How Neighbourhood Characteristics can Predict Your Longevity

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Outline

- Context and Background
- Data
- Methodology
- Results

Context and Background

- Life insurance and pensions
- Mortality: traditional $\rightarrow$ big data
  $\Rightarrow$ improved pricing and reserving
- Considering here:
  male mortality in England
  (results for females similar and consistent)
- Aim: improved base tables – not forecasting
- Stylised facts:
  - Mortality varies by socio-economic group
  - Mortality varies by region

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Background: Variation By Region

North East
North West
Yorkshire & Humber
East Midlands
West Midlands
East of England
London
South East
South West

Not in dataset:
Scotland, Wales,
Northern Ireland

Background: Relative mortality by region

England Variation by region (males 60-69)	
North East	118%
North West	116%
Yorkshire and The Humber	107%
East Midlands	98%
West Midlands	105%
East	88%
London	105%
South East	89%
South West	87%

Values show standardised mortality (ages 60-69) by region as a percentage of national standardised mortality

Note: Regional variation $<$ variation by income deprivation

Background

- *How much of this can be explained by underlying socio-economic differences?*
- *And how much variation is geographical?*

  E.g. due to higher or lower levels of smoking than national levels by socio-economic group.

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Data: LSOA's

- England only
- Lower Layer Super Output Areas: LSOA's
- $L = 32,844$ small geographical areas
- Socio-economically homogeneous
- Average size $\approx$ 1600 persons
- LSOA's $i = 1, \ldots, L$,
  single years (t =2001-2016), single ages, x:
  - Deaths: $D(i, t, x)$
  - Exposures: $E(i, t, x)$ (population)
- Plus many *static* predictive variables for each LSOA

Predictive variables by LSOA

- Indices of deprivation (2015) (single scores per LSOA)
  - income deprivation (benefits)
  - employment deprivation (unemployment)
  - education deprivation
  - crime
  - barriers to housing and services
    - geographical barriers (distance to services)
    - wider barriers (overcrowding; homelessness)
  - living environment (housing quality; unmodernised; air quality)
- Educational attainment (levels $\times$ age groups)
- Occupation groups (types $\times$ age groups)
- Average weekly income
- Average number of bedrooms
- # people in care homes with/without nursing
- Urban/rural classification (categorical)
- ....

Methodology

- $D(i,t,x)$, $E(i,t,x)$ deaths and exposures by LSOA
- National death rates (all t and x)

$$m(t,x) = \frac{\sum_{i=1}^{L} D(i,t,x)}{\sum_{i=1}^{L} E(i,t,x)}$$

- LSOA's ($i = 1, \ldots, L$)
  Local death rates: $m(i,t,x)$
  General Model: $D(i,t,x) \sim \text{Poisson}\Big(m(i,t,x)E(i,t,x)\Big)$

Methodology (cont.)

General approach:

- Over a limited age range (e.g. 60-69); and
- Over a (potentially) limited range of years:

$$m(i,t,x) = m(t,x)F_1(i)F_2(i)$$

- $F_1(i)$ = relative risk due to socio-economic characteristics
  - GLM
  - kernel smoothing
  - local, weighted linear regression

- $F_2(i)$ = additional relative risk capturing spatial effects
  - kernel smoothing

Methodology (cont.)

- Years: $t = t_0, \ldots, t_1$
- Ages: $x = x_0, \ldots, x_1$
- Actual deaths by LSOA

$$D(i) = \sum_{t=t_0}^{t_1} \sum_{x=x_0}^{x_1} D(i,t,x)$$

- Expected deaths by LSOA (no modelled effects)

$$\hat{D}_0(i) = \sum_{t=t_0}^{t_1} \sum_{x=x_0}^{x_1} m(t,x) E(i,t,x)$$

- Actual-over-expected by LSOA

$$R_0(i) = D(i)/\hat{D}_0(i)$$

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Stage 1: Introduce Predictive Variables

