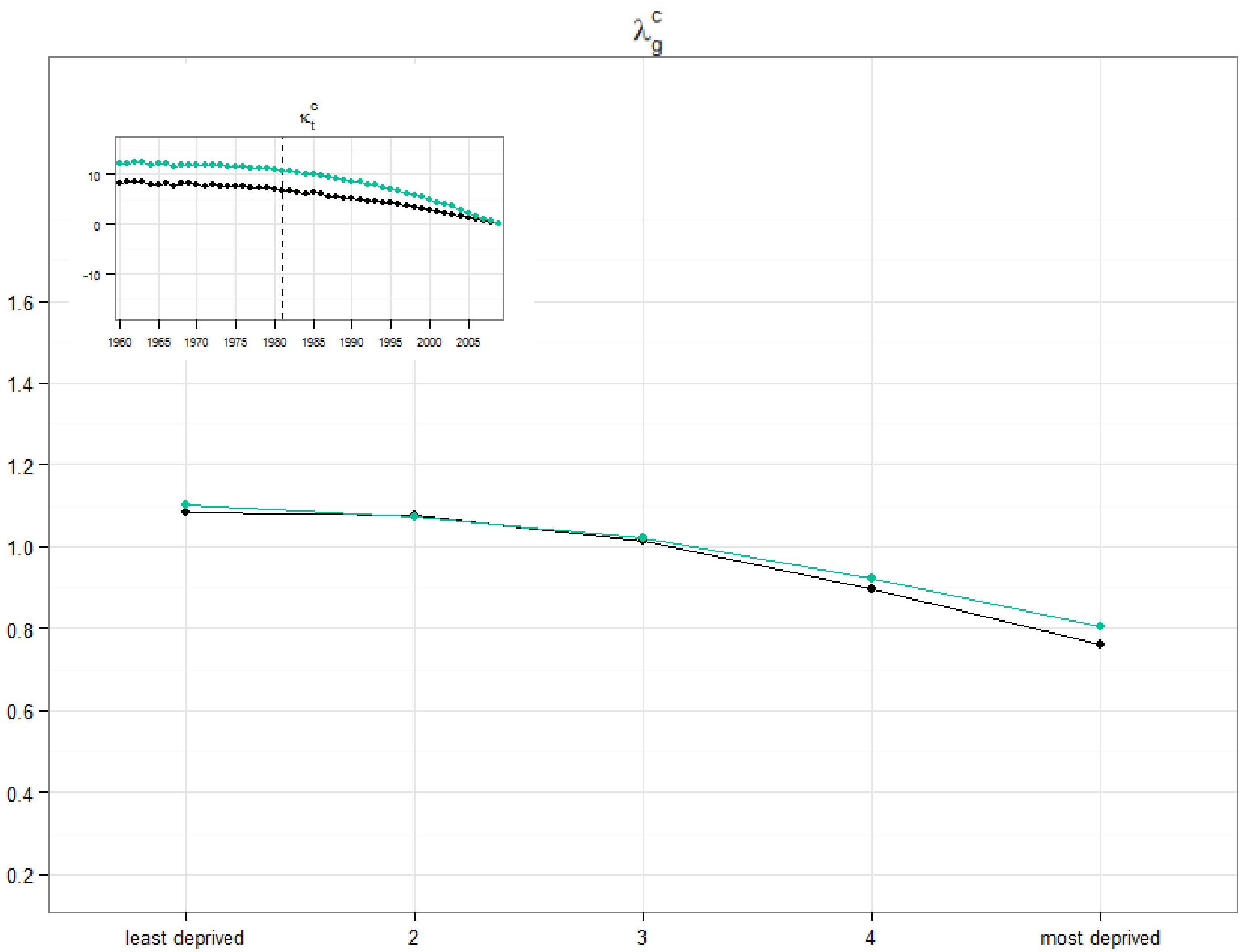
*Average annual Improvement for England and Wales for the period 1981-2009 computed as

$$\frac{\kappa_{1981}^{c} - \kappa_{2009}^{c}}{2009 - 1981} \times \frac{1}{\#Age\ Bands}$$

Case study: Mortality by deprivation in England

Trend differences by deprivation quintile (Males)

$$\log \mu^c_{xtg} = \alpha^c_x + \alpha^c_{xg} + \beta^c_x \lambda^c_g \kappa^c_t + \sum^h \delta^{c,(i)}_x f^{(i)}(t)$$



Cause	Average annual Improvement*
All cause	1.99%
Circulatory	3.18%
Neoplasms	
Respiratory	
Digestive	
Mental & Behavioral	
External causes	
Other	

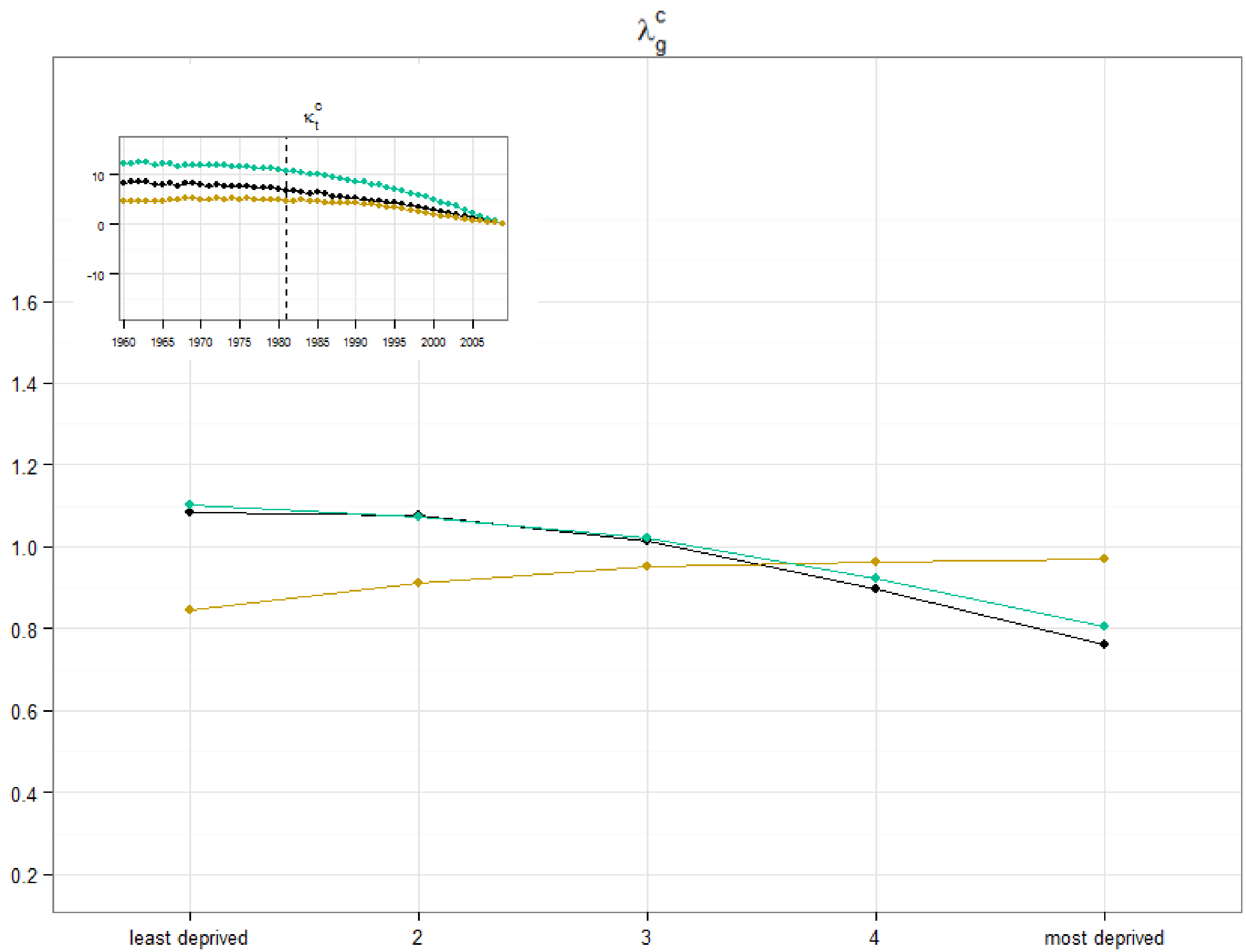
*Average annual Improvement for England and Wales for the period 1981-2009 computed as

$$\frac{\kappa^c_{1981} - \kappa^c_{2009}}{2009 - 1981} \times \frac{1}{\#Age\ Bands}$$

Case study: Mortality by deprivation in England

Trend differences by deprivation quintile (Males)

$$\log \mu^c_{xtg} = \alpha^c_x + \alpha^c_{xg} + \beta^c_x \lambda^c_g \kappa^c_t + \sum^h \delta^{c,(i)}_x f^{(i)}(t)$$



Cause	Average annual Improvement*
All cause	1.99%
Circulatory	3.18%
Neoplasms	1.41%
Respiratory	
Digestive	
Mental & Behavioral	
External causes	
Other	

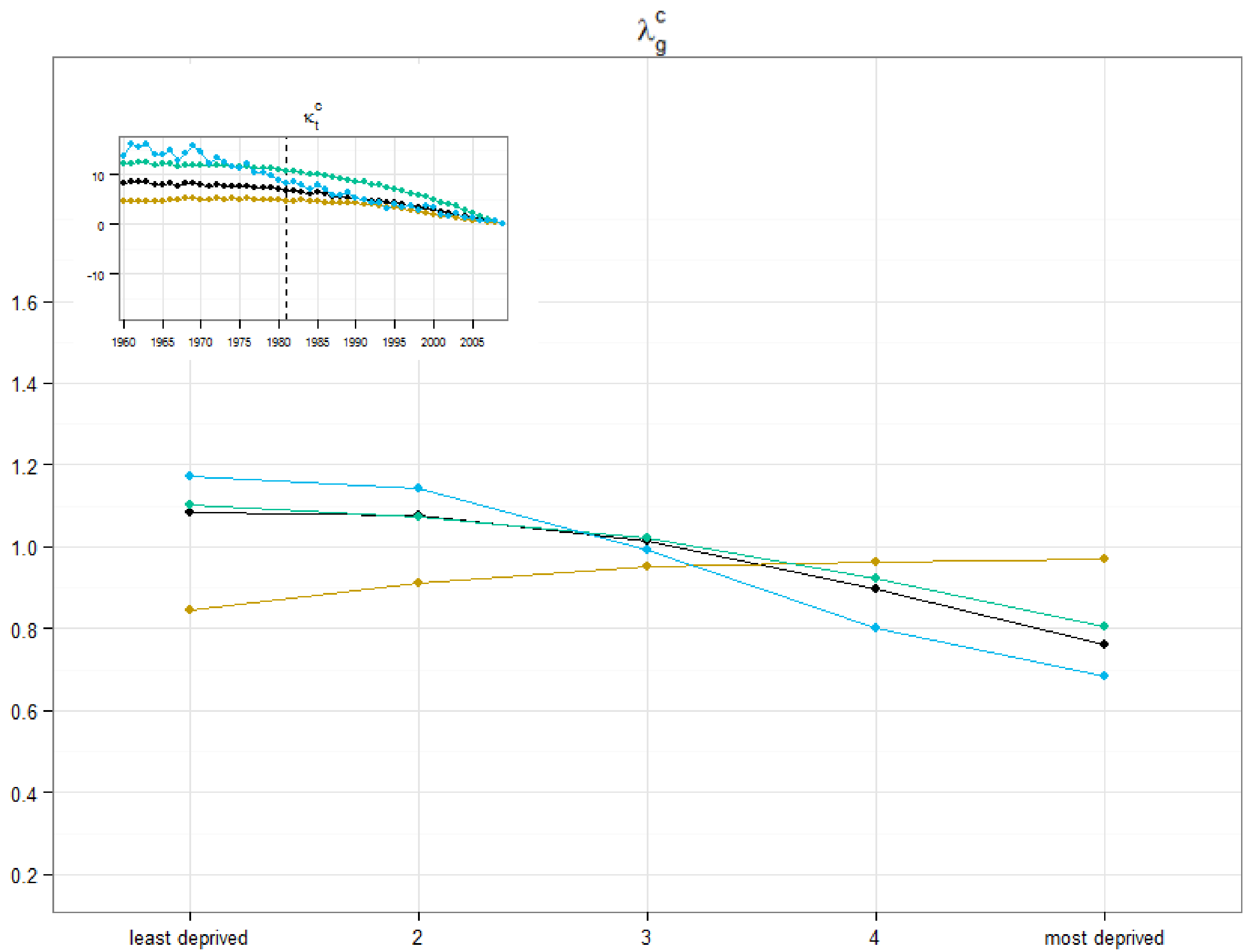
*Average annual Improvement for England and Wales for the period 1981-2009 computed as

$$\frac{\kappa^c_{1981} - \kappa^c_{2009}}{2009 - 1981} \times \frac{1}{\#Age\ Bands}$$

Case study: Mortality by deprivation in England

Trend differences by deprivation quintile (Males)

$$\log \mu^{c}_{xtg} = \alpha^{c}_{x} + \alpha^{c}_{xg} + \beta^{c}_{x}\lambda^{c}_{g}\kappa^{c}_{t} + \sum^{h} \delta^{c,(i)}_{x} f^{(i)}(t)$$



Cause	Average annual Improvement*
All cause	1.99%
Circulatory	3.18%
Neoplasms	1.41%
Respiratory	2.42%
Digestive	
Mental & Behavioral	
External causes	
Other	

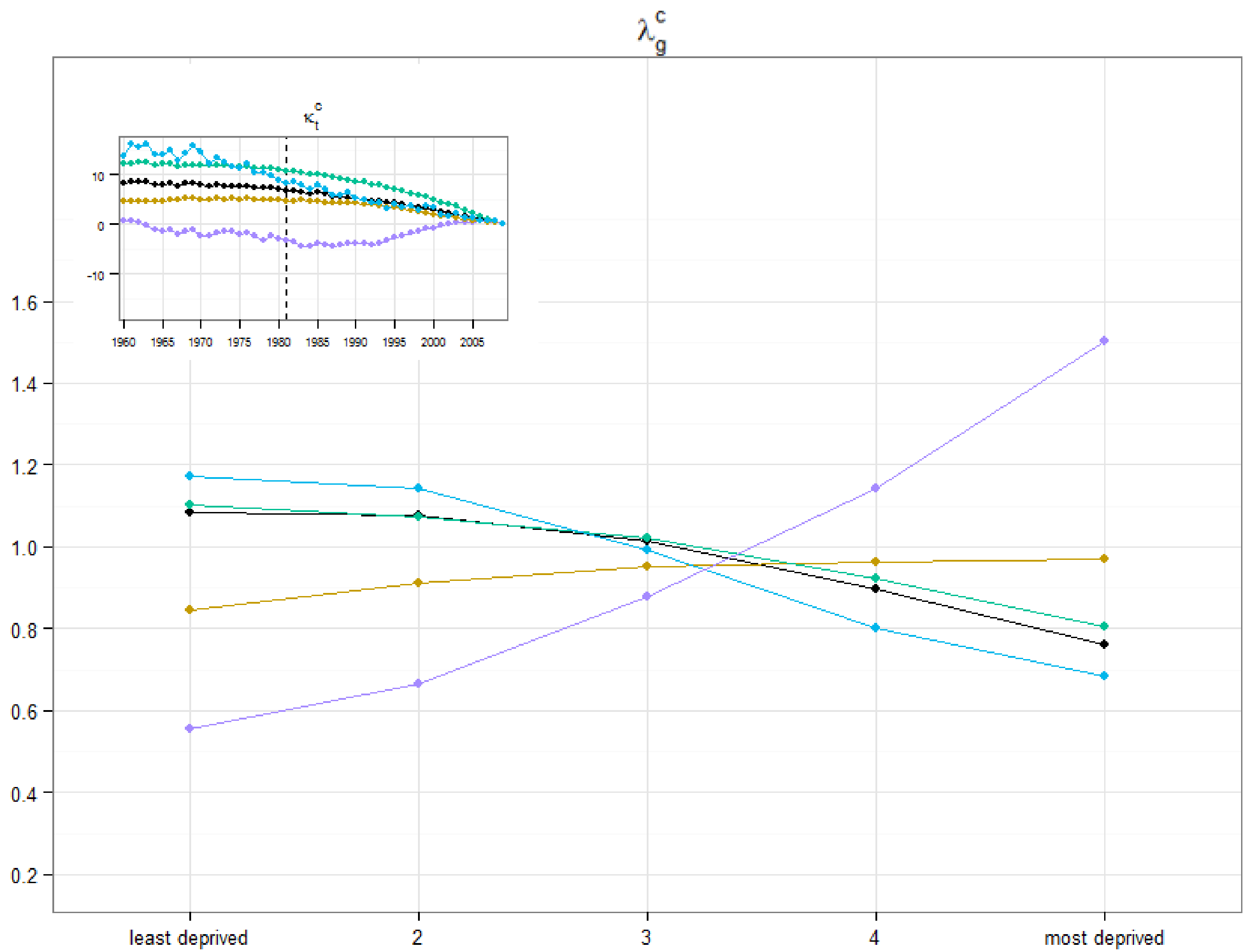
*Average annual Improvement for England and Wales for the period 1981-2009 computed as

$$\frac{\kappa^{c}_{1981} - \kappa^{c}_{2009}}{2009 - 1981} \times \frac{1}{\#Age\ Bands}$$

Case study: Mortality by deprivation in England

Trend differences by deprivation quintile (Males)

$$\log \mu^c_{xtg} = \alpha^c_x + \alpha^c_{xg} + \beta^c_x \lambda^c_g \kappa^c_t + \sum^{h} \delta^{c,(i)}_x f^{(i)}(t)$$



Cause	Average annual Improvement*
All cause	1.99%
Circulatory	3.18%
Neoplasms	1.41%
Respiratory	2.42%
Digestive	-0.97%
Mental & Behavioral	
External causes	
Other	

*Average annual Improvement for England and Wales for the period 1981-2009 computed as

$$\frac{\kappa^c_{1981} - \kappa^c_{2009}}{2009 - 1981} \times \frac{1}{\#Age\ Bands}$$

Case study: Mortality by deprivation in England

Trend differences by deprivation quintile (Males)

