Population forecasting

with Bayesian hierarchical models

https://github.com/violetacln/SIPP

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Content

- Production of population projections: problems and solutions
- Difficulties and new demands
- New methods and implementation in 
- Future plans

Problem and solution

for migration, fertility, mortality (by age, time & Z- characteristics)*
which give, via ccpm & stochastically: the population predictions

- ***Problem**:*
- *estimating and predicting* in the presence of:
- small area/population issues and/or rare events/ shocks
- expert assumptions
- uncertainty of parameters and errors in data (e.g. *deregistration*)
- while reporting *uncertainty* of estimates/predictions

- ***Solution must be based on***:
- Modeling and combining (prior) information

Types of models

Recent years: *functional models, ARDL & bsts models* *f(age, time)*

- smoothing and orthogonal expansions for Fertility and Mortality components
- econometric / decay models for short / intermediate term
- time series / assumptions for long term

New: *hierarchical* and/or *Bayesian models of response(s)*

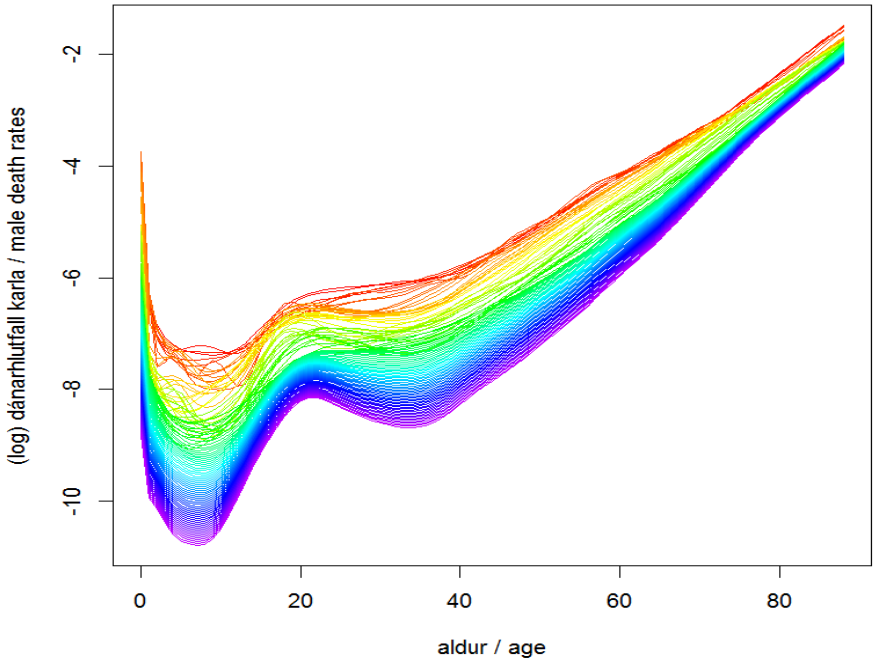
- smoothing/processes (t, space, age,…)
- complex correlation structures, spatial, demographic, social, … characteristics
- incorporate quantitative & qualitative info: *priors*