- LSOA's: $i = 1, \ldots, L$
- Predictive variables (PV): $j = 1, \ldots, n_P$
- Standardised: PV type j, LSOA i

$$X(i,j) \sim N(0,1)$$

- Purpose of standardisation:
  Simplifies the system of weighting later in Stage 1
- Vector: $X(i) = (X(i,1), \ldots, X(i,n_P))'$

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Stage 1: Urban versus Rural

- Urban-rural classification
  - 1: Conurbation; London (4810 LSOA's)
  - 2: Conurbation: not London (7921)
  - 3: City or town (14515)
  - 4: Rural town (3056)
  - 5: Rural village and dispersed (2542)
- Preliminary experiments $\Rightarrow$
  contribution and importance of specific predictive variables varies significantly between urban and rural LSOA's

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Stage 1: Local Linear Regression

- LSOA, i:
- Estimate the socio-economic-specific Relative Risk, $F_1(i)$
- For each i, fit an n_P-dimensional sheet around $X(i)$

$$F(i, \mathbf{x}) = a(i) + \mathbf{b}(i)^T \mathbf{x}$$

- n_P predictive variables exclude urban-rural classification urban-rural handled in the weights, $w_1(i, j)$
- Minimise

$$S(a(i), b(i)) = \sum_j w_1(i, j) \left(R_0(j) - a(i) - b(i)^T X(j) \right)^2$$

over $a(i)$ and $b(i)$

Stage 1: Local Linear Regression (cont.)

- Then set

$$F_1(i) = a(i) + b(i)^T X(i)$$

$\Rightarrow$ relative risk accounting for socio-economic factors

- Update estimated deaths:

$$\hat{D}_1(i) = \hat{D}_0(i) F_1(i)$$

Stage 1: Local Linear Regression (cont.)

How to calculate the weights?

- $w(i,i) = 0$
- $w(i,j) = 0$ if LSOA's i and j are in different urban-rural groups Otherwise:

- $w(i,j)$ depends on the "distance" between predictive variables $X(i)$ and $X(j)$
- $w(i,j) \to 0$ as the distance gets larger

Stage 1 → Stage 2

$$
\begin{aligned}
D(i) &= \text{LSOA actual deaths} \\
\hat{D}_0(i) &= \text{LSOA expected deaths with no predictive variables} \\
\hat{D}_1(i) &= \text{LSOA expected deaths with predictive variables} \\
R_1(i) &= \frac{D(i)}{\hat{D}_1(i)} = \text{updated actual-over-expected}
\end{aligned}
$$

Stage 2: Add location data:

$$
\begin{aligned}
Y(i) &= \text{LSOA location co-ordinates} \\
&= \text{(latitude, longitude)}
\end{aligned}
$$

Kernel smooth the $R_1(i)$ using location data.

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Stage 2: Smooth A/E by Location

Estimate the *additional* location-specific relative risk

$$F_2(i) = \frac{\sum_j w_2(i,j) R_1(i)}{\sum_j w_2(i,j)}$$

Then the fitted expected deaths are

$$\hat{D}_2(i) = \hat{D}_0(i) F_1(i) F_2(i)$$

Weights, $w_2(i,j)$, depend on the physical distance between the two LSOA's

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Data and Results So Far

- 2001-2015; 2001-2008; 2009-2016
- Ages: 40-49, 50-59, 60-69, 70-79, 80-89
- Predictive variables:
  - income deprivation (elderly; receiving government benefits)
  - employment deprivation (unemployment)
  - average number of bedrooms
  - living environment deprivation (housing quality and air quality)
  - wider barriers (overcrowding)
  - % in care home (60+ with nursing)
  - % in care home (60+ without nursing)
  - urban-rural classification