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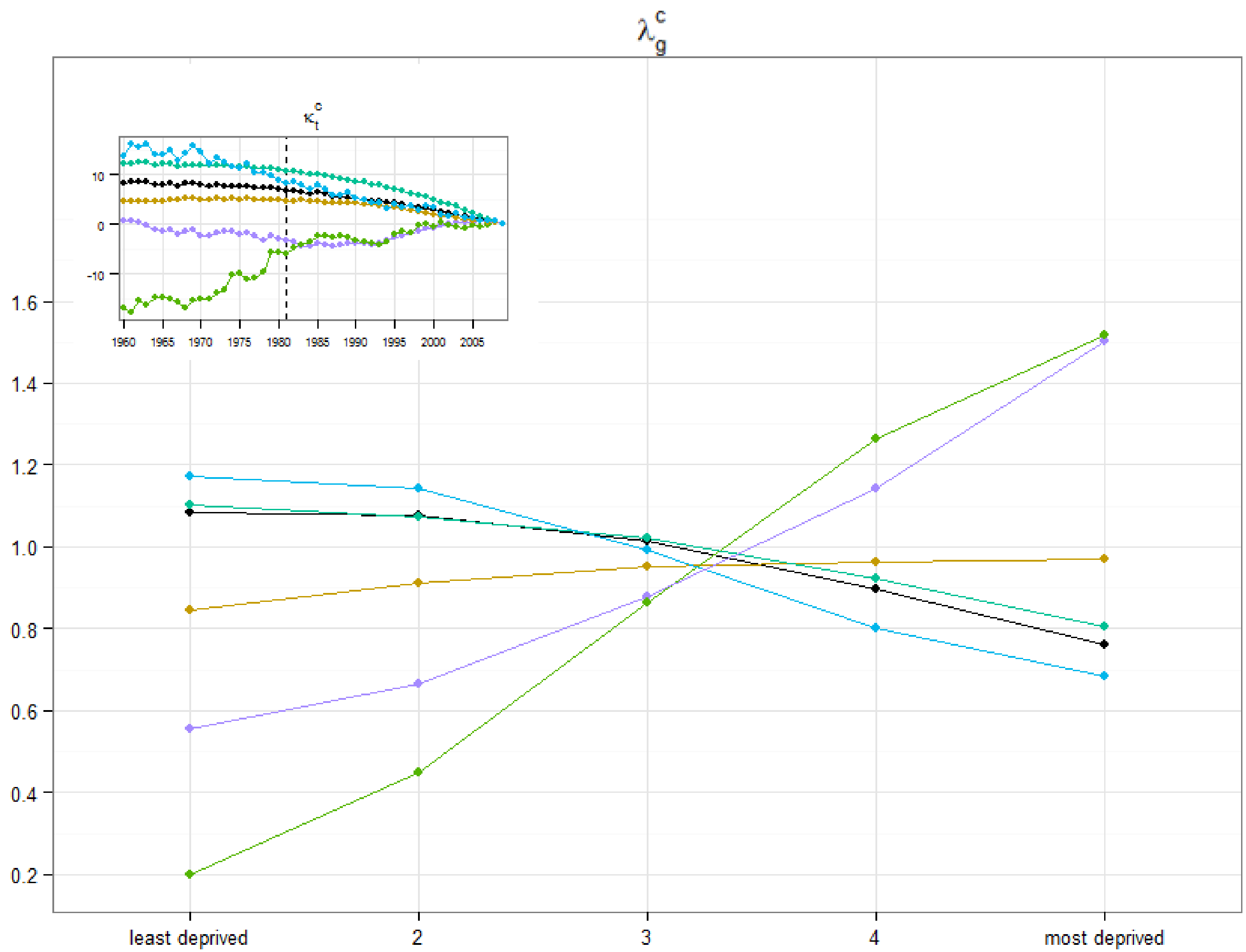

Cause	Average annual Improvement*
All cause	1.99%
Circulatory	3.18%
Neoplasms	1.41%
Respiratory	2.42%
Digestive	-0.97%
Mental & Behavioral	-1.79%
External causes	
Other	

*Average annual Improvement for England and Wales for the period 1981-2009 computed as

$$\frac{\kappa^c_{1981} - \kappa^c_{2009}}{2009 - 1981} \times \frac{1}{\#Age\ Bands}$$

Case study: Mortality by deprivation in England

Trend differences by deprivation quintile (Males)

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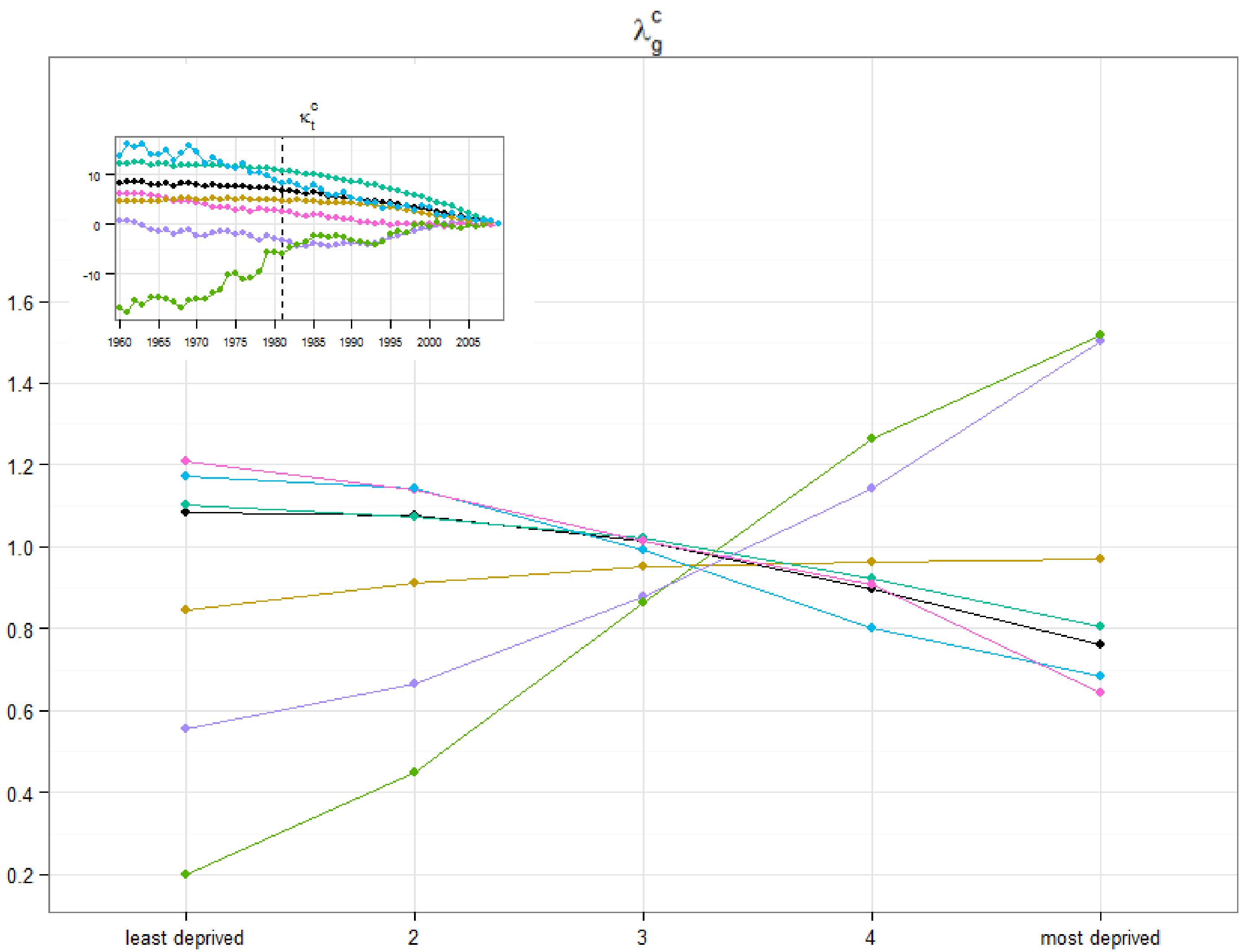

Cause	Average annual Improvement*
All cause	1.99%
Circulatory	3.18%
Neoplasms	1.41%
Respiratory	2.42%
Digestive	-0.97%
Mental & Behavioral	-1.79%
External causes	0.70%
Other	

*Average annual Improvement for England and Wales for the period 1981-2009 computed as

$$\frac{\kappa^c_{1981} - \kappa^c_{2009}}{2009 - 1981} \times \frac{1}{\#Age\ Bands}$$

Case study: Mortality by deprivation in England

Trend differences by deprivation quintile (Males)

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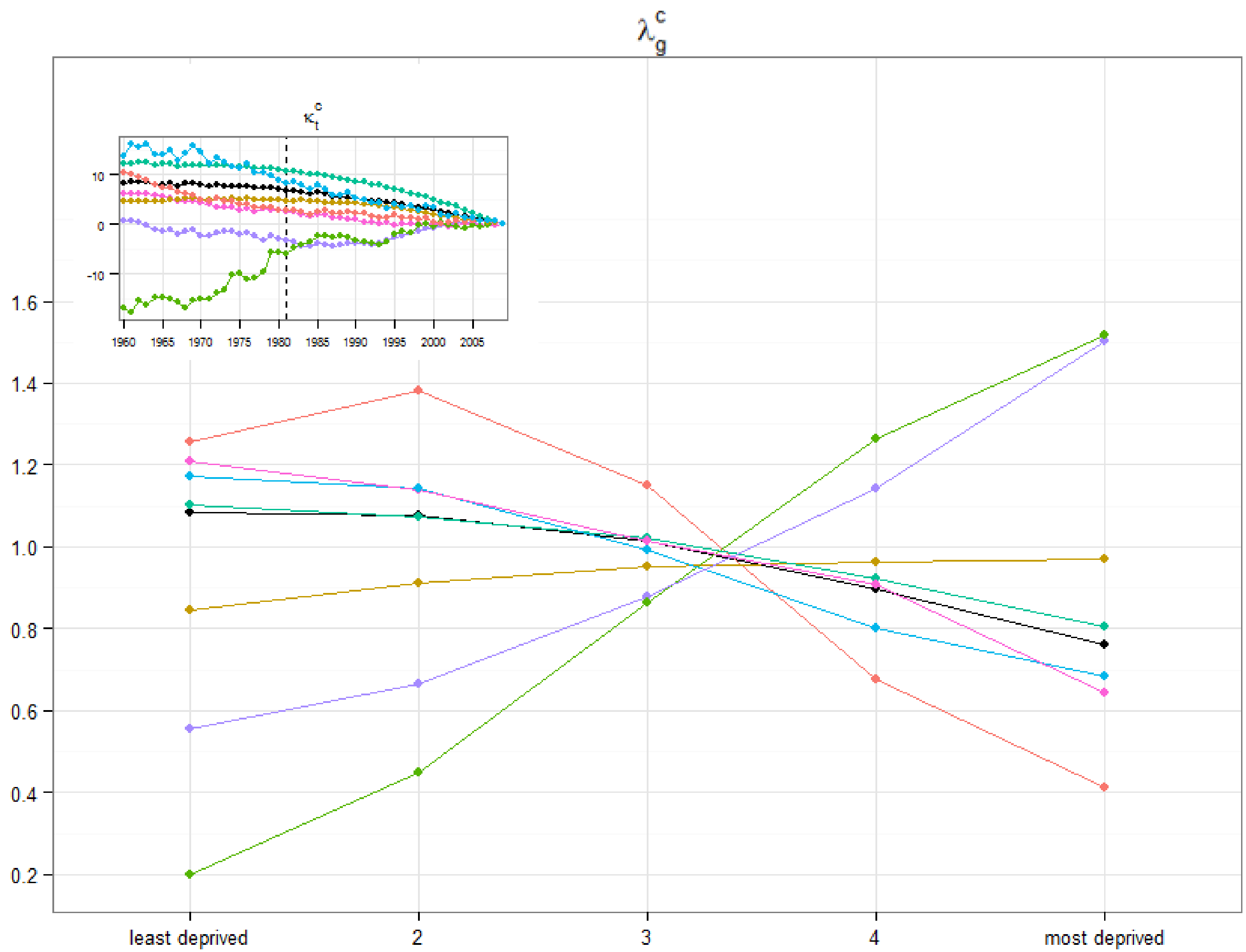


Cause	Average annual Improvement*
All cause	1.99%
Circulatory	3.18%
Neoplasms	1.41%
Respiratory	2.42%
Digestive	-0.97%
Mental & Behavioral	-1.79%
External causes	0.70%
Other	0.81%

*Average annual Improvement for England and Wales for the period 1981-2009 computed as

$$\frac{\kappa_{1981}^{c} - \kappa_{2009}^{c}}{2009 - 1981} \times \frac{1}{\#Age\ Bands}$$

Conclusions and future work

- Introduce an extension of the Lee-Carter model to deal with production changes in cause-specific mortality
- Embed this model in a multipopulation framework to assess socio-economic differences in cause of death
- Application in the analysis of the extent of mortality differentials across deprivation subgroups in England for the period 1981- 2007
  - Clear inverse relationship between area deprivation and mortality for all causes
  - Reduction of relative differentials in cancer mortality?
  - Offset of this reduction by marked increase in differentials in digestive, respiratory and mental and behavioural diseases
- Future work
  - Consideration of cohort effects (Particularly important for cancer)
  - Projection of differentials

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.

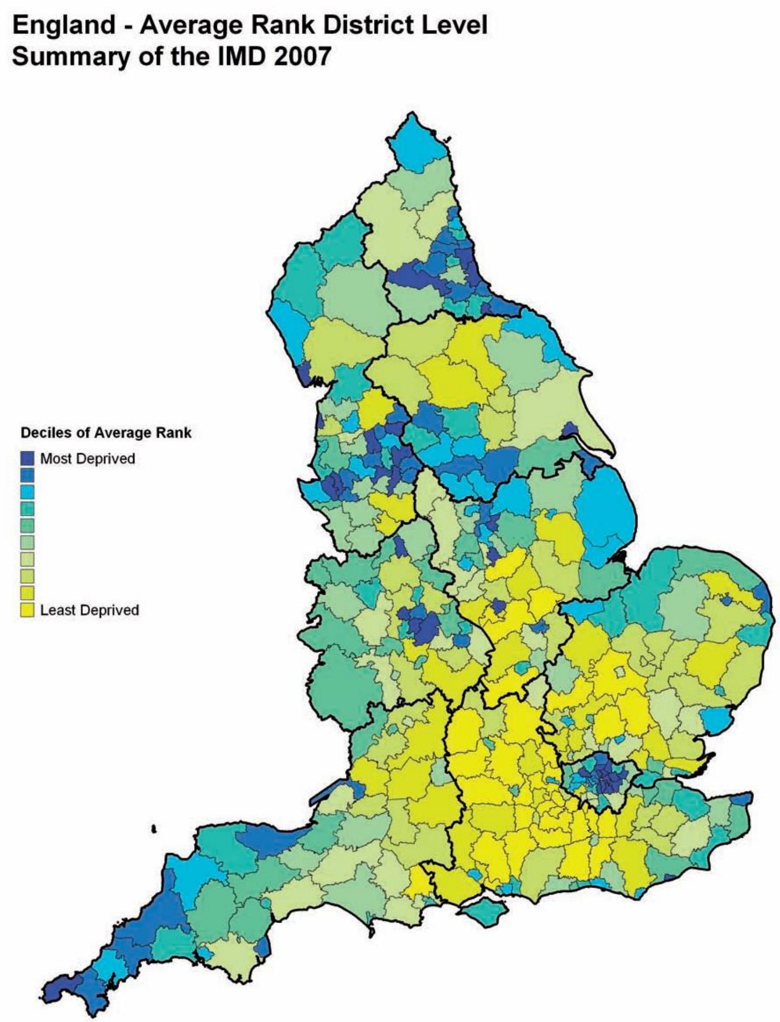
Institute and Faculty of Actuaries

Reserve Slides

Case study: Mortality by deprivation in England

Application data - IMD 2007

- Socio-economic classification of the population obtained using the Index of Multiple Deprivation 2007 (IMD 2007)
- IMD 2007 combines indicators across 7 deprivation domains into a single deprivation score for each geographically defined Lower Layer Super Output Area (LSOA)
  - Income, employment, health, education, housing and services, crime, and living environment
- 32,482 LSOA in England with approximately 1,500 people each
- LSOAs ranked from 1 to 32.482 by their IMD 2007 score and grouped into quintiles
  - Q1: Least deprived quintile
  - Q5: Most deprived quintile

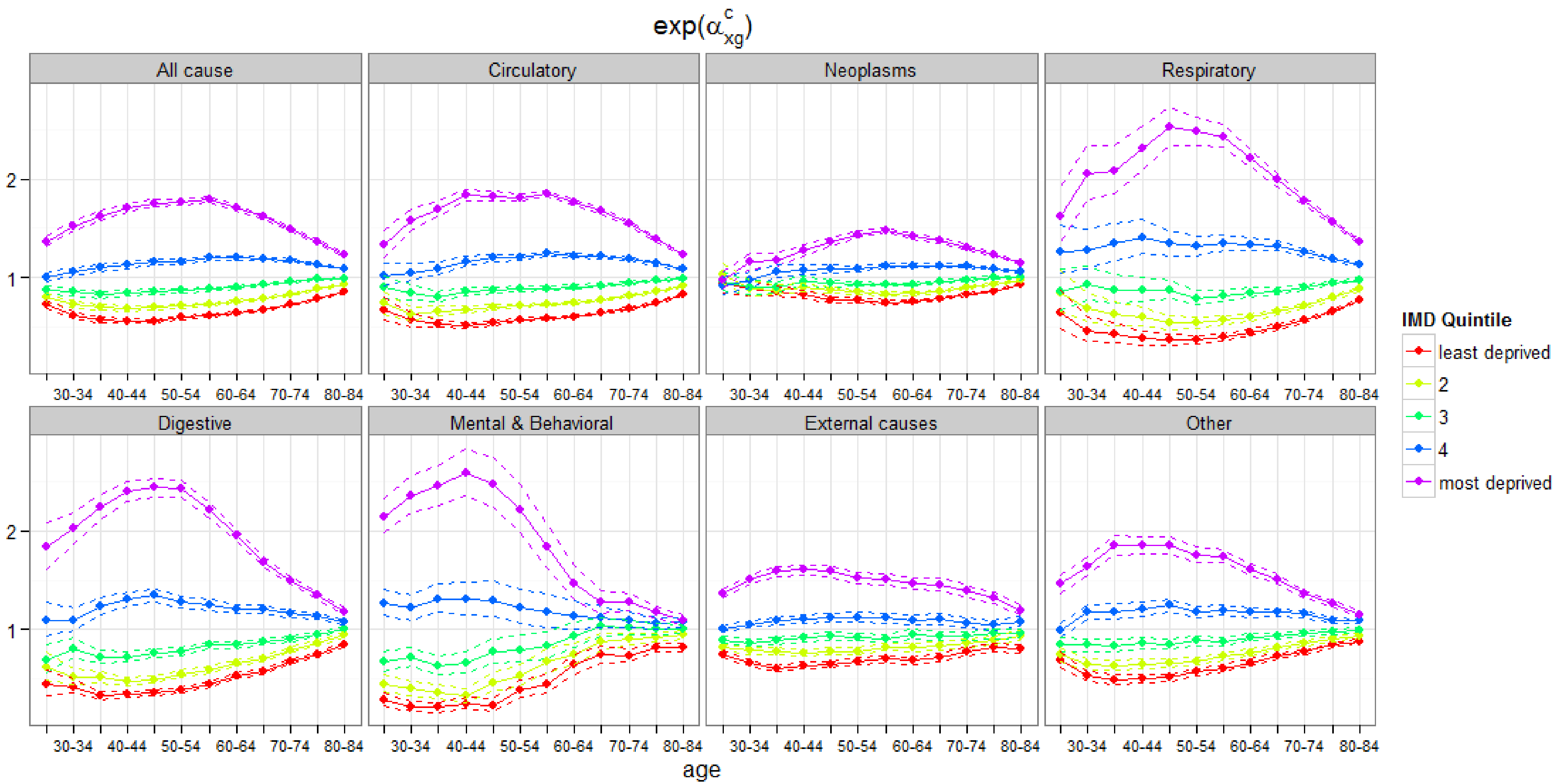


Source: Noble et al (2007)