** *Model averaging options*

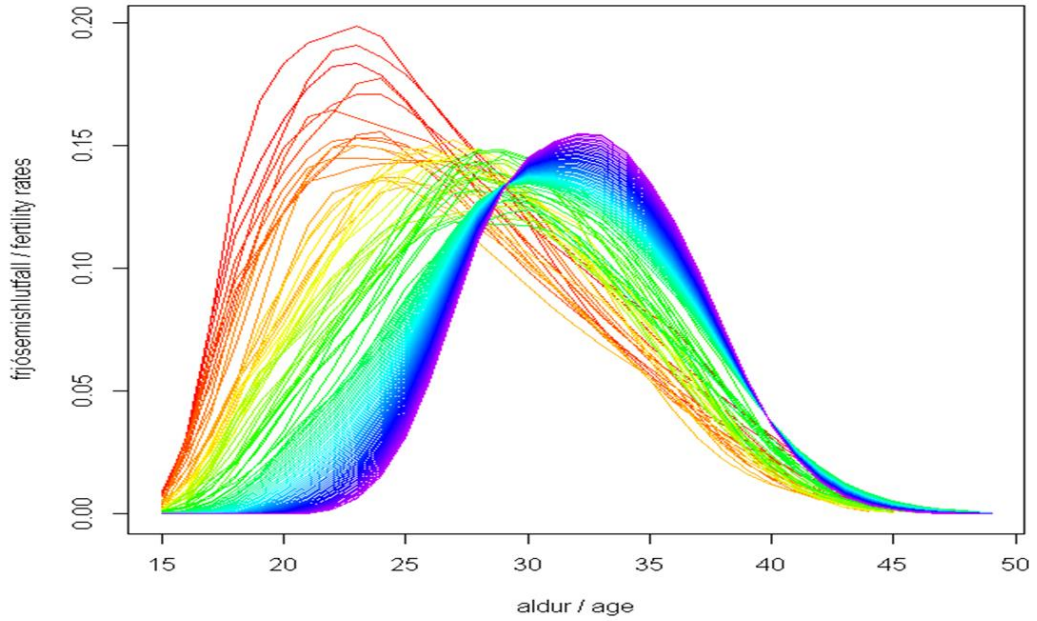
Typical result of functional models

https://cran.r-project.org/web/packages/demography/index.html

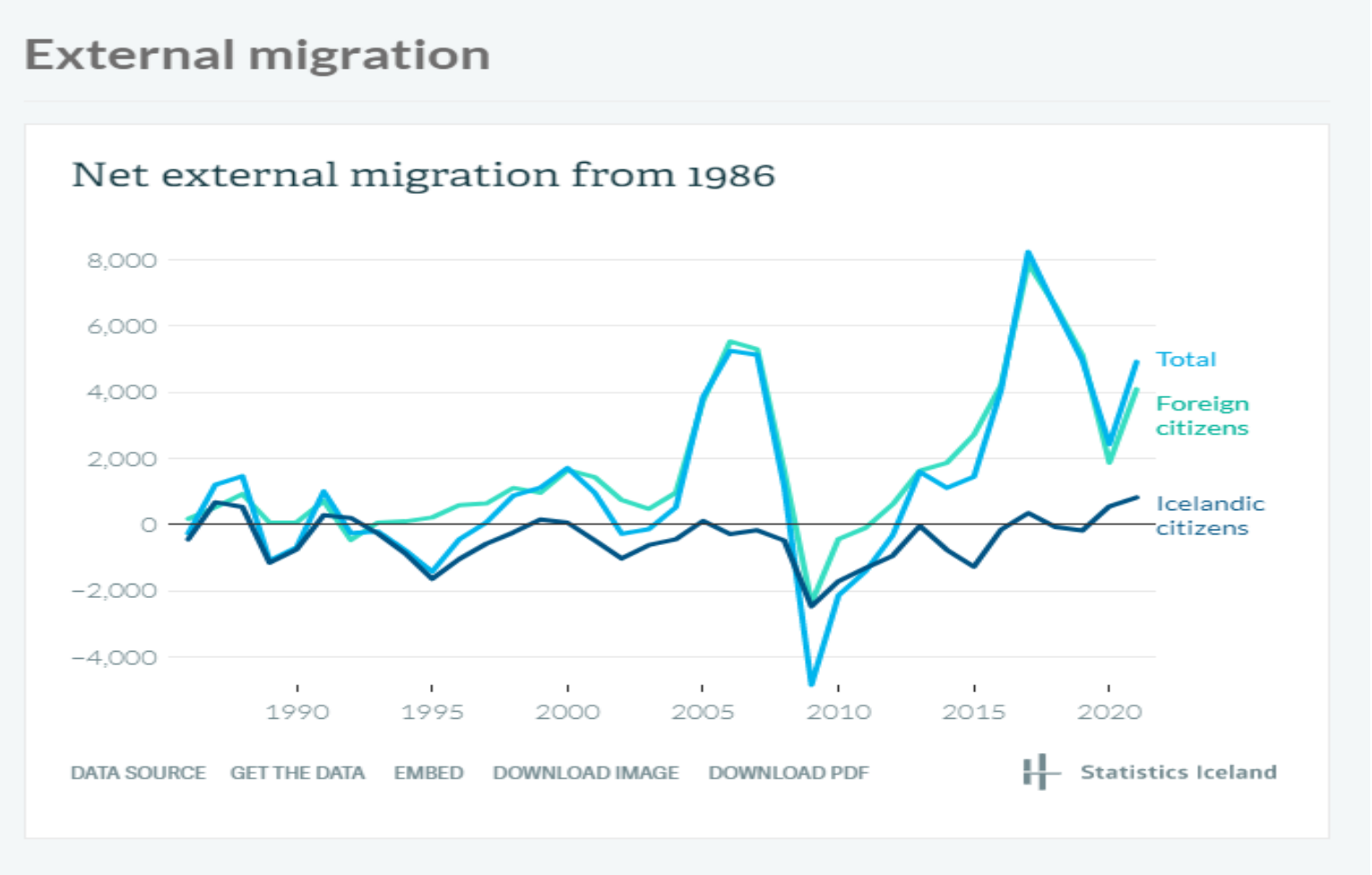
Mortality rates



Fertility rates



Migration issues and options for modeling



Predicting future values of migration/fertility/mortality:

- projections versus forecast

- advantages of Bayesian approach

Past

- Disjoint, long and short term migration predictions

- Unique models for predicting mortality and fertility, but *only* as functions of time, age (and gender)

New

& allowing for local predictions

- *Difficulties and new user demands* → Strengths of the new approach

- *Exceptions:* shocks (economical, political, natural, …)

New Models (parametric or not!)