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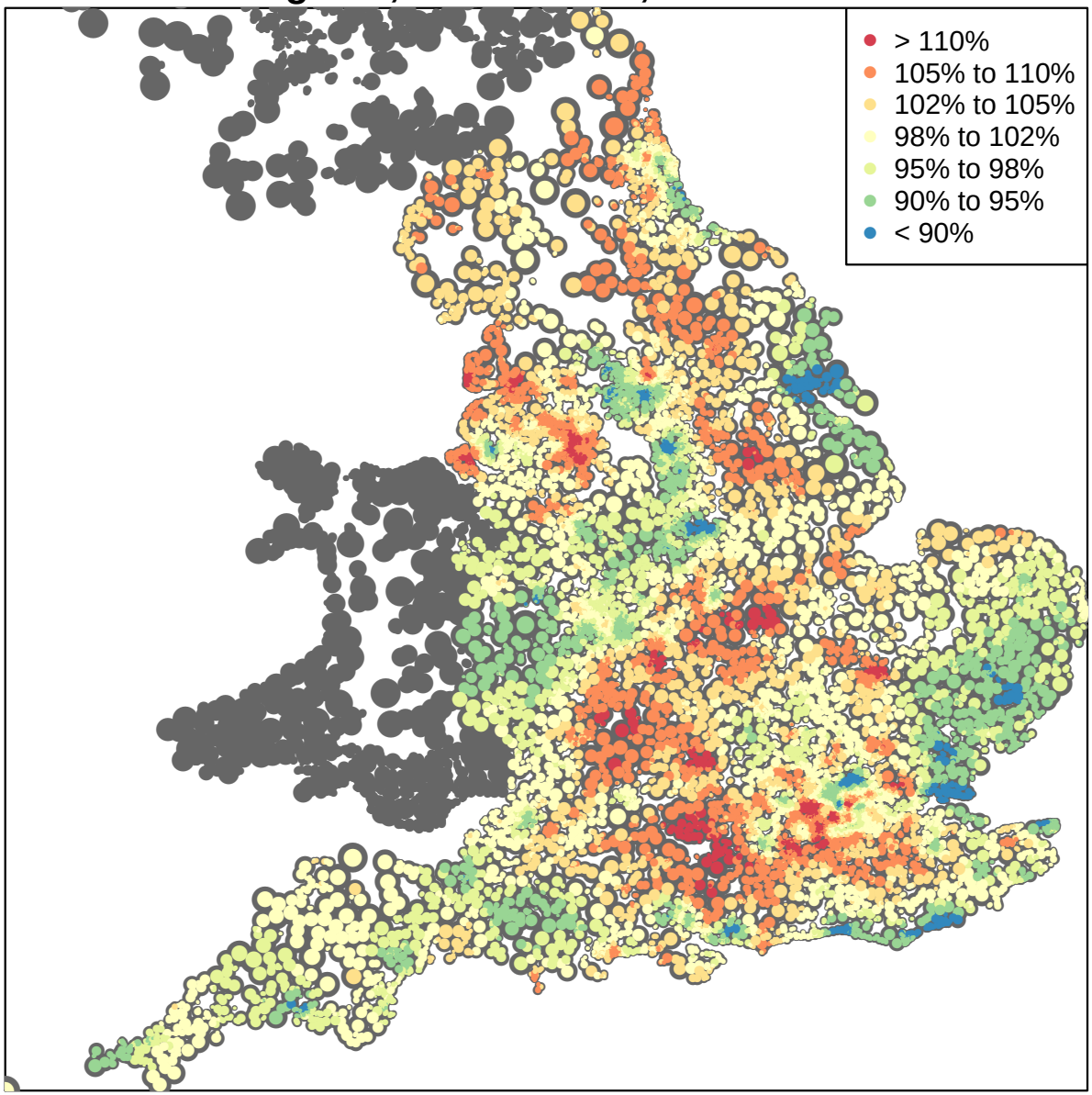