Case study: Mortality by deprivation in England

Level differences by deprivation quintile (Males)

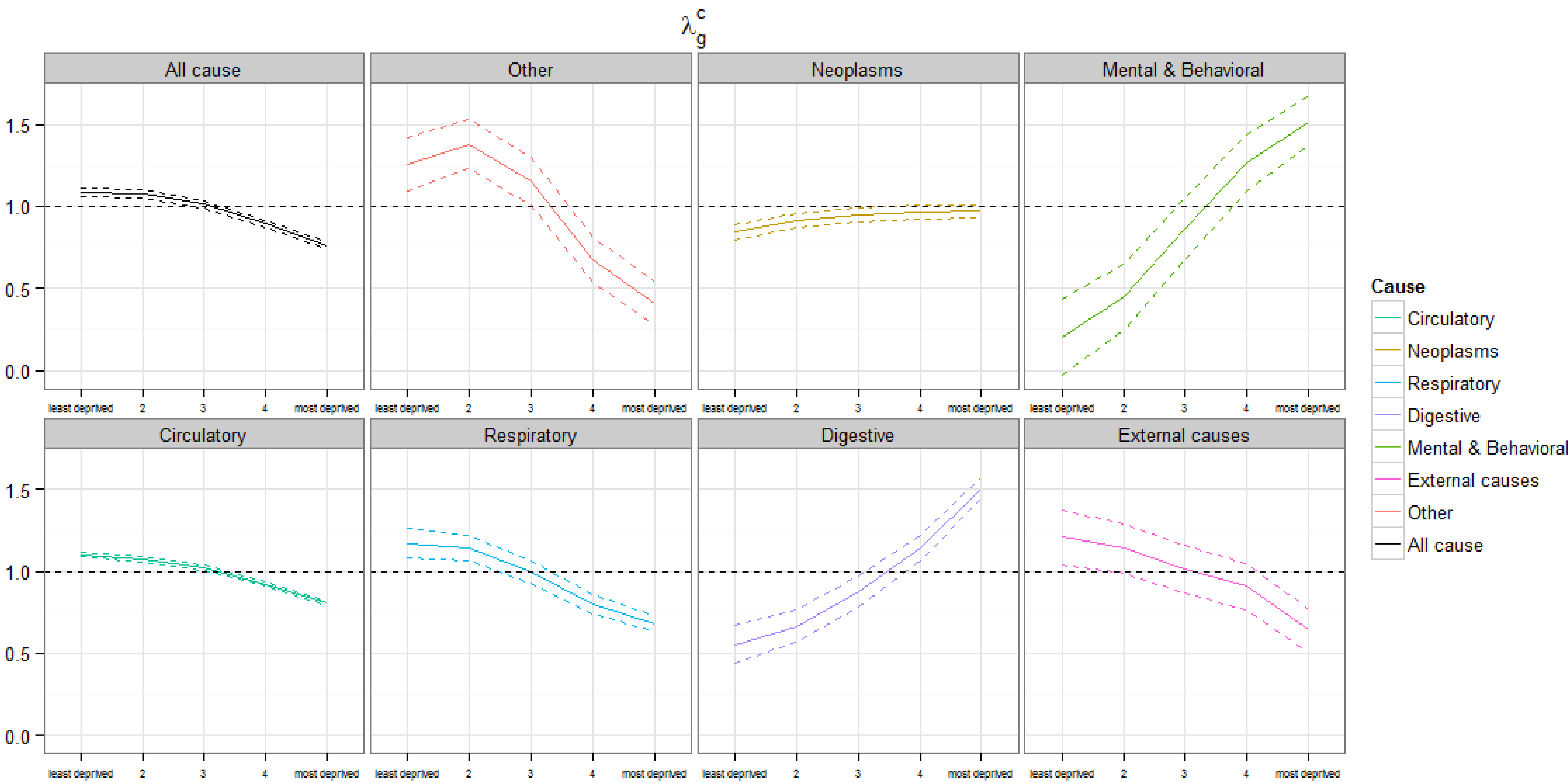
$$\log \mu^c_{xtg} = \alpha^c_x + \alpha^c_{xg} + \beta^c_x \lambda^c_g \kappa^c_t$$



Case study: Mortality by deprivation in England

Trend differences by deprivation quintile (Males)

$$\log \mu_{xtg}^{c} = \alpha_x^c + \alpha_{xg}^c + \beta_x^c \lambda_g^c \kappa_t^c$$

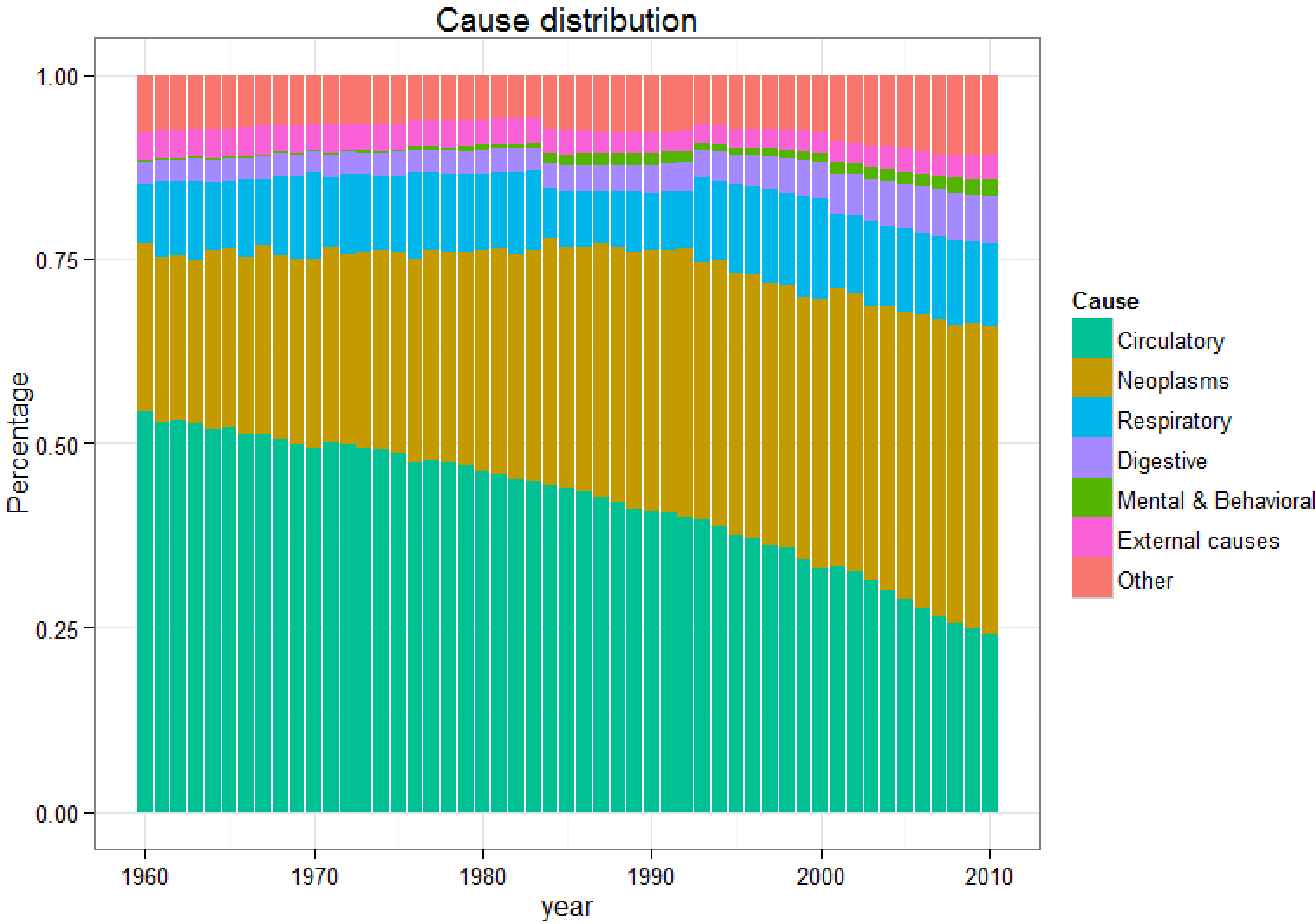


Institute and Faculty of Actuaries

Results for females

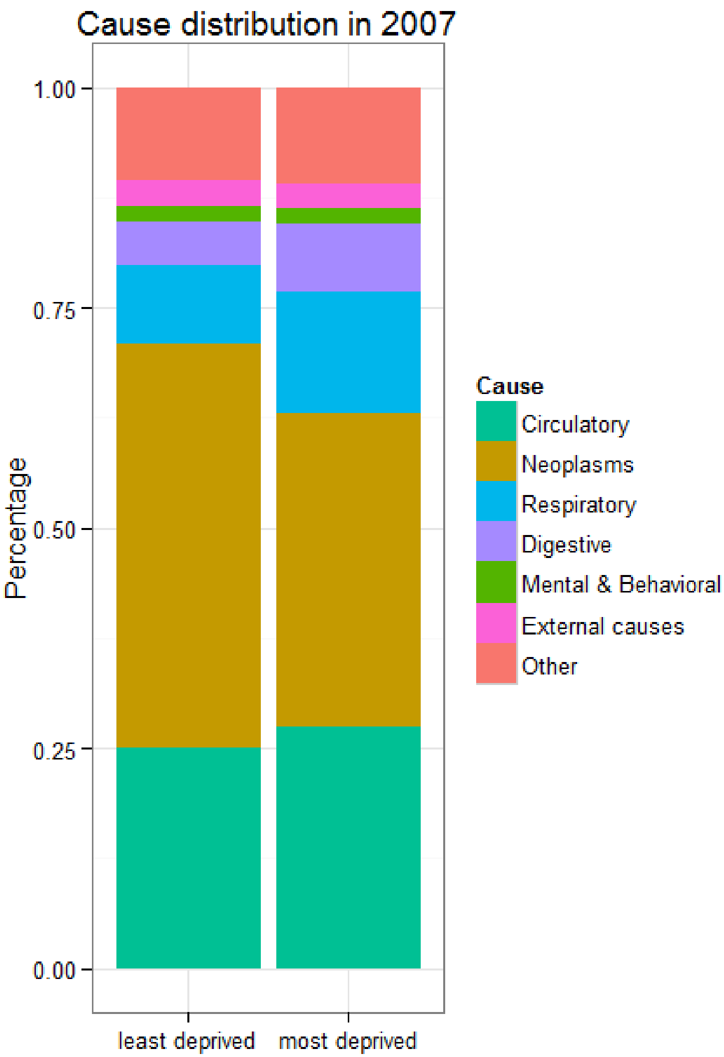
Causes of mortality in England and Wales

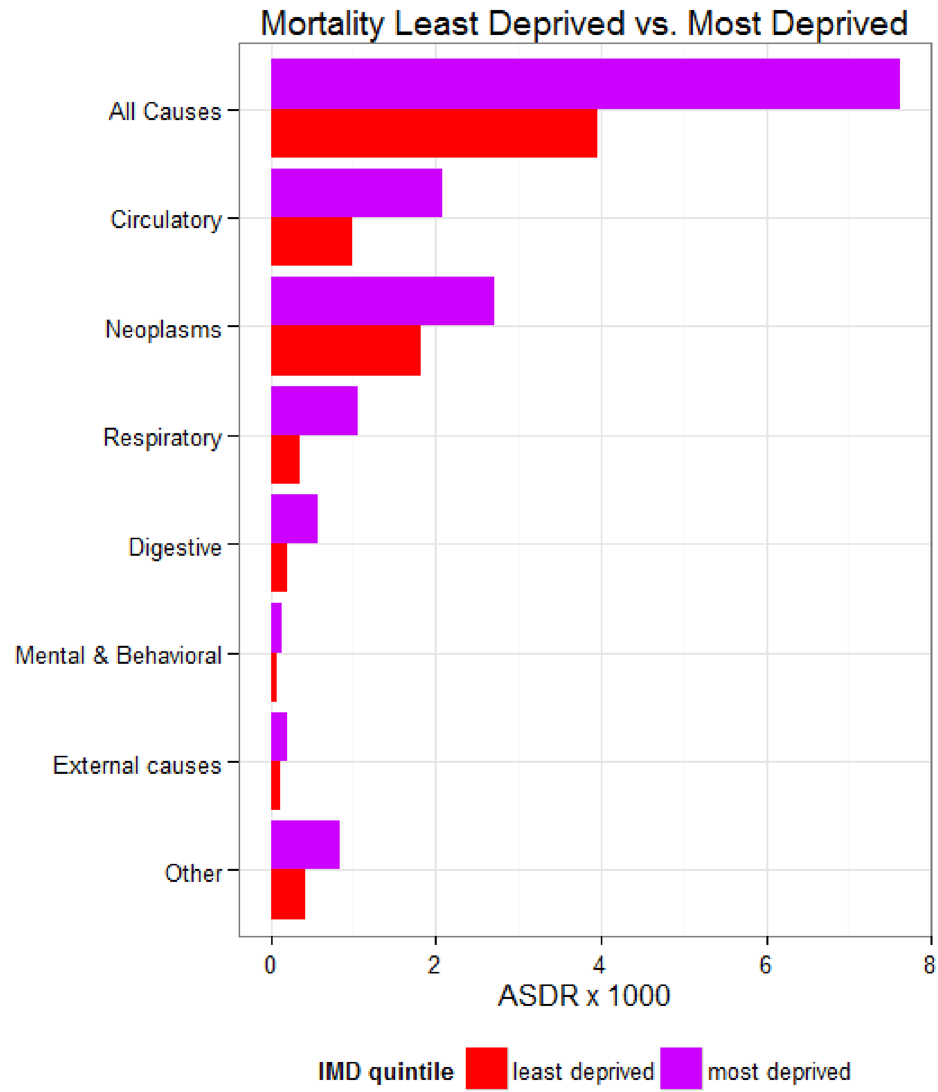
Causes distribution in time (ASDR females age 25-84)



Causes of mortality in England

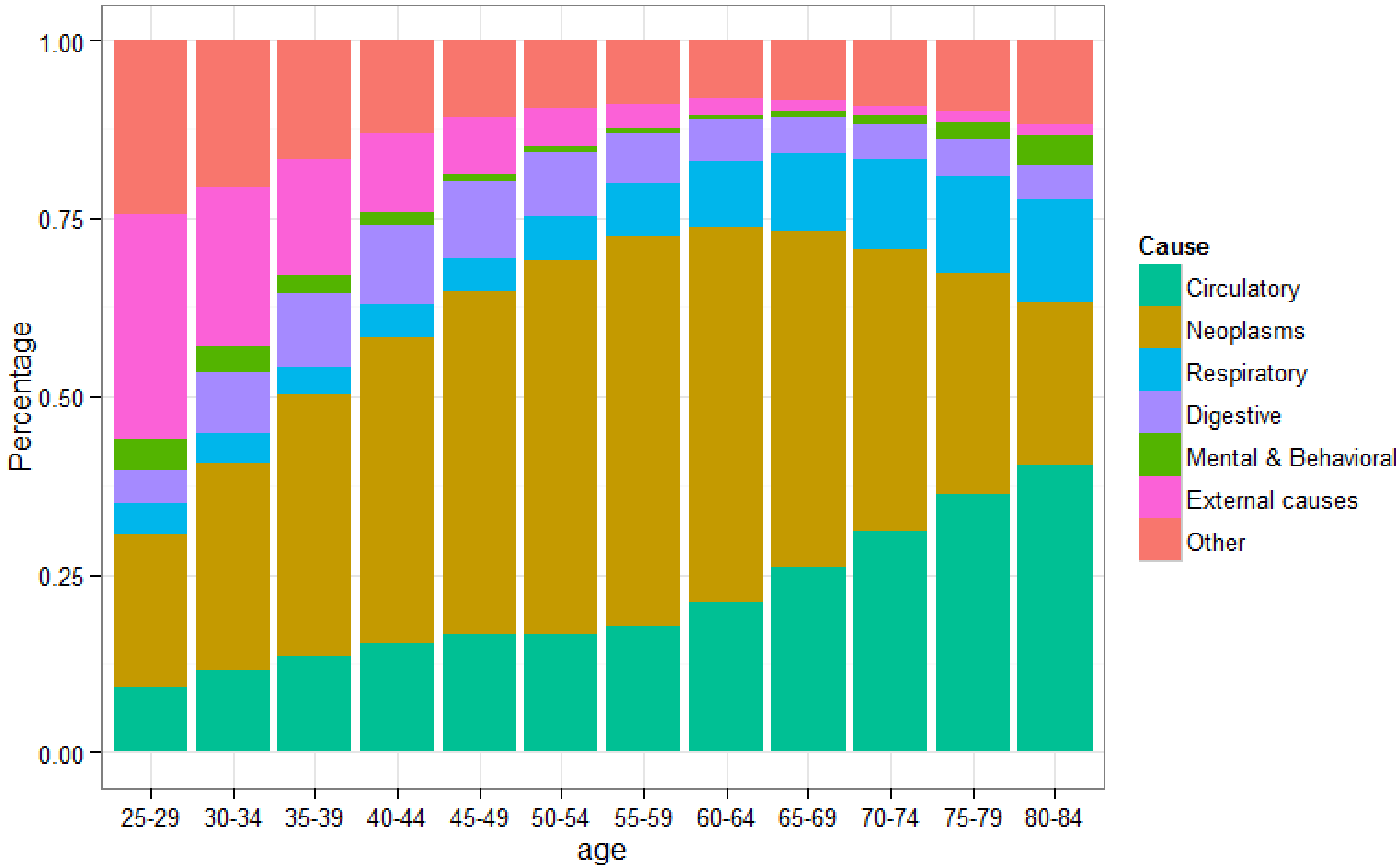
Variation by deprivation quintile (ASDR females age 25-84)