$P(Y|a) = F1(X)$ *where* $P(a|b) = F2(c, Z)$ *where…*

- Type: **Hierarchical / Multilevel**, Bayesian / frequentist

  - data used: *individual or aggregated* response (Y) versions

  - what: ***processes,*** since *time series* data $P(Yi, \ldots Yn|a)$, versus $P(Yi)$: account for (auto-) correlations

- Why:

  - {components/prior information/characteristics/local&total} & **uncertainty** report

- ***R***-Tools:

  several *Stan*-running R packages like ***brms***, arm, bayestestR, …

  and the faster: *lme4, **mgcv**, …* for frequentist / as initializations

***Structure**, novelty and advantages*

x=(year, age, gender, citizenship, municipality, education, …)

- V1. Counts/rates
- $N(x, \dots) \sim Poisson(e^{f(x,\dots)} N_0(x, \dots))$ (or: neg. binom, over-disperssion issues, etc)
- $f_m(\{x, \dots\}) \sim GP(\, m(\{x, \dots\}), C(\{x, \dots\}, \{x', \dots\})\,)$ + …

- V2. Microdata
- $N(x, \dots) \sim B(e^{f(x,\dots)} N_0(x, \dots))$
- $f_m(\{x, \dots\}) \sim GP(\, m(\{x, \dots\}), C(\{x, \dots\}, \{x', \dots\})\,)$ + …

- *GP* – denotes here: sums of smooths/re/t2 and/or by {grouping factors} OR unknown functions with Gaussian Processes as priors (with m -> long term behaviour, C -> correl between any two response values)

Tests, Correlations, Dimensions

- Variability

- of:

  fertility, mortality, migration

- through (and with auto-correl):

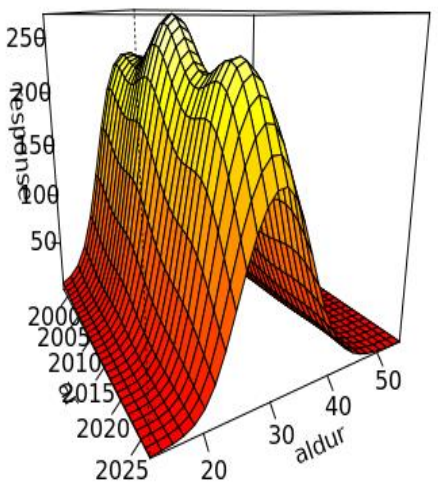
  Time & age *(s(t) , gp(t, age, …), t2(t, age), …)*

- by:
  - **Municipality**, Region – significant for: migration but not/less for mortality, fertility
  - Other characteristics: education, family related, municipality attributes, …
  - More grouping characteristics (ut/is, im/e, f/m)