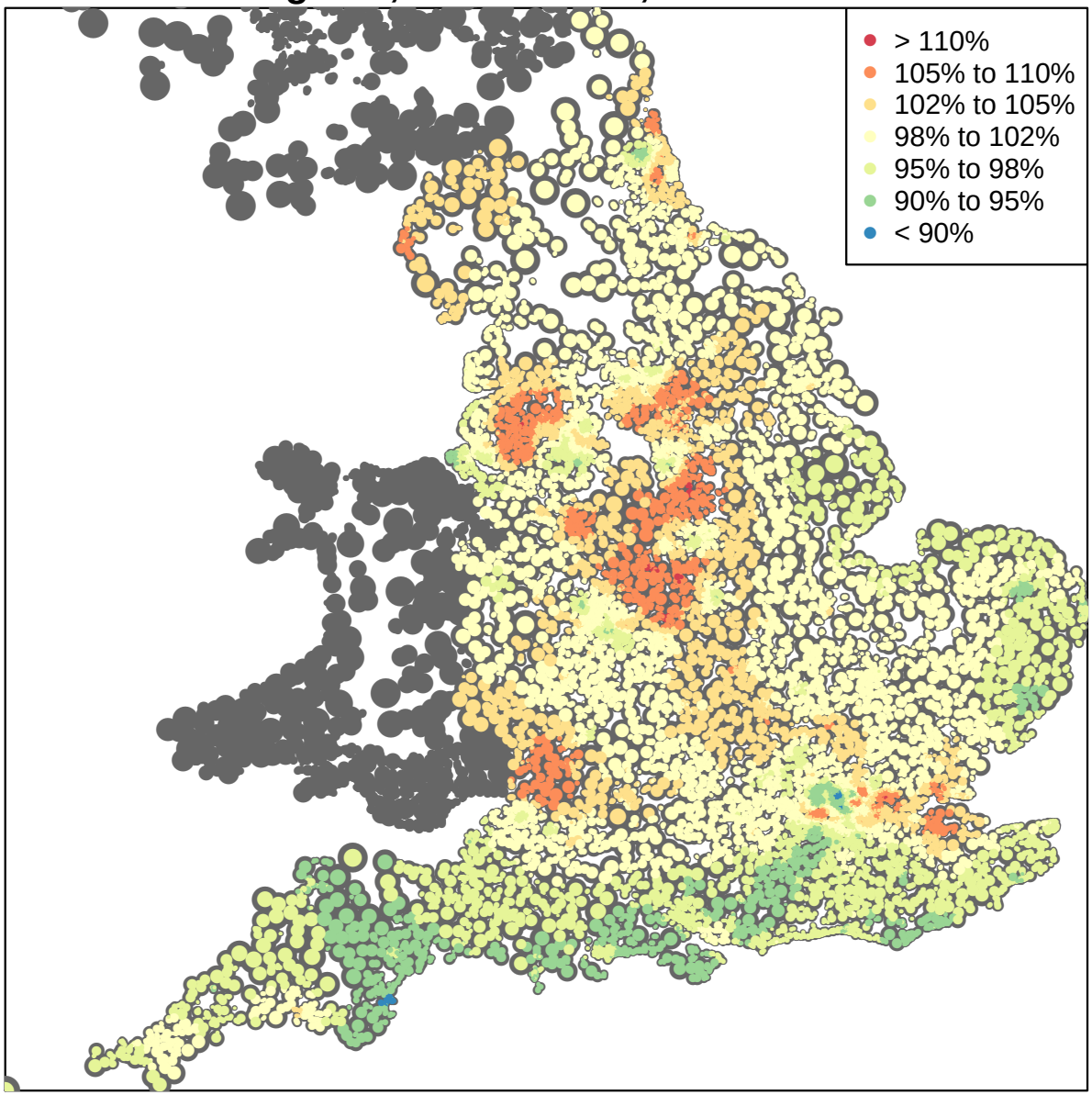
Role of Predictive Variables: Socio-Economic