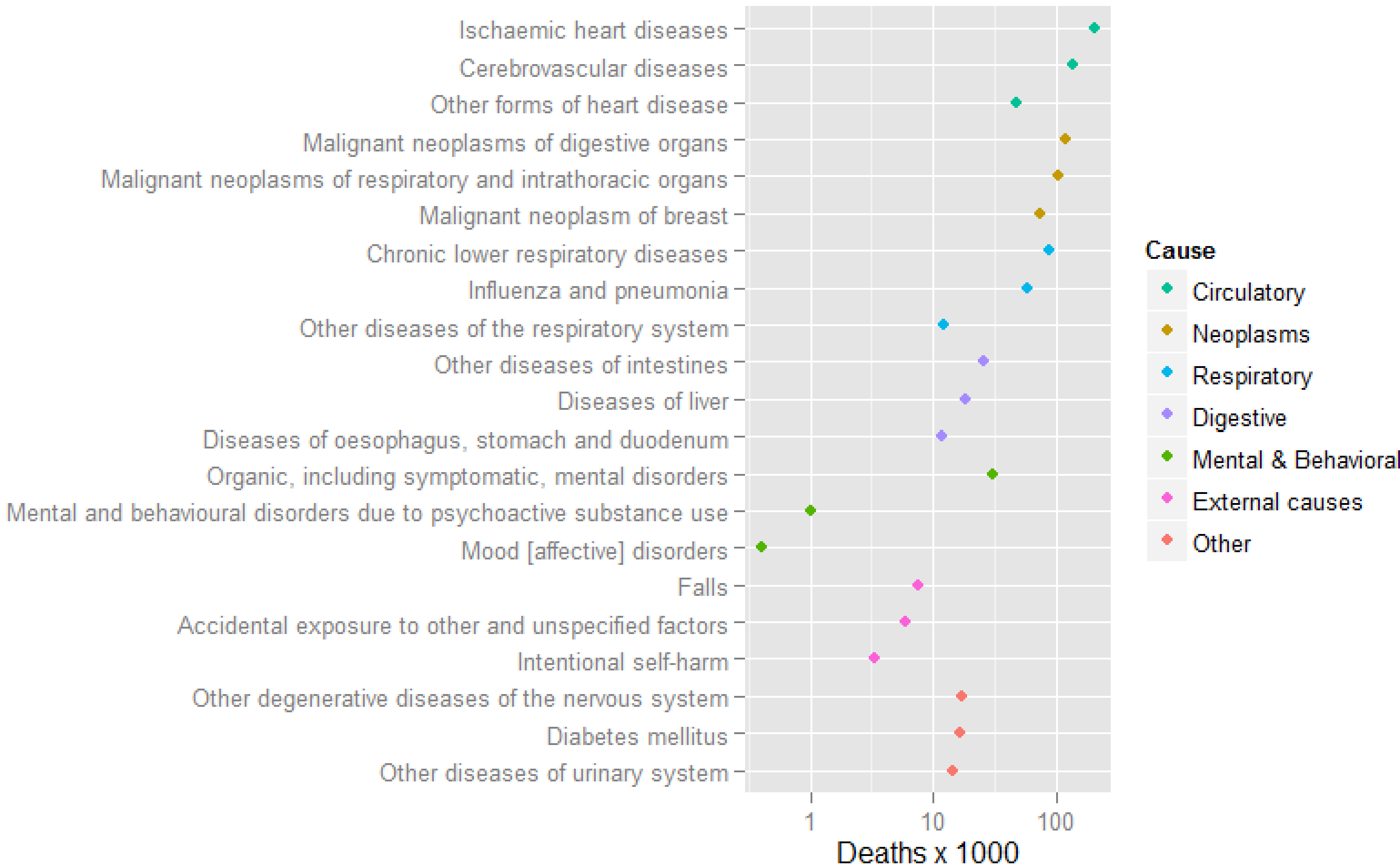
Causes of mortality in England and Wales

Causes distribution by age (females 2001-2010)



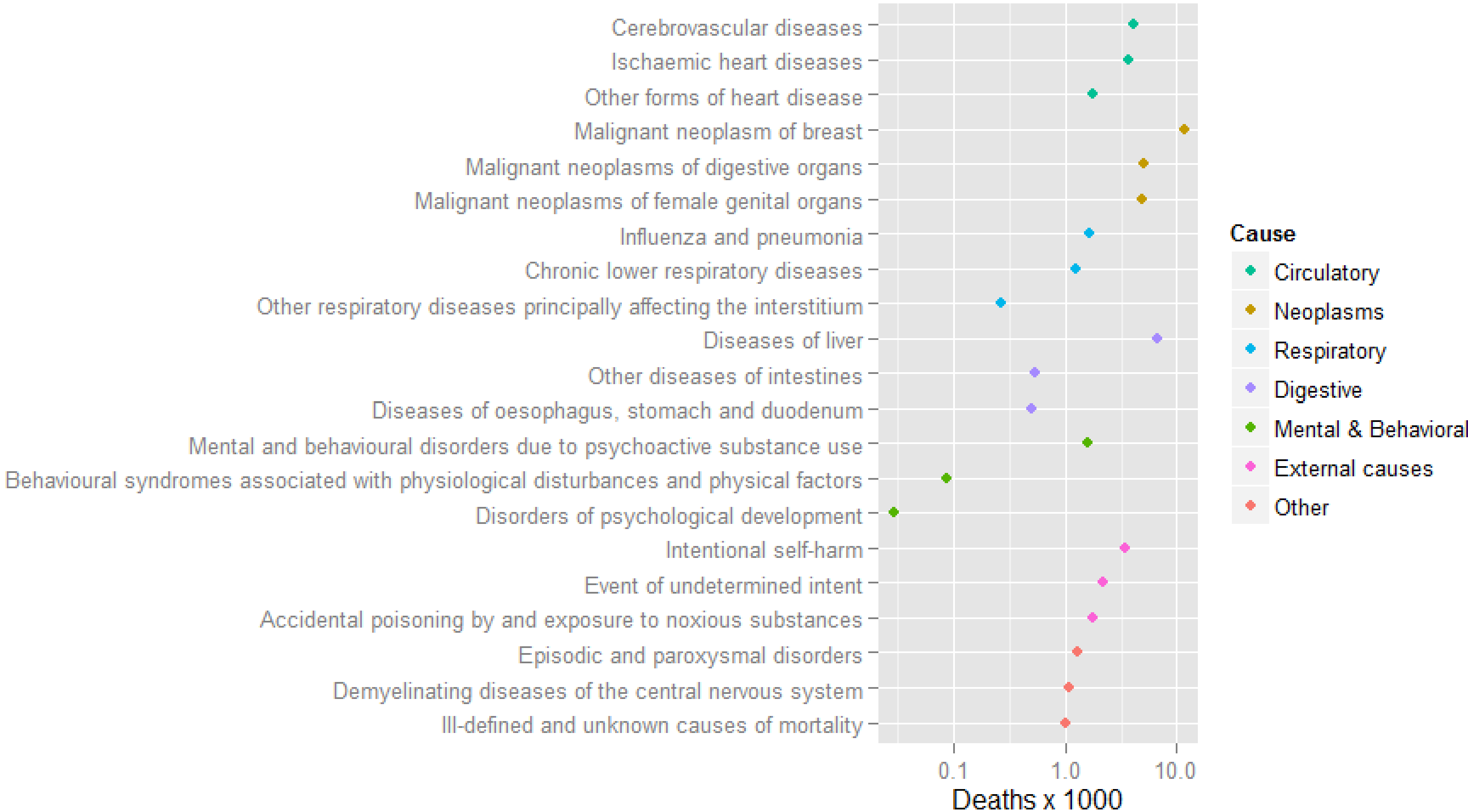
Causes of mortality in England and Wales

Main causes for females aged 50-84 (2001-2010)



Causes of mortality in England and Wales

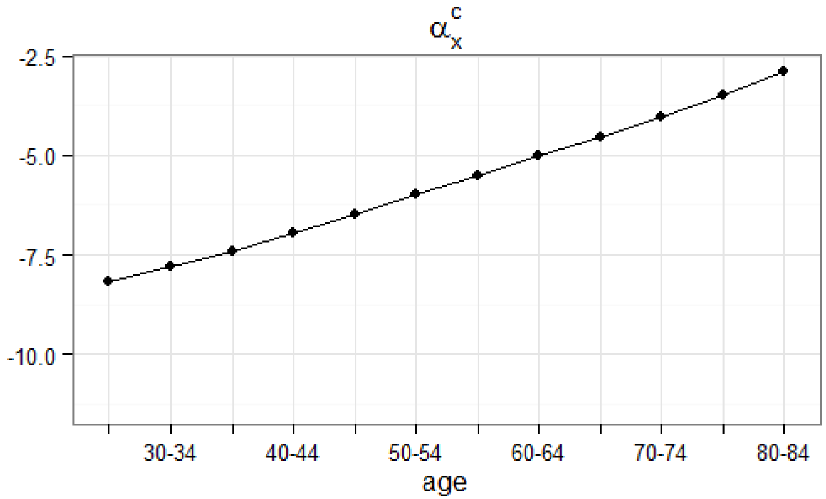
Main causes for females aged 25-49 (2001-2010)

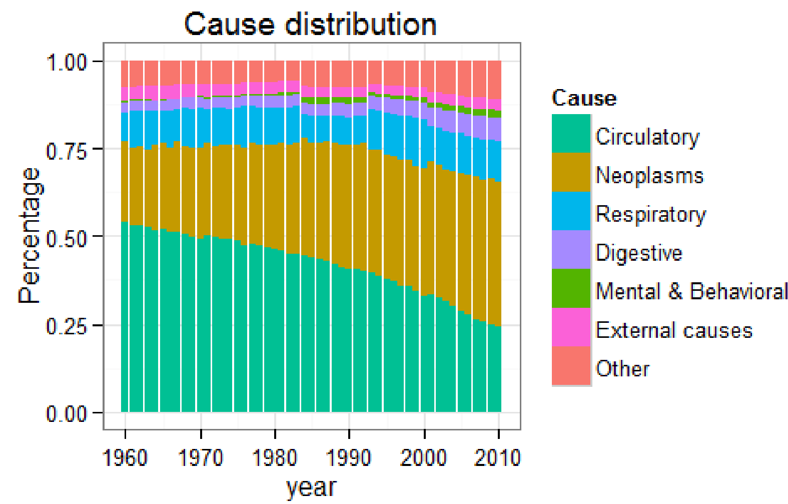


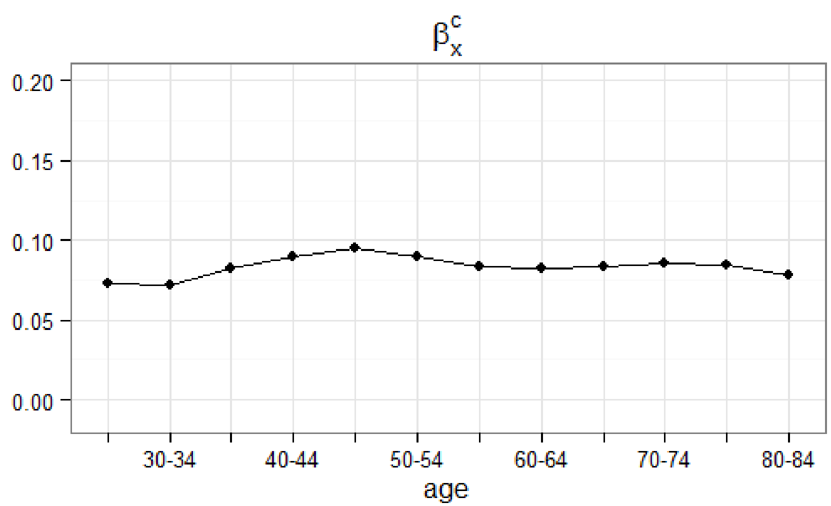
Case study: Mortality by deprivation in England

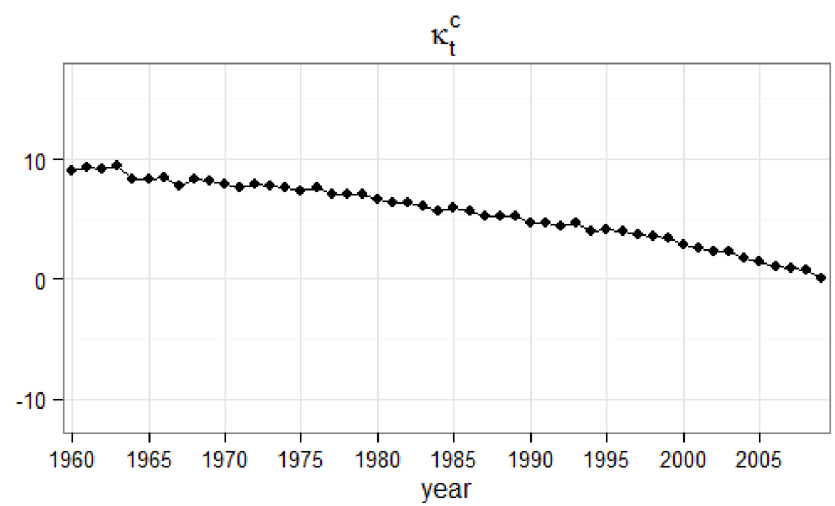
England and Wales Female population parameters

$$\log \mu^c_{xtg} = \alpha^c_x + \alpha^c_{xg} + \beta^c_x \lambda^c_g \kappa^c_t + \sum_{i=1}^{h} \delta^{c,(i)}_x f^{(i)}(t)$$









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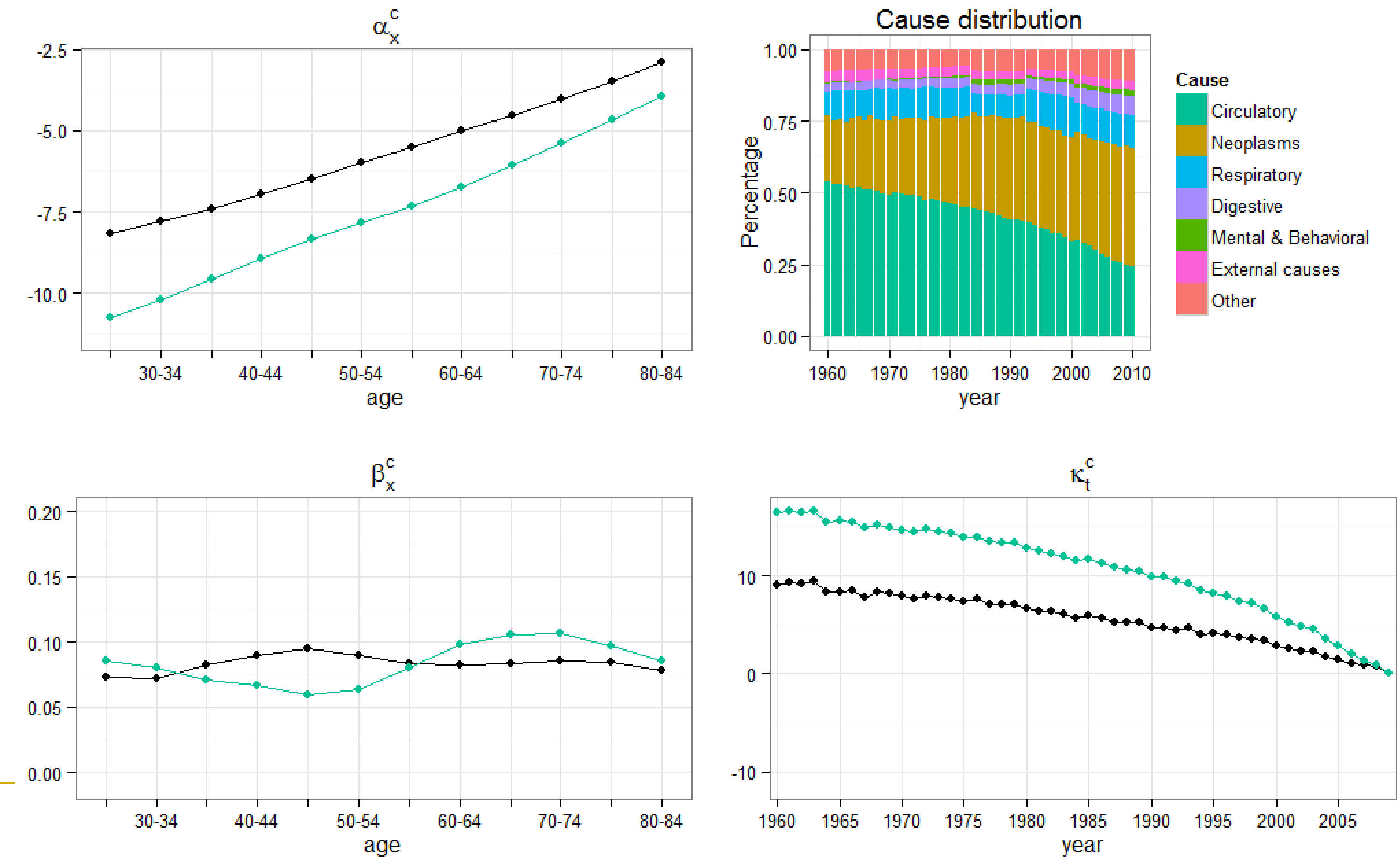