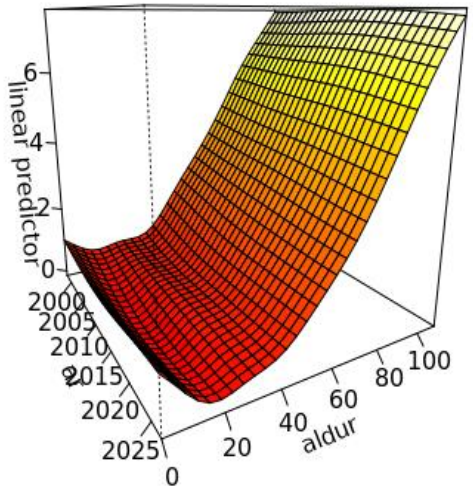
V1. Count data input

https://cran.r-project.org/web/packages/mgcv/index.html

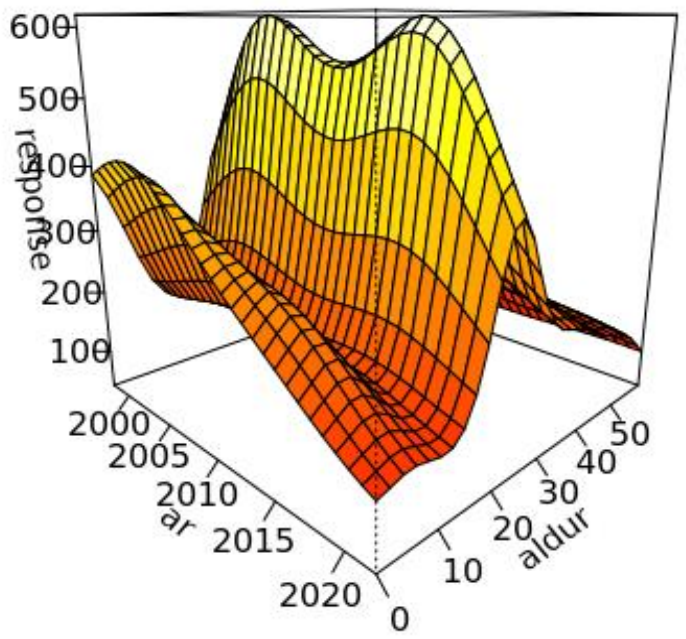
Births



Death rates (log)



Migration


600
500
400
300
200
100
response
2000
2005
2010
2015
2020
ar
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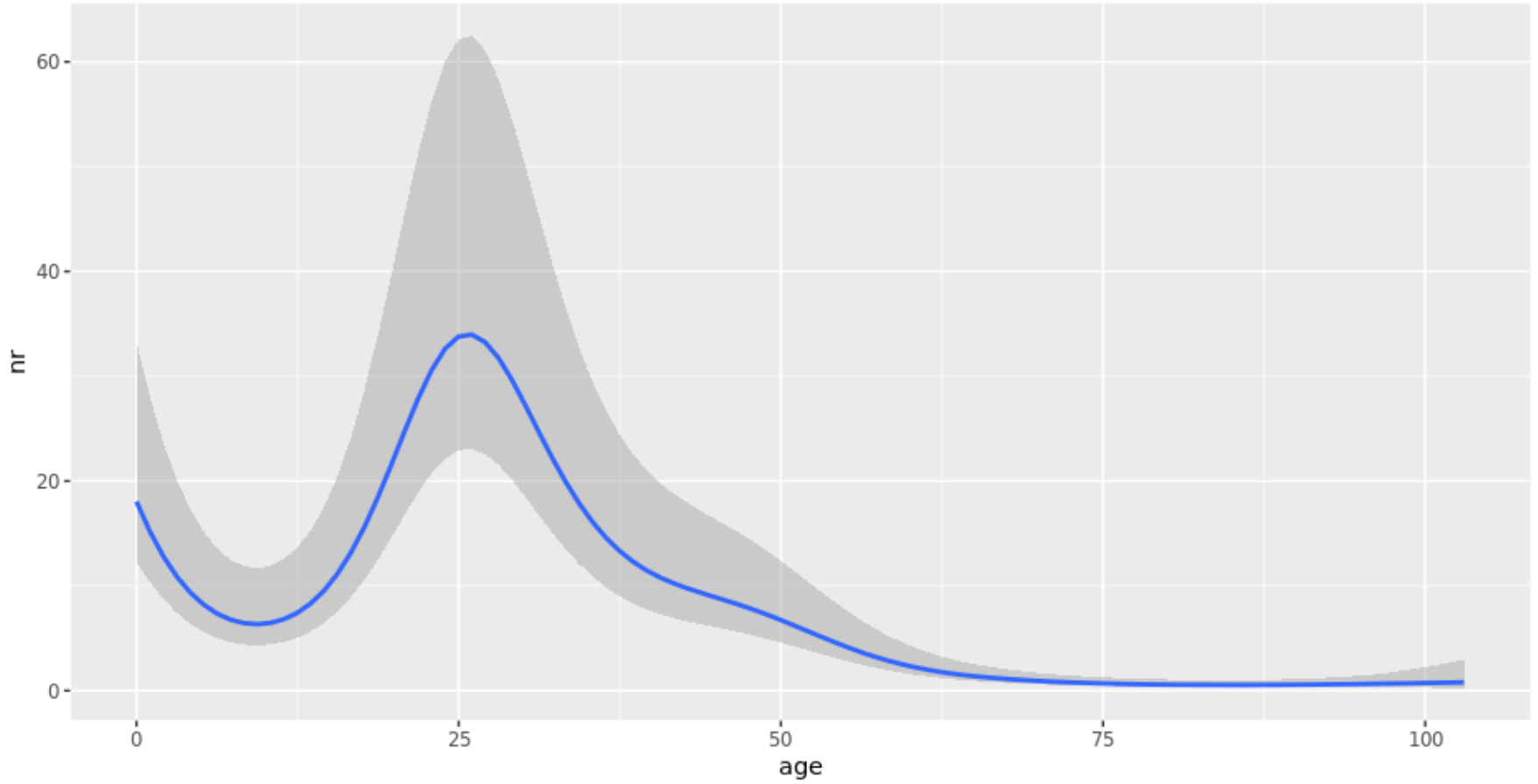