- Income deprivation (elderly) and employment deprivation are the main drivers
- Employment deprivation is the main driver for younger age groups
- Income deprivation (elderly) is the main driver for older age groups
- Urban-rural classification is also an important driver
- Bedrooms, living environment and wider barriers are second order but significant
- Care homes:
  - "nuisance" variables when considering socio-economic effects
  - but including these predictive variables is very important
  - methodology allows us to filter out the impact of care homes on individual LSOA mortality
  - E.g. males 80-89 in a care home with nursing:
    mortality is 3x to 6x higher than not in a care home

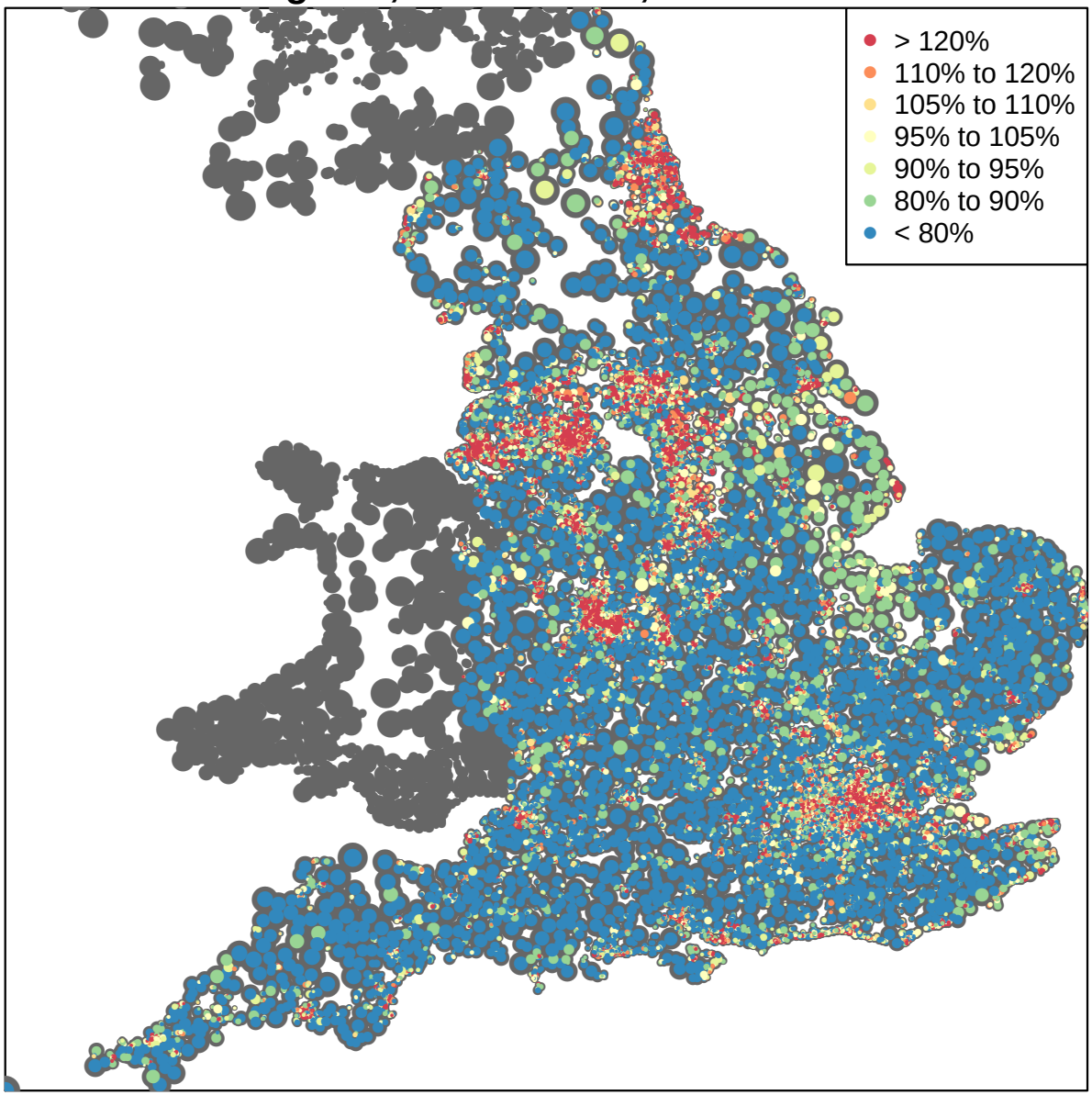
Location−Specific Relative Risk
England, Males 40−49, 2001−2015