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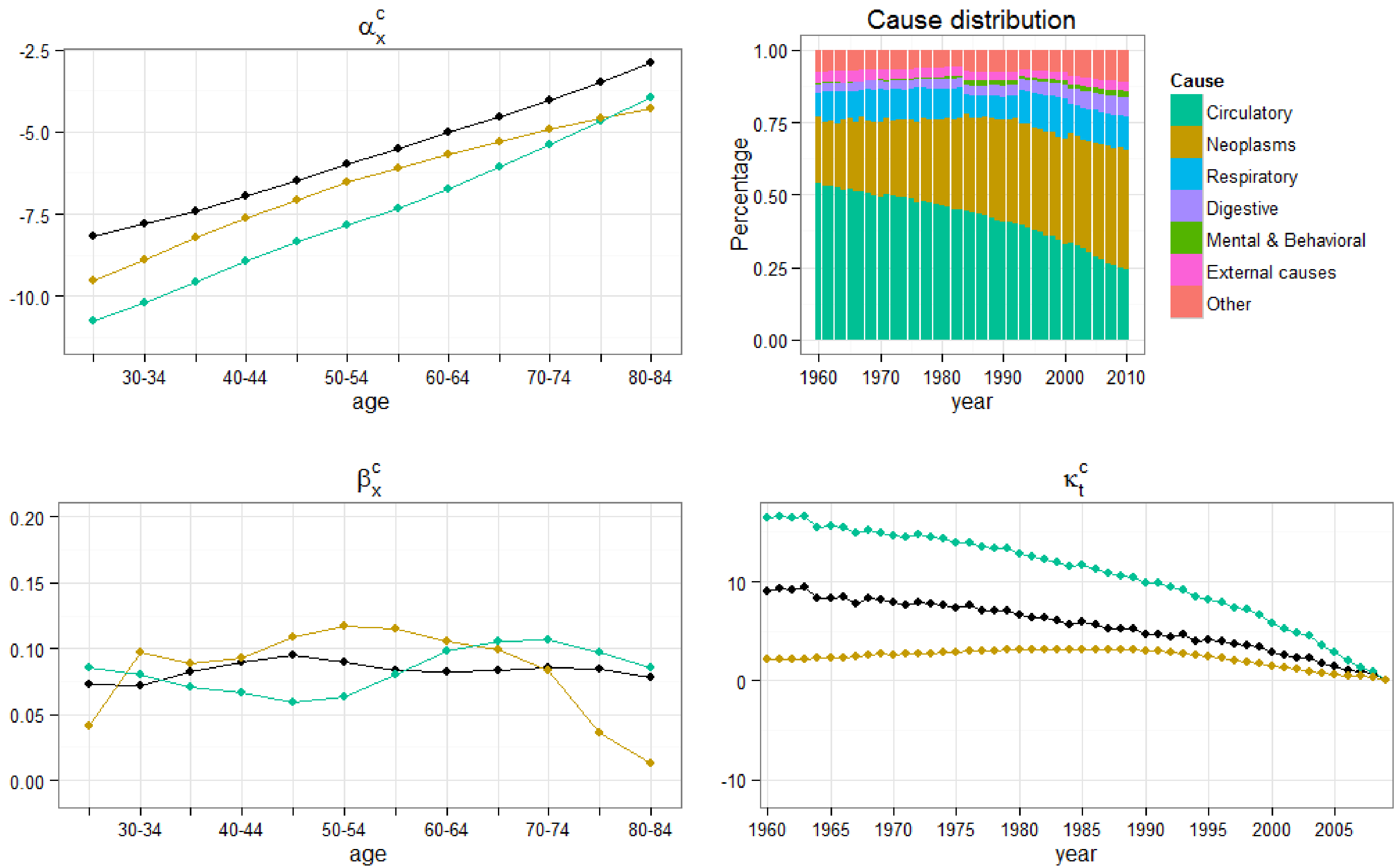

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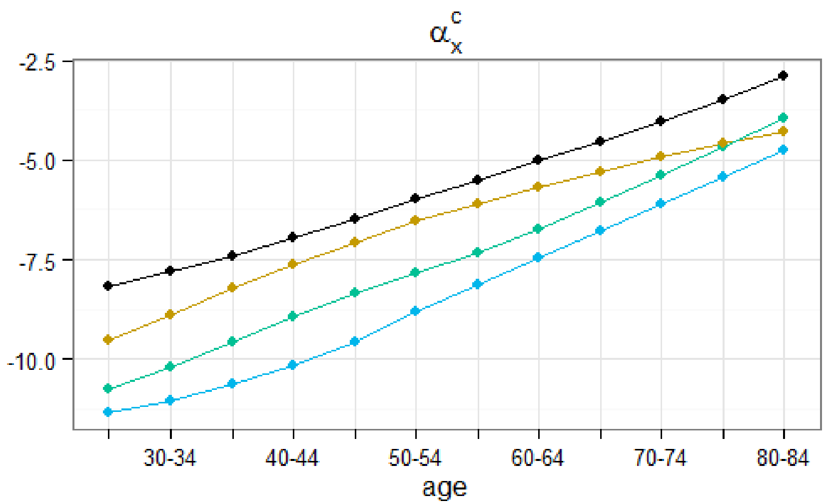

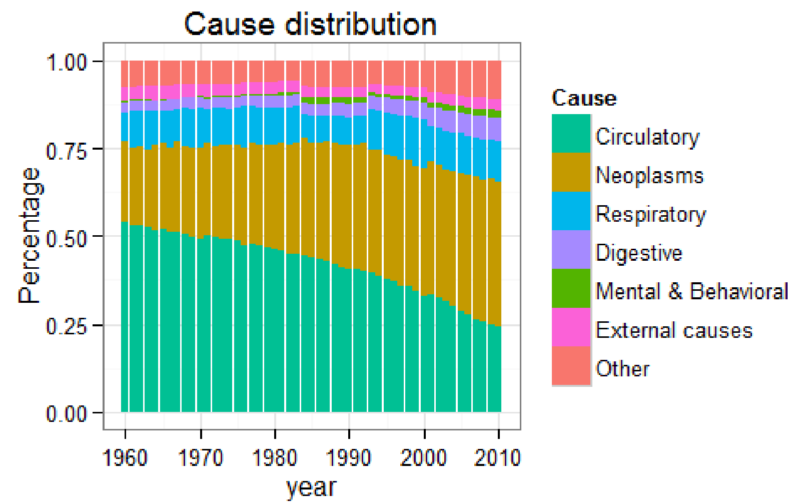

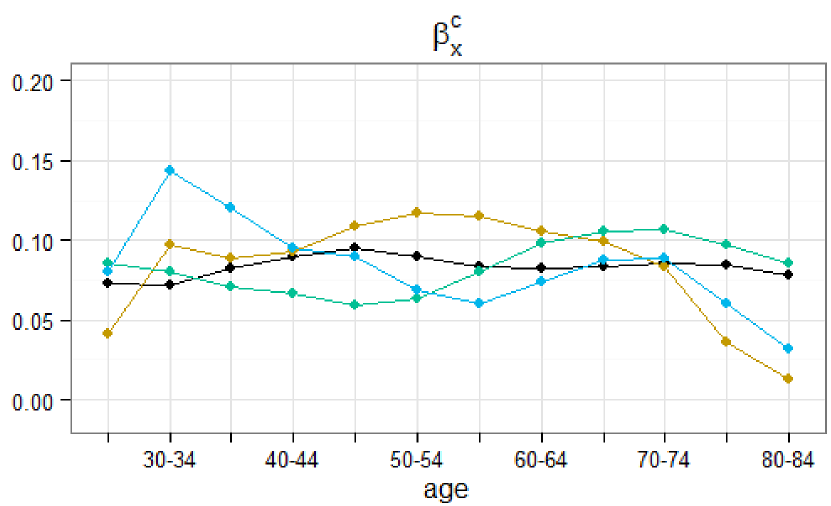

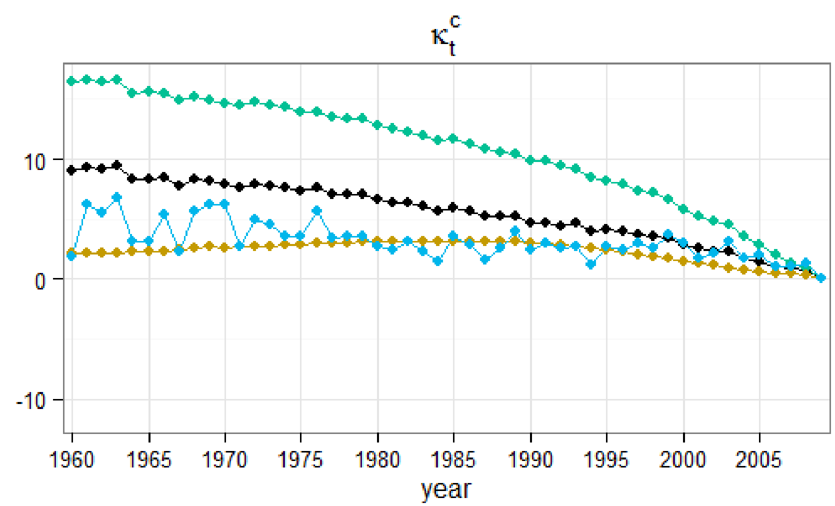

Case study: Mortality by deprivation in England

England and Wales Female population parameters

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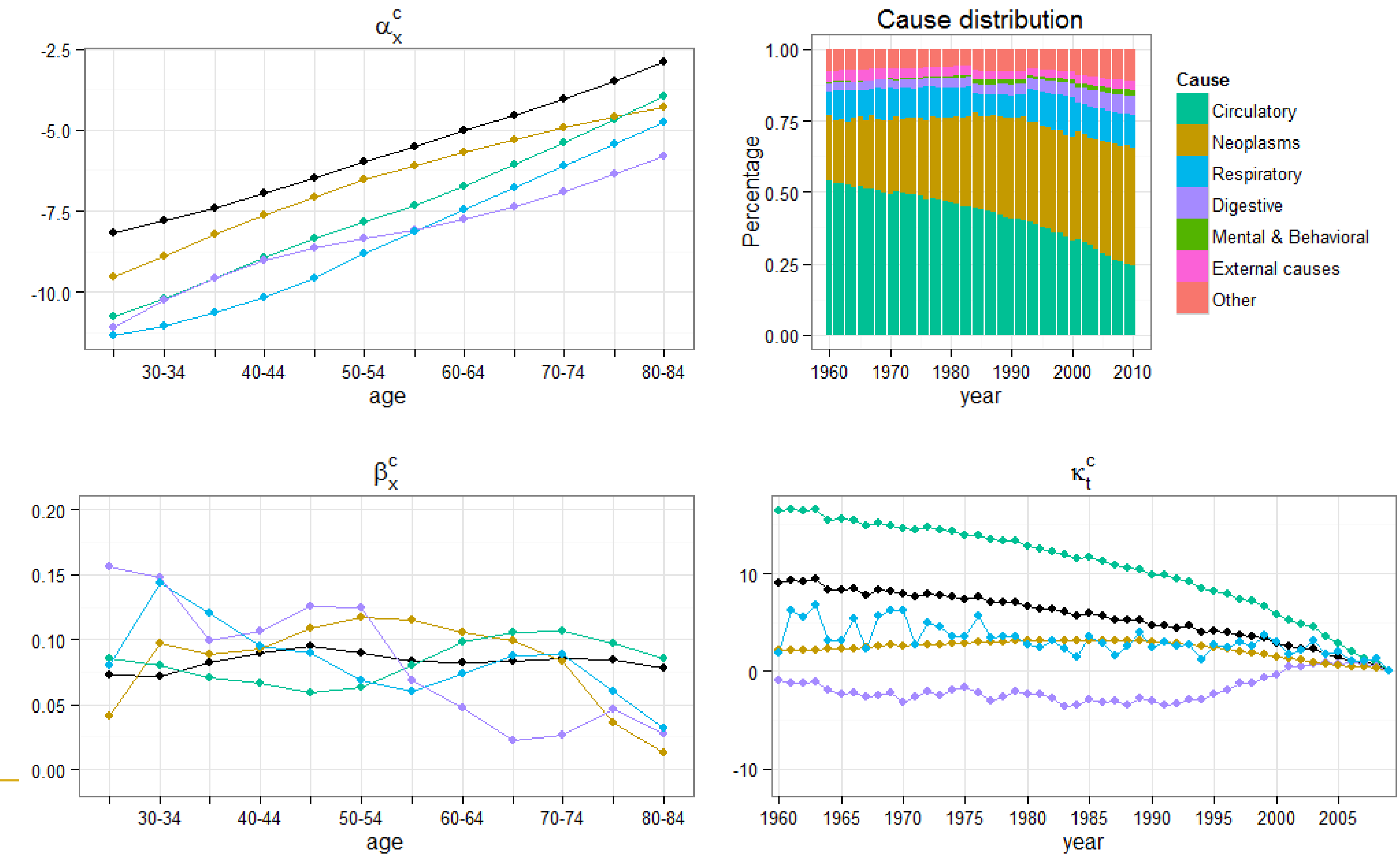

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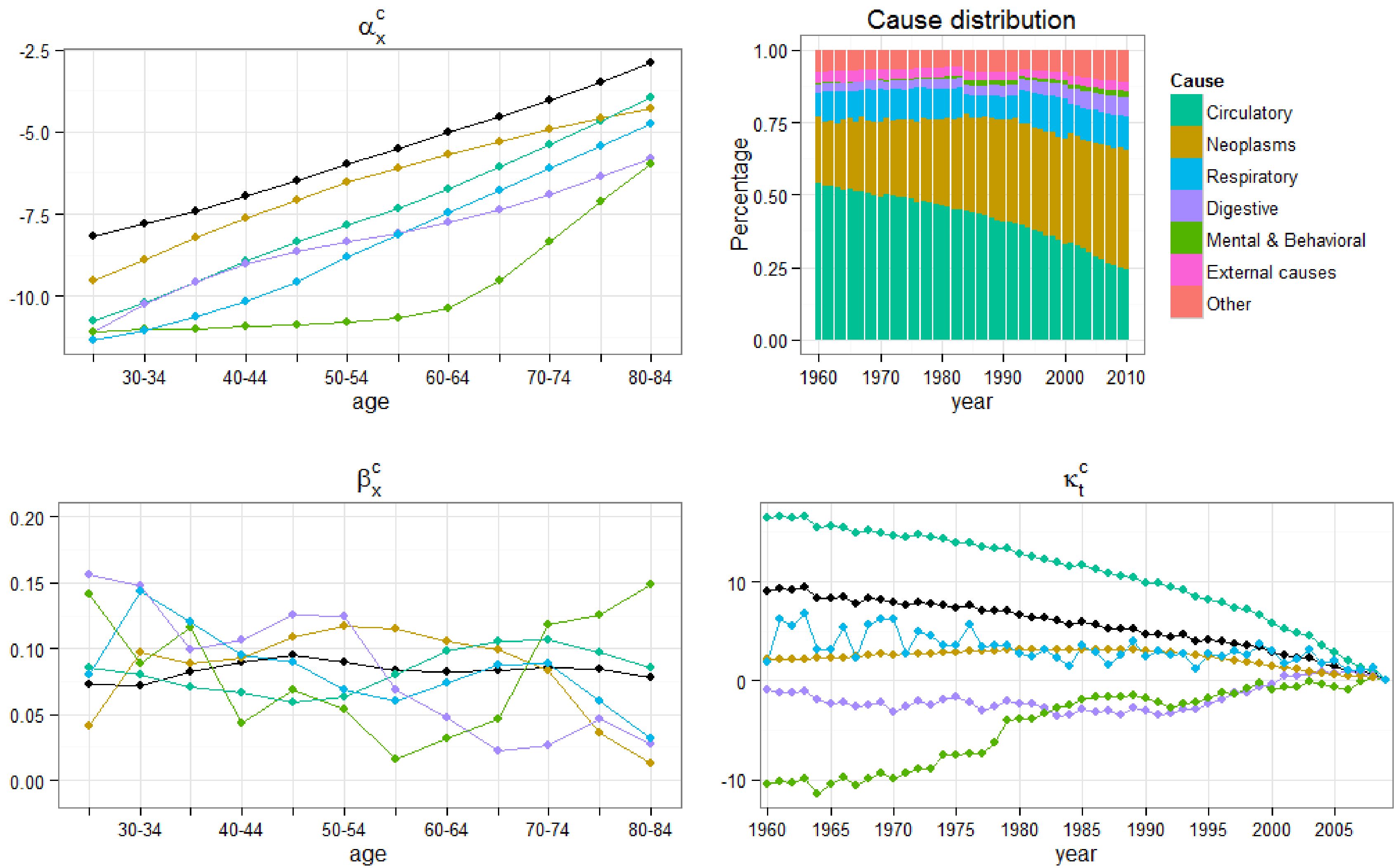

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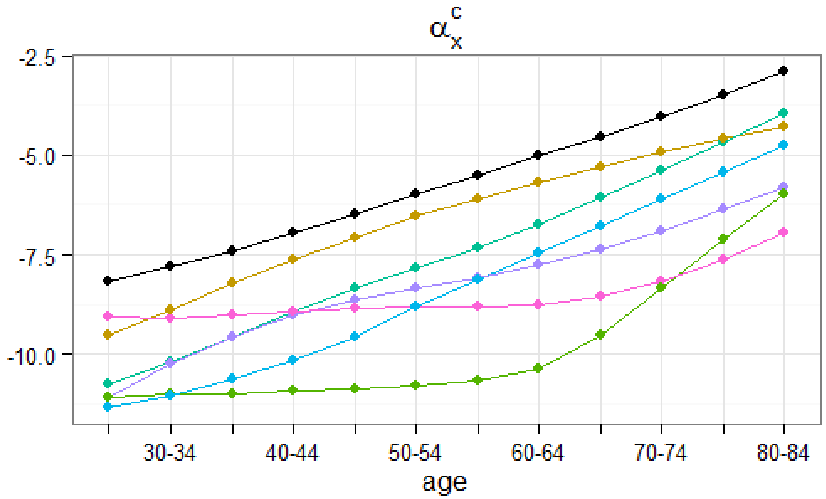
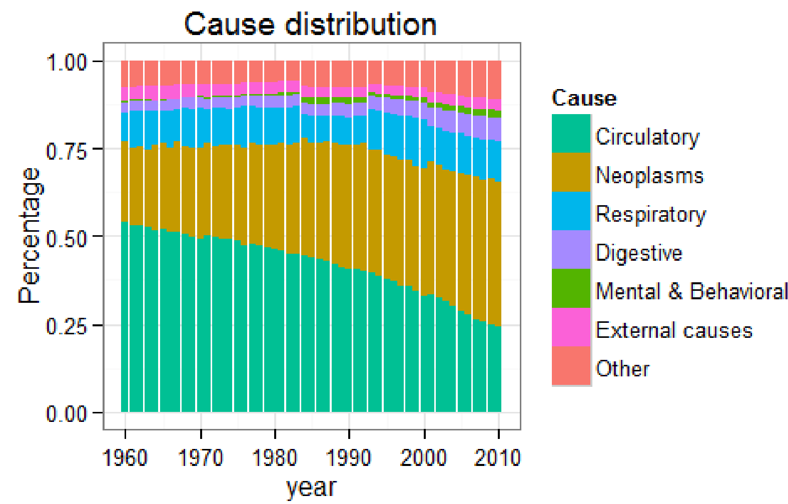
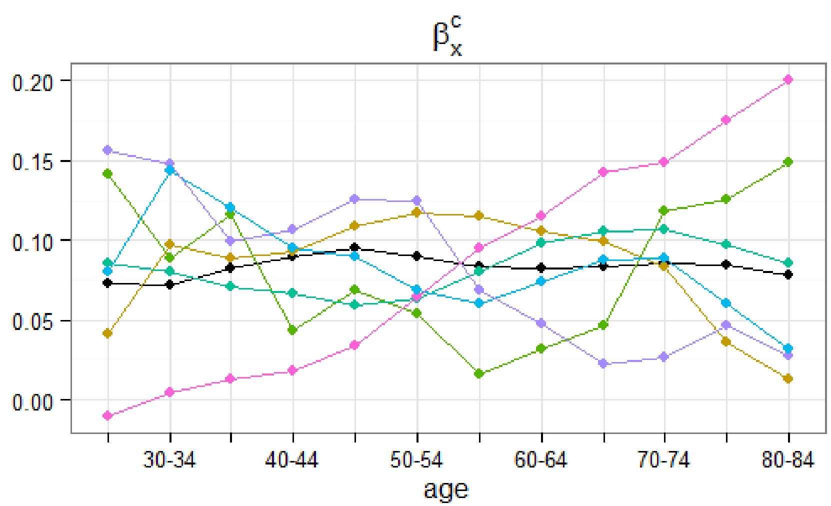
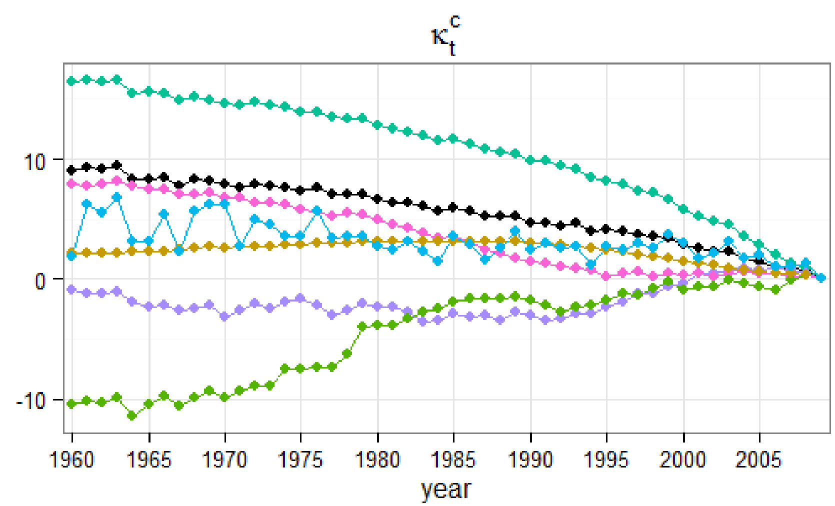
England and Wales Female population parameters

$$\log \mu^c_{xtg} = \alpha^c_x + \alpha^c_{xg} + \beta^c_x \lambda^c_g \kappa^c_t + \sum_{i=1}^{h} \delta_x^{c,(i)} f^{(i)}(t)$$





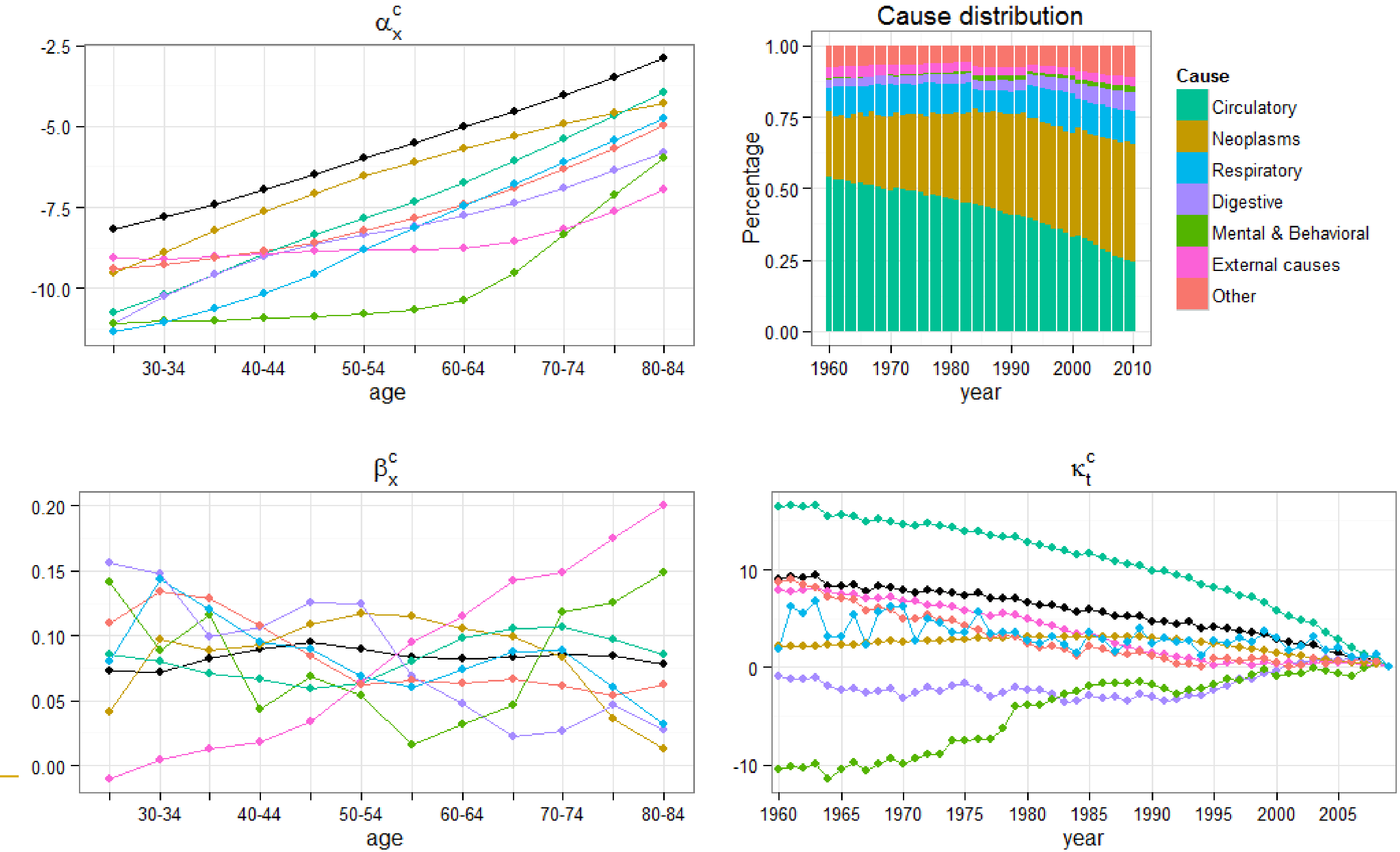




Case study: Mortality by deprivation in England

England and Wales Female population parameters

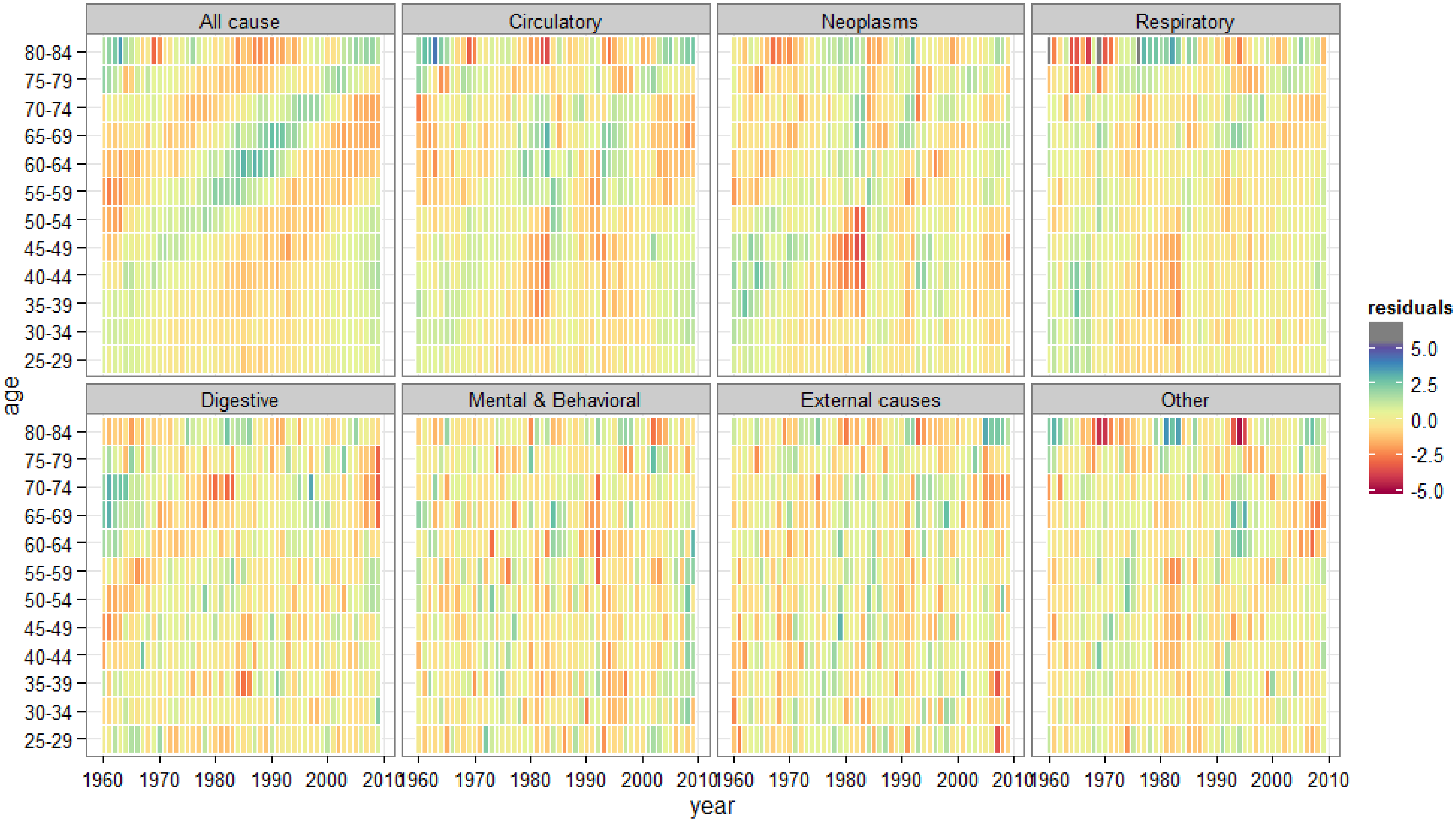
$$\log \mu_{xtg}^{c} = \alpha_x^{c} + \alpha_{xg}^{c} + \beta_x^{c}\lambda_g^{c}\kappa_t^{c} + \sum_{i=1}^{h} \delta_x^{c,(i)} f^{(i)}(t)$$



Case study: Mortality by deprivation in England

England and Wales Female population - Residuals

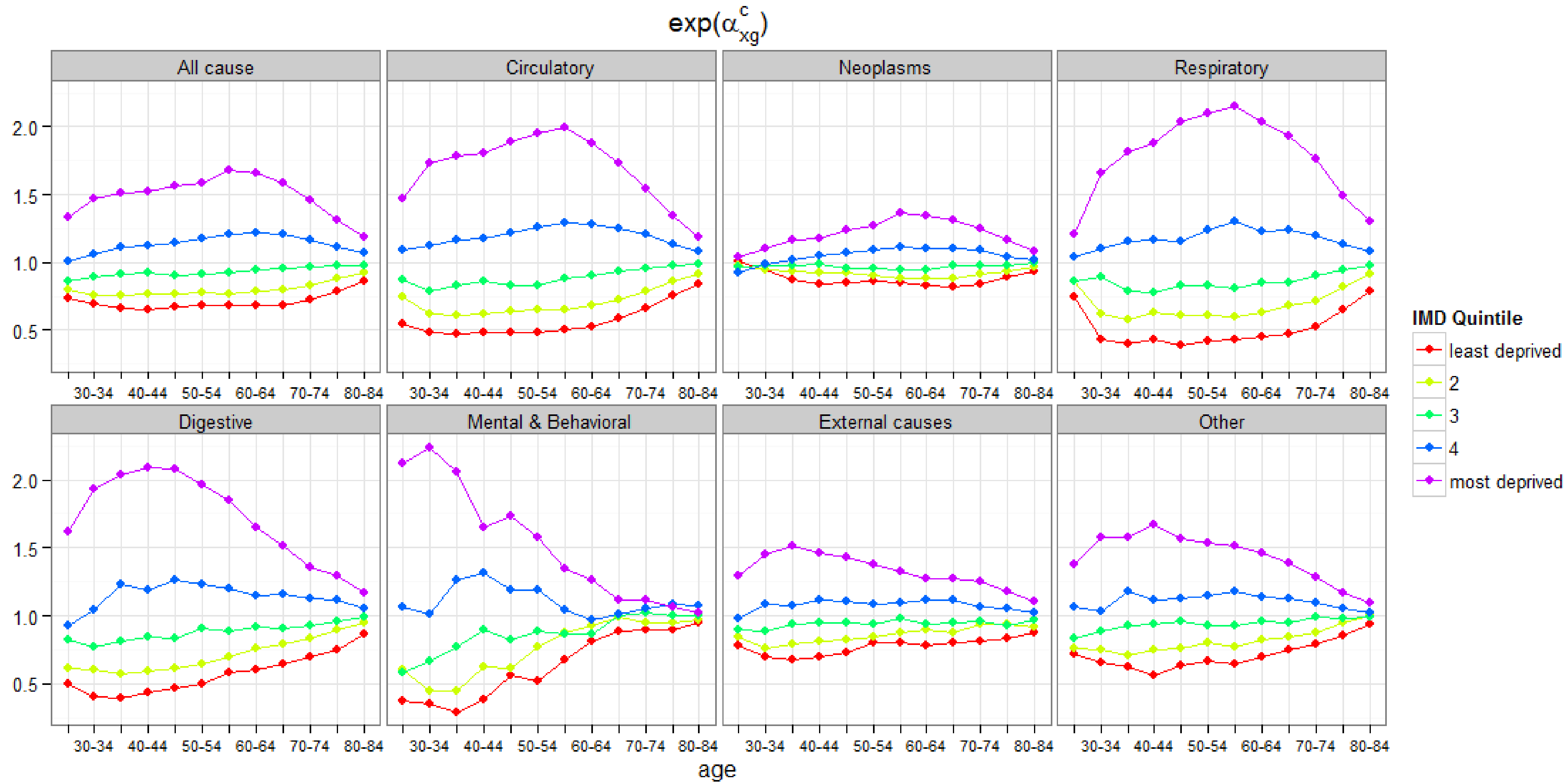
$$\log \mu^c_{xtg} = \alpha^c_x + \alpha^c_{xg} + \beta^c_x \lambda^c_g \kappa^c_t + \sum_{i=1}^{h} \delta^{c,(i)}_x f^{(i)}(t)$$



Case study: Mortality by deprivation in England

Level differences by deprivation quintile (Females)

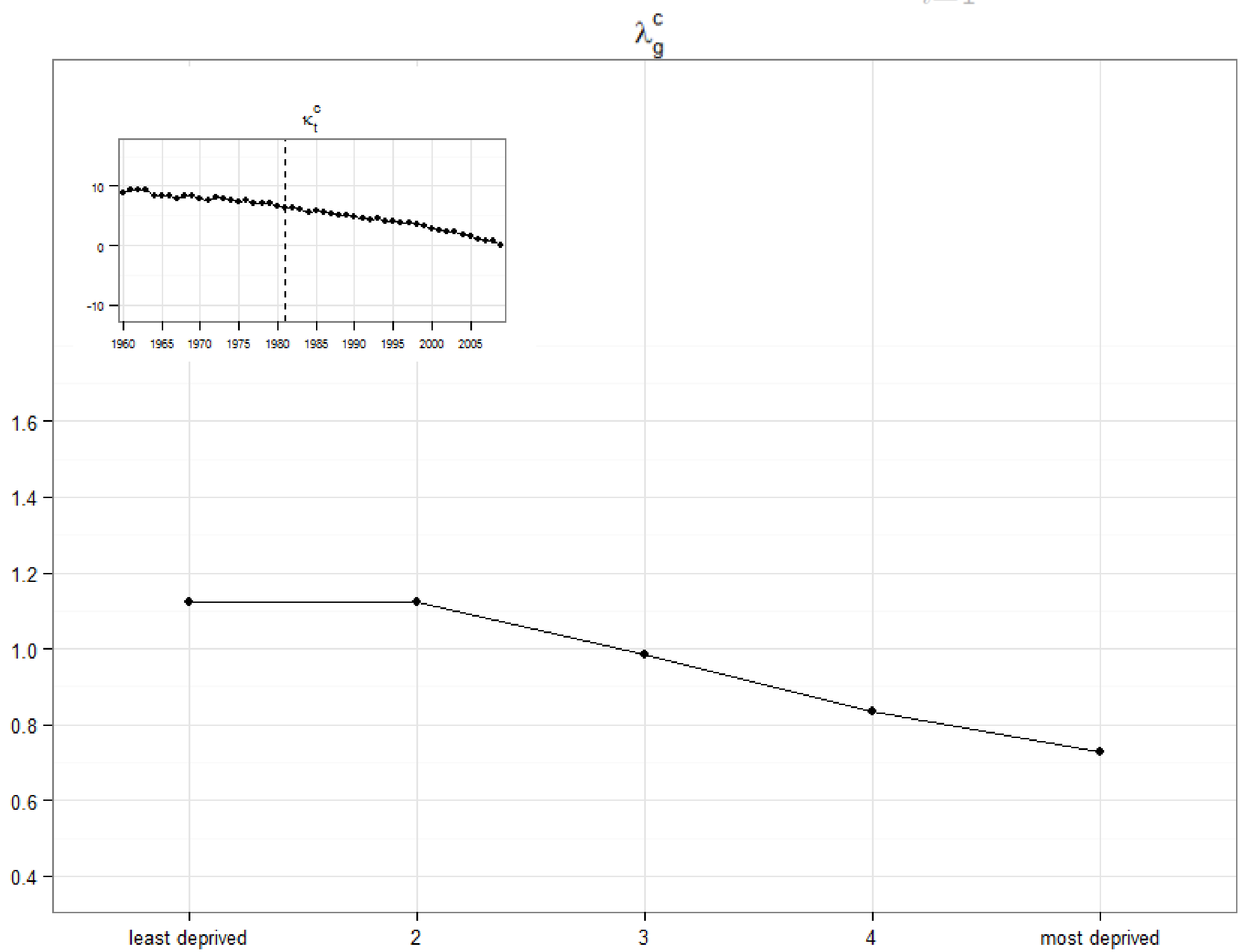
$$\log \mu^c_{xtg} = \alpha^c_x + \alpha^c_{xg} + \beta^c_x \lambda^c_g \kappa^c_t + \sum_{i=1}^{h} \delta^{c,(i)}_x f^{(i)}(t)$$