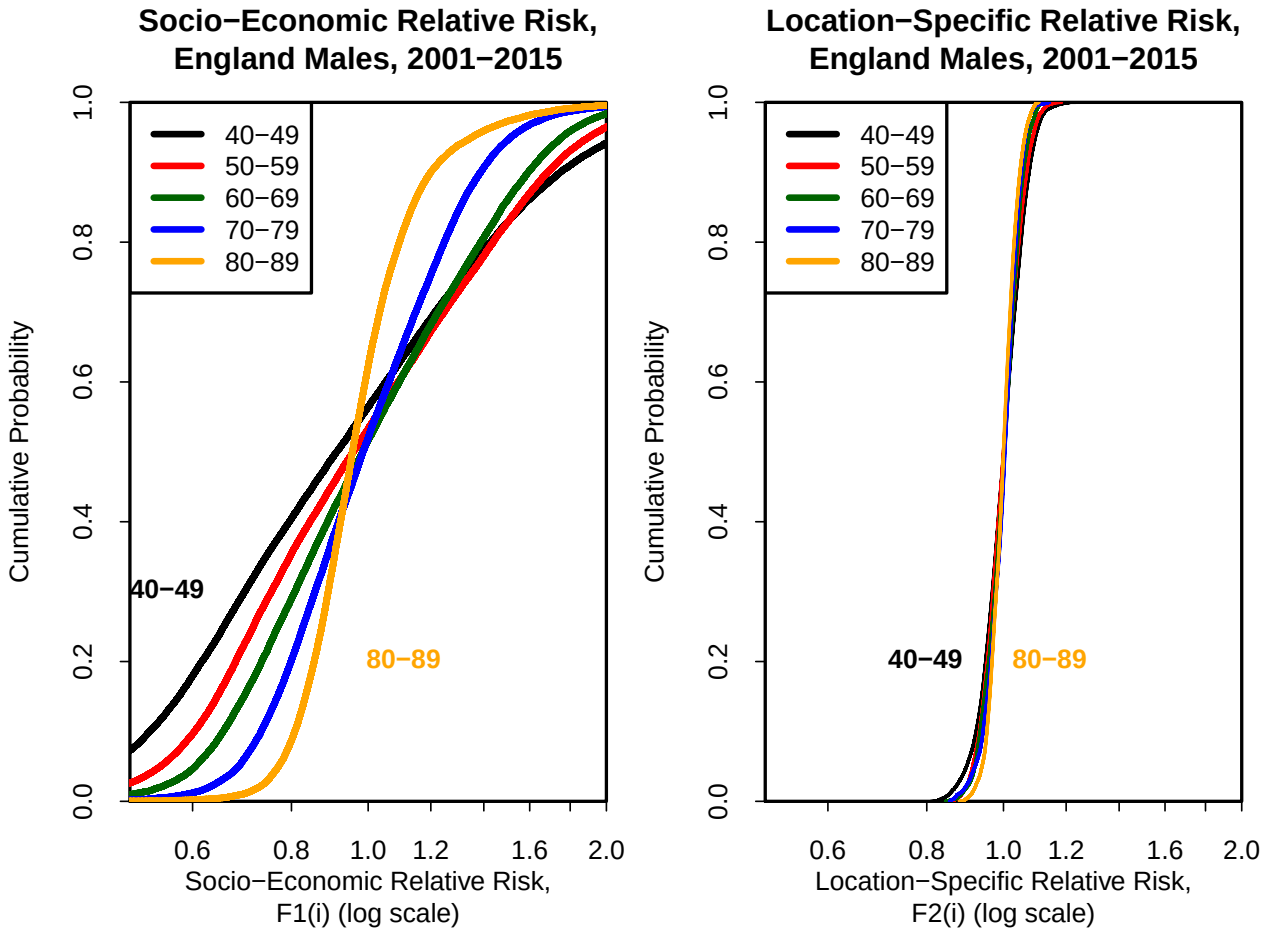
Location−Specific Relative Risk
England, Males 80−89, 2001−2015