Case study: Mortality by deprivation in England

Trend differences by deprivation quintile (Females)

$$\log \mu_{xtg}^{c} = \alpha_x^c + \alpha_{xg}^c + \beta_x^c \lambda_g^c \kappa_t^c + \sum_{i=1}^{h} \delta_x^{c,(i)} f^{(i)}(t)$$



Cause	Average annual Improvement*
All cause	1.90%
Circulatory	
Neoplasms	
Respiratory	
Digestive	
Mental & Behavioral	
External causes	
Other	

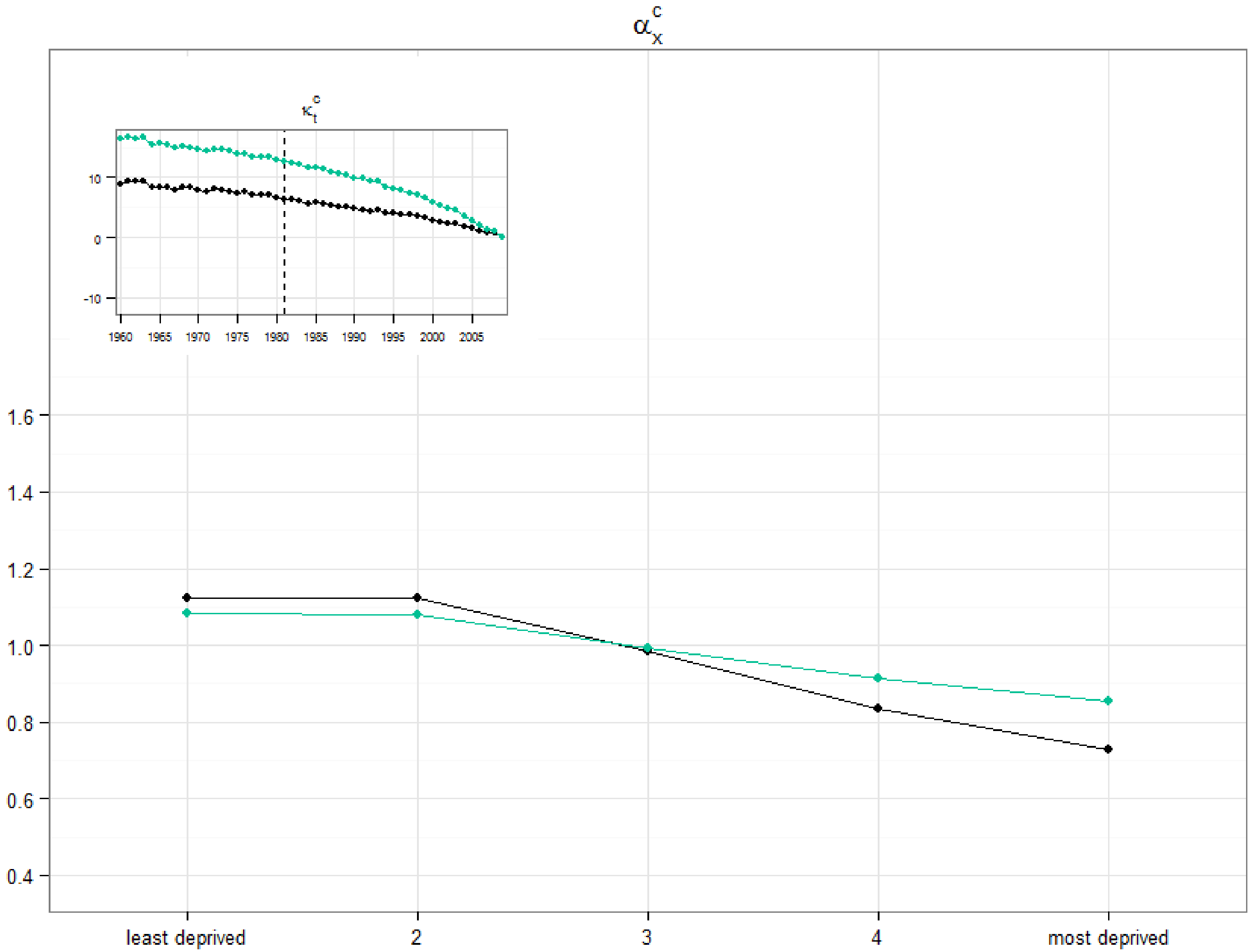
*Average annual Improvement for England and Wales for the period 1981-2009 computed as

$$\frac{\kappa_{1981}^{c} - \kappa_{2009}^{c}}{2009 - 1981} \times \frac{1}{\#Age\ Bands}$$

Case study: Mortality by deprivation in England

Trend differences by deprivation quintile (Females)

$$\log \mu^c_{xtg} = \alpha^c_x + \alpha^c_{xg} + \beta^c_x \lambda^c_g \kappa^c_t + \sum_{i=1}^{h} \delta^{c,(i)}_x f^{(i)}(t)$$



Cause	Average annual Improvement*
All cause	1.90%
Circulatory	3.72%
Neoplasms	
Respiratory	
Digestive	
Mental & Behavioral	
External causes	
Other	

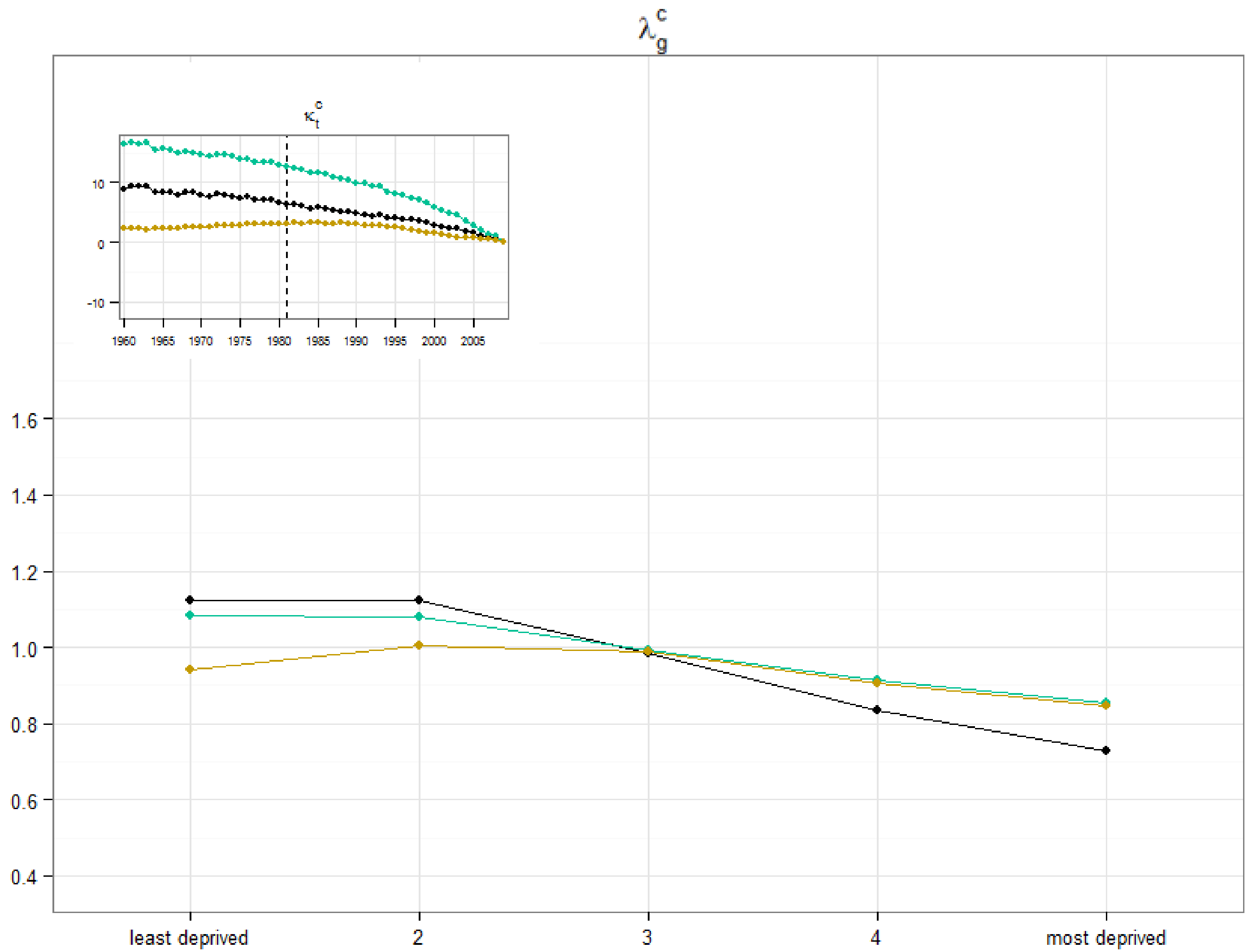
*Average annual Improvement for England and Wales for the period 1981-2009 computed as

$$\frac{\kappa^c_{1981} - \kappa^c_{2009}}{2009 - 1981} \times \frac{1}{\#Age\ Bands}$$

Case study: Mortality by deprivation in England

Trend differences by deprivation quintile (Females)

$$\log \mu^c_{xtg} = \alpha^c_x + \alpha^c_{xg} + \beta^c_x \lambda^c_g \kappa^c_t + \sum_{i=1}^{h} \delta^{c,(i)}_x f^{(i)}(t)$$



Cause	Average annual Improvement*
All cause	1.90%
Circulatory	3.72%
Neoplasms	0.92%
Respiratory	
Digestive	
Mental & Behavioral	
External causes	
Other	

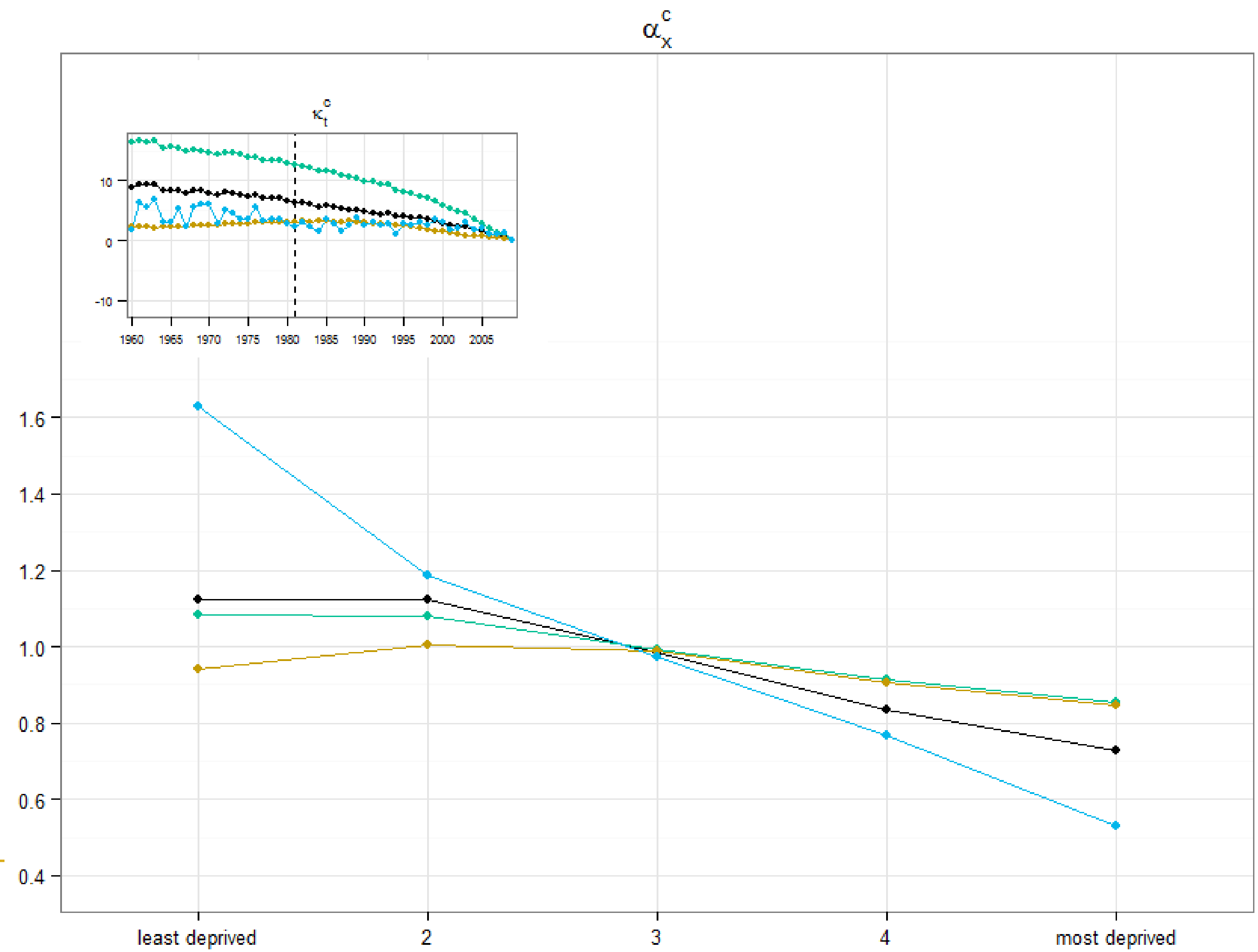
*Average annual Improvement for England and Wales for the period 1981-2009 computed as

$$\frac{\kappa^c_{1981} - \kappa^c_{2009}}{2009 - 1981} \times \frac{1}{\#Age\ Bands}$$

Case study: Mortality by deprivation in England

Trend differences by deprivation quintile (Females)

$$\log \mu^{c}_{xtg} = \alpha^{c}_{x} + \alpha^{c}_{xg} + \beta^{c}_{x}\lambda^{c}_{g}\kappa^{c}_{t} + \sum_{i=1}^{h} \delta^{c,(i)}_{x} f^{(i)}(t)$$



Cause	Average annual Improvement*
All cause	1.90%
Circulatory	3.72%
Neoplasms	0.92%
Respiratory	0.74%
Digestive	
Mental & Behavioral	
External causes	
Other	

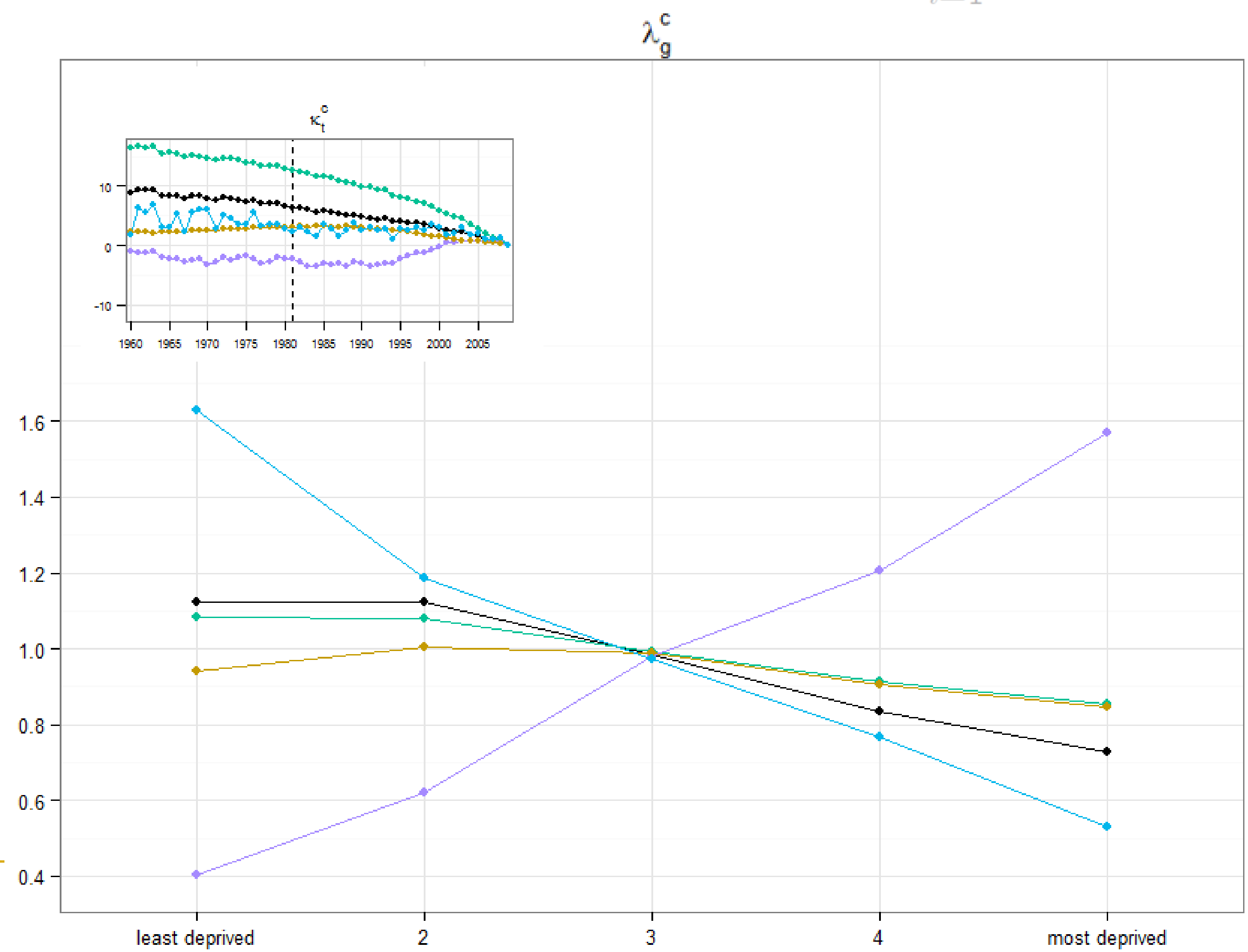
*Average annual Improvement for England and Wales for the period 1981-2009 computed as

$$\frac{\kappa^{c}_{1981} - \kappa^{c}_{2009}}{2009 - 1981} \times \frac{1}{\#Age\ Bands}$$

Case study: Mortality by deprivation in England

Trend differences by deprivation quintile (Females)

$$\log \mu^c_{xtg} = \alpha^c_x + \alpha^c_{xg} + \beta^c_x \lambda^c_g \kappa^c_t + \sum_{i=1}^{h} \delta^{c,(i)}_x f^{(i)}(t)$$



Cause	Average annual Improvement*
All cause	1.90%
Circulatory	3.72%
Neoplasms	0.92%
Respiratory	0.74%
Digestive	-0.68%
Mental & Behavioral	
External causes	
Other	

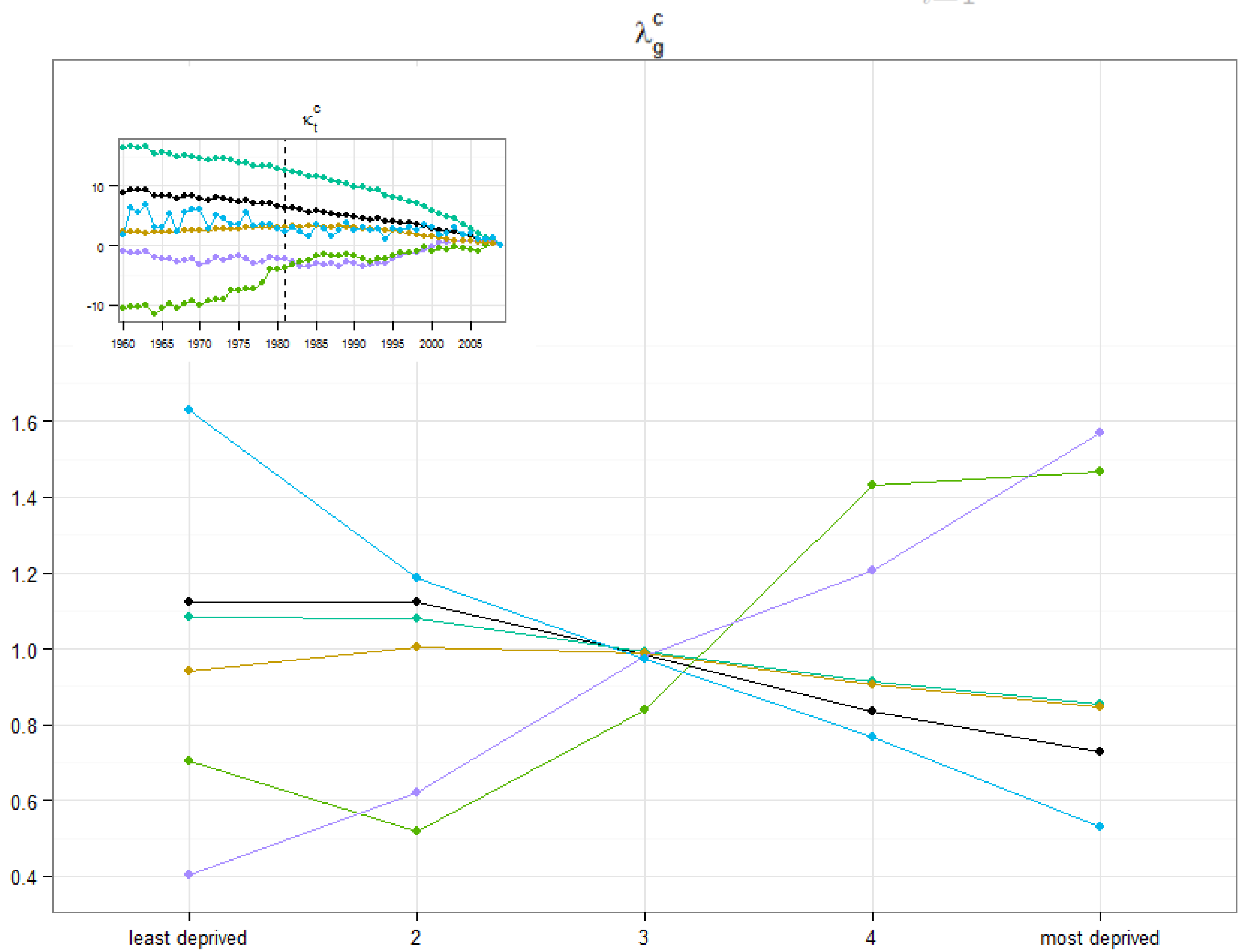
*Average annual Improvement for England and Wales for the period 1981-2009 computed as

$$\frac{\kappa^c_{1981} - \kappa^c_{2009}}{2009 - 1981} \times \frac{1}{\#Age\ Bands}$$

Case study: Mortality by deprivation in England

Trend differences by deprivation quintile (Females)

$$\log \mu^c_{xtg} = \alpha^c_x + \alpha^c_{xg} + \beta^c_x \lambda^c_g \kappa^c_t + \sum_{i=1}^{h} \delta^{c,(i)}_x f^{(i)}(t)$$



Cause	Average annual Improvement*
All cause	1.90%
Circulatory	3.72%
Neoplasms	0.92%
Respiratory	0.74%
Digestive	-0.68%
Mental & Behavioral	-1.14%
External causes	
Other	

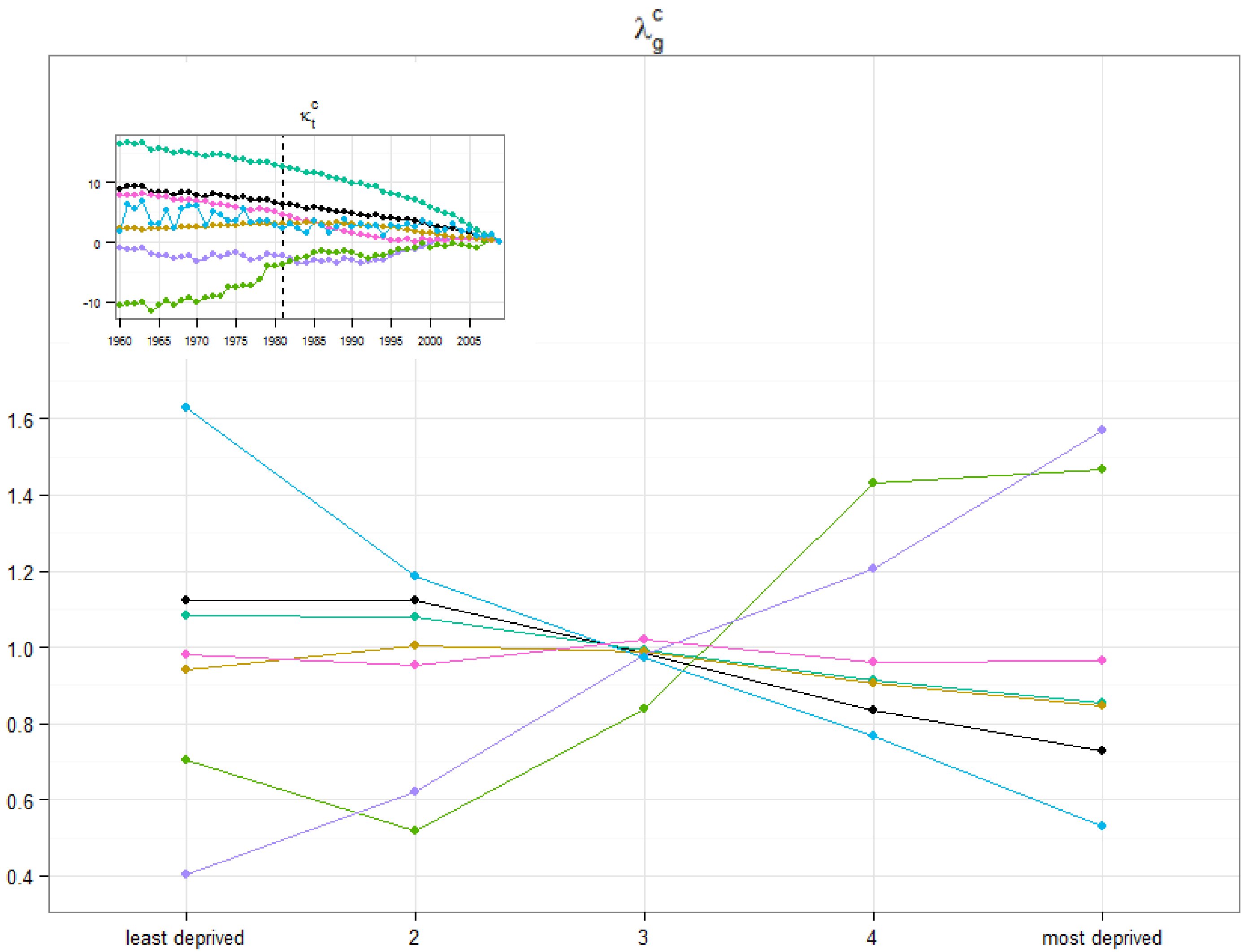
*Average annual Improvement for England and Wales for the period 1981-2009 computed as

$$\frac{\kappa^c_{1981} - \kappa^c_{2009}}{2009 - 1981} \times \frac{1}{\#Age\ Bands}$$

Case study: Mortality by deprivation in England

Trend differences by deprivation quintile (Females)

$$\log \mu^{c}_{xtg} = \alpha^{c}_{x} + \alpha^{c}_{xg} + \beta^{c}_{x}\lambda^{c}_{g}\kappa^{c}_{t} + \sum_{i=1}^{h} \delta^{c,(i)}_{x} f^{(i)}(t)$$



Cause	Average annual Improvement*
All cause	1.90%
Circulatory	3.72%
Neoplasms	0.92%
Respiratory	0.74%
Digestive	-0.68%
Mental & Behavioral	-1.14%
External causes	1.36%
Other	

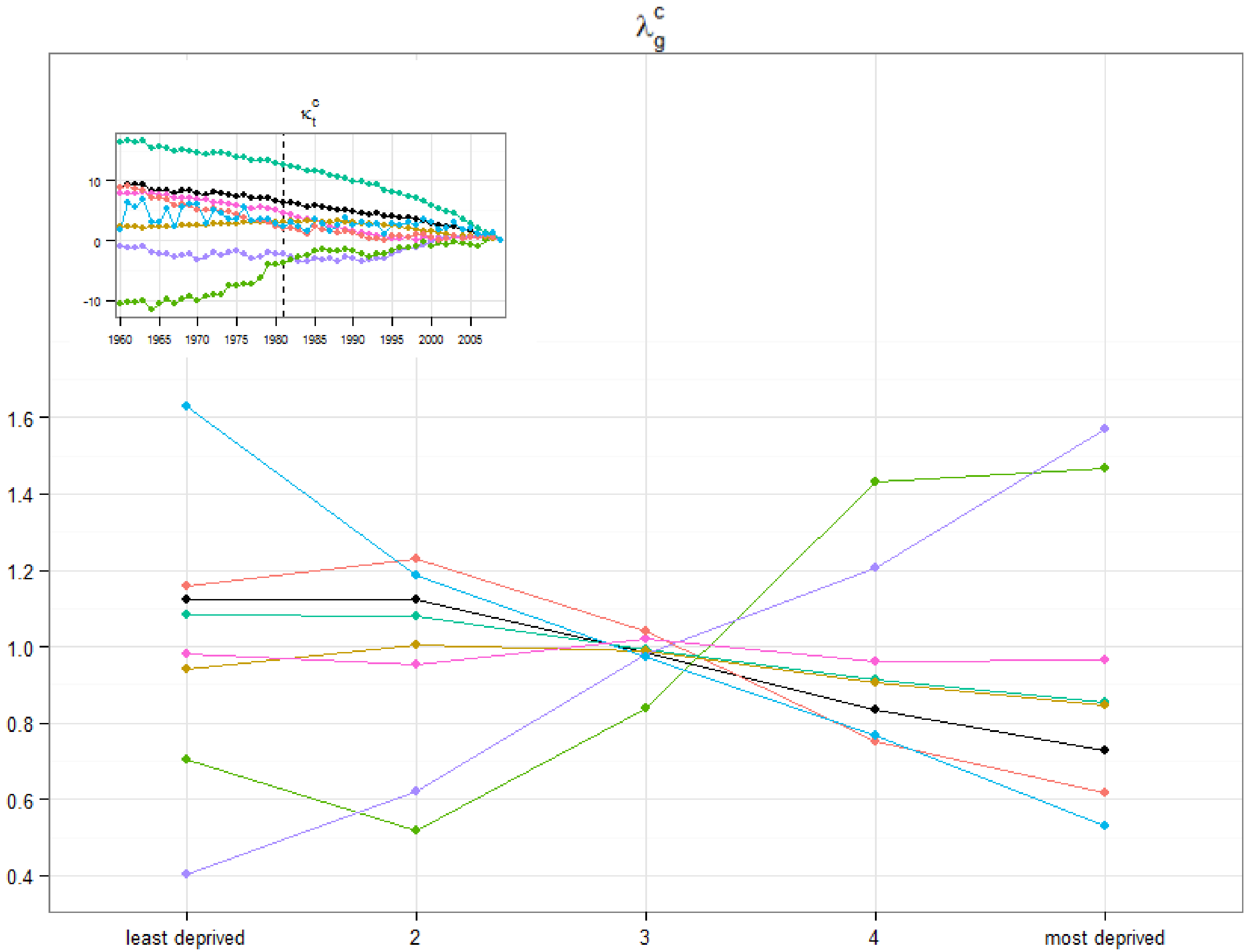
*Average annual Improvement for England and Wales for the period 1981-2009 computed as

$$\frac{\kappa^{c}_{1981} - \kappa^{c}_{2009}}{2009 - 1981} \times \frac{1}{\#Age\ Bands}$$

Case study: Mortality by deprivation in England

Trend differences by deprivation quintile (Females)

$$\log \mu_{xtg}^{c} = \alpha_x^c + \alpha_{xg}^c + \beta_x^c \lambda_g^c \kappa_t^c + \sum_{i=1}^{h} \delta_x^{c,(i)} f^{(i)}(t)$$



Cause	Average annual Improvement*
All cause	1.90%
Circulatory	3.72%
Neoplasms	0.92%
Respiratory	0.74%
Digestive	-0.68%
Mental & Behavioral	-1.14%
External causes	1.36%
Other	0.59%

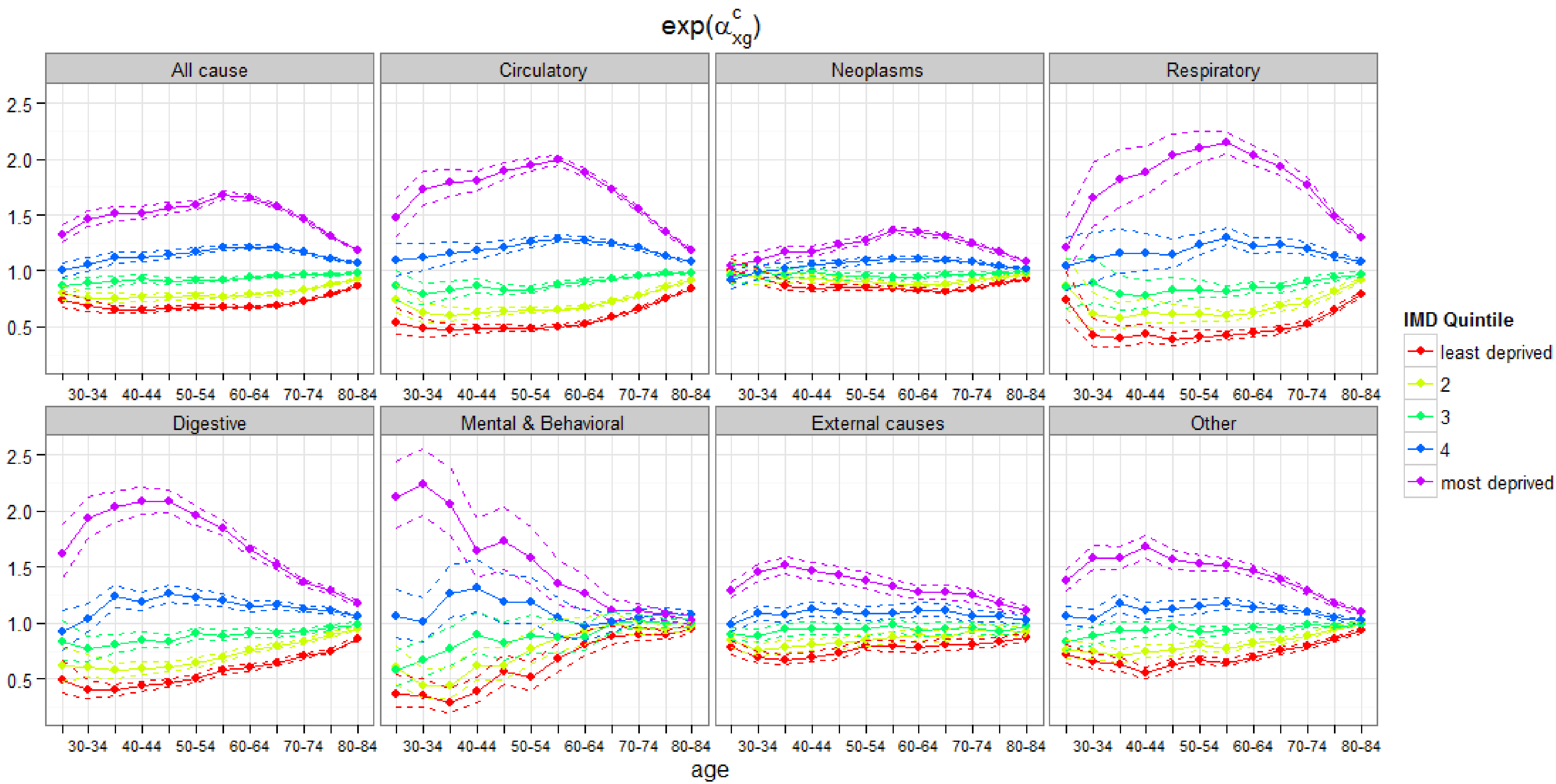
*Average annual Improvement for England and Wales for the period 1981-2009 computed as

$$\frac{\kappa_{1981}^{c} - \kappa_{2009}^{c}}{2009 - 1981} \times \frac{1}{\#Age\ Bands}$$

Case study: Mortality by deprivation in England

Level differences by deprivation quintile (Females)

$$\log \mu_{xtg}^{c} = \alpha_x^c + \alpha_{xg}^c + \beta_x^c \lambda_g^c \kappa_t^c$$



Case study: Mortality by deprivation in England

Trend differences by deprivation quintile (Females)

$$\log \mu_{xtg}^{c} = \alpha_x^c + \alpha_{xg}^c + \beta_x^c \lambda_g^c \kappa_t^c$$