Combined Relative Risk
England, Males 60−69, 2001−2015



Socio-Economic vs Spatial Effects



- Empirical CDF's of $F_{1/2}(1), \ldots, F_{1/2}(32844)$ relative risks over all LSOAs
- Location contributes 1.3% to 3.5% of the variance in the relative risk

Actual-over-expected: Ages 60-69

Region	No effect	Socio-economic only	Full Model
North East	118	100	99
North West	116	102	100
Yorkshire and The Humber	107	100	100
East Midlands	98	100	99
West Midlands	105	99	100
East	88	96	98
London	105	100	99
South East	89	101	100
South West	87	94	99

- Similar patterns for other age groups and for females

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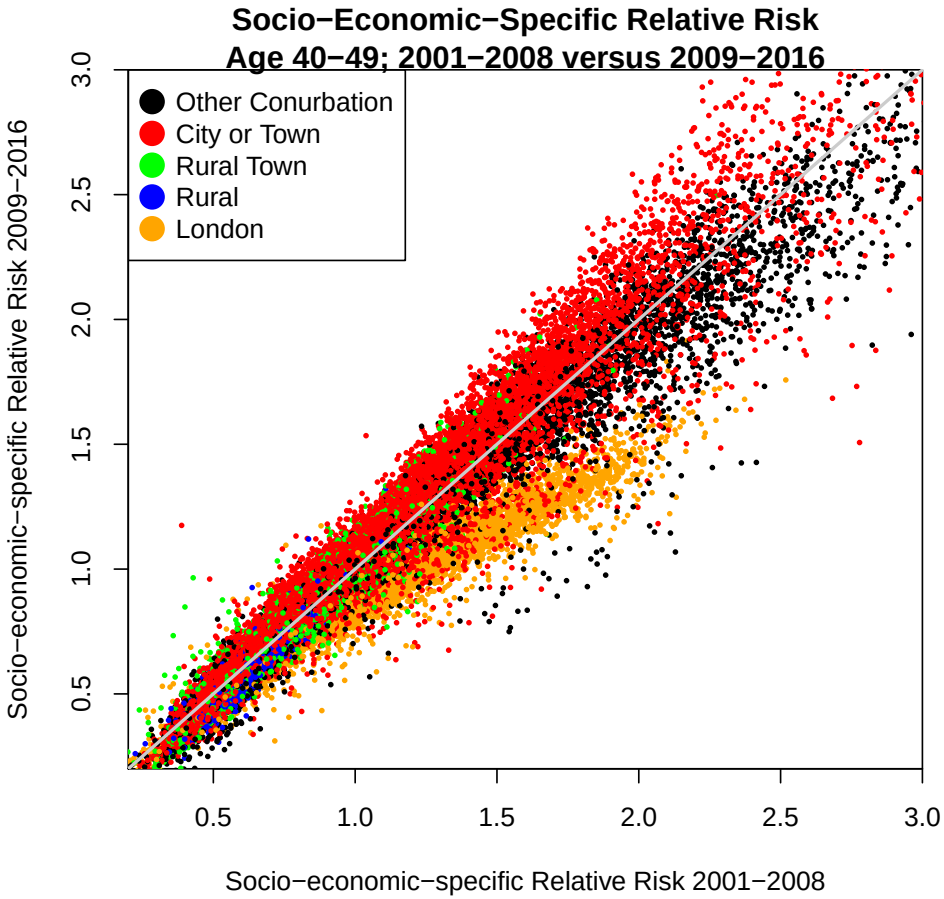
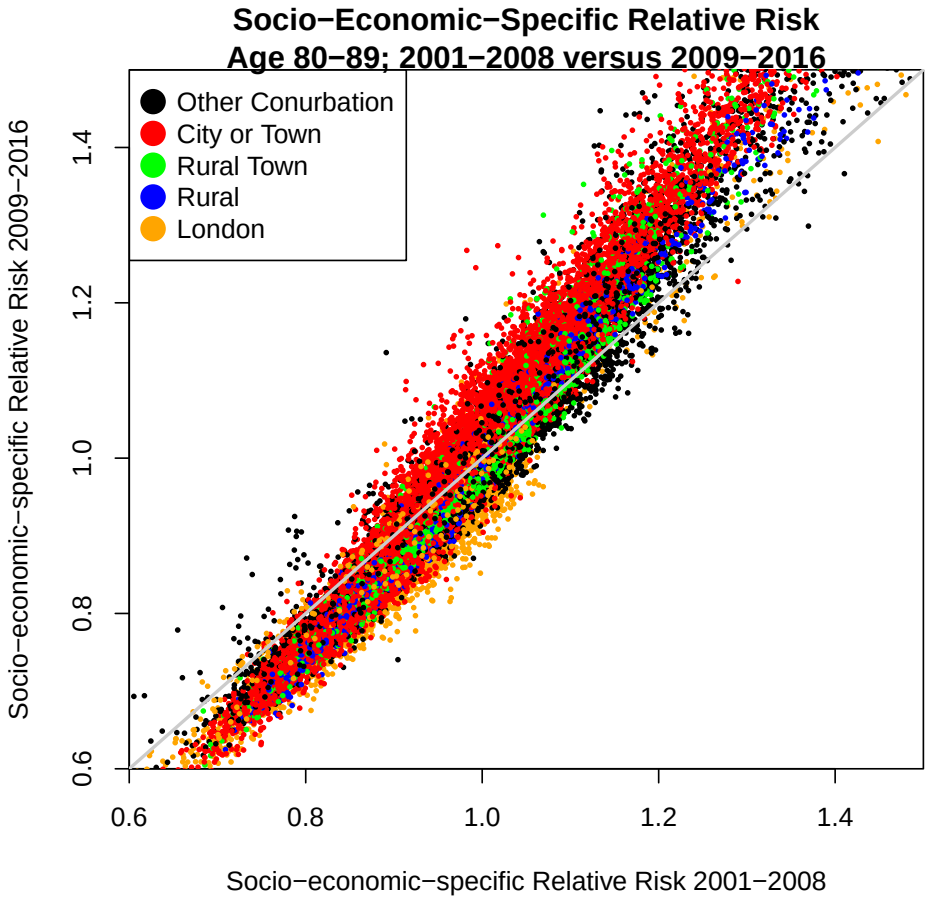
2001-2008 versus 2009-2016: Ages 40-49 and 80-89





- Widening inequality gap at 80-89
- Stable gap at 40-49, except London: narrowing gap

Conclusions

- Spatial/regional effects are significant
- But much less important than socio-economic (non-regional) effects
- Next steps:
  - Both effects: can these be used to improve the assessment of base tables in insurance and pensions?
  - Methodology $\Rightarrow$ continuous spectrum of relative risks
    $\Rightarrow$ can be used to complement *geo-demographic profiling* (clusters)
    $\Rightarrow$ improved risk assessment during longevity risk transfer pricing

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Thank You!

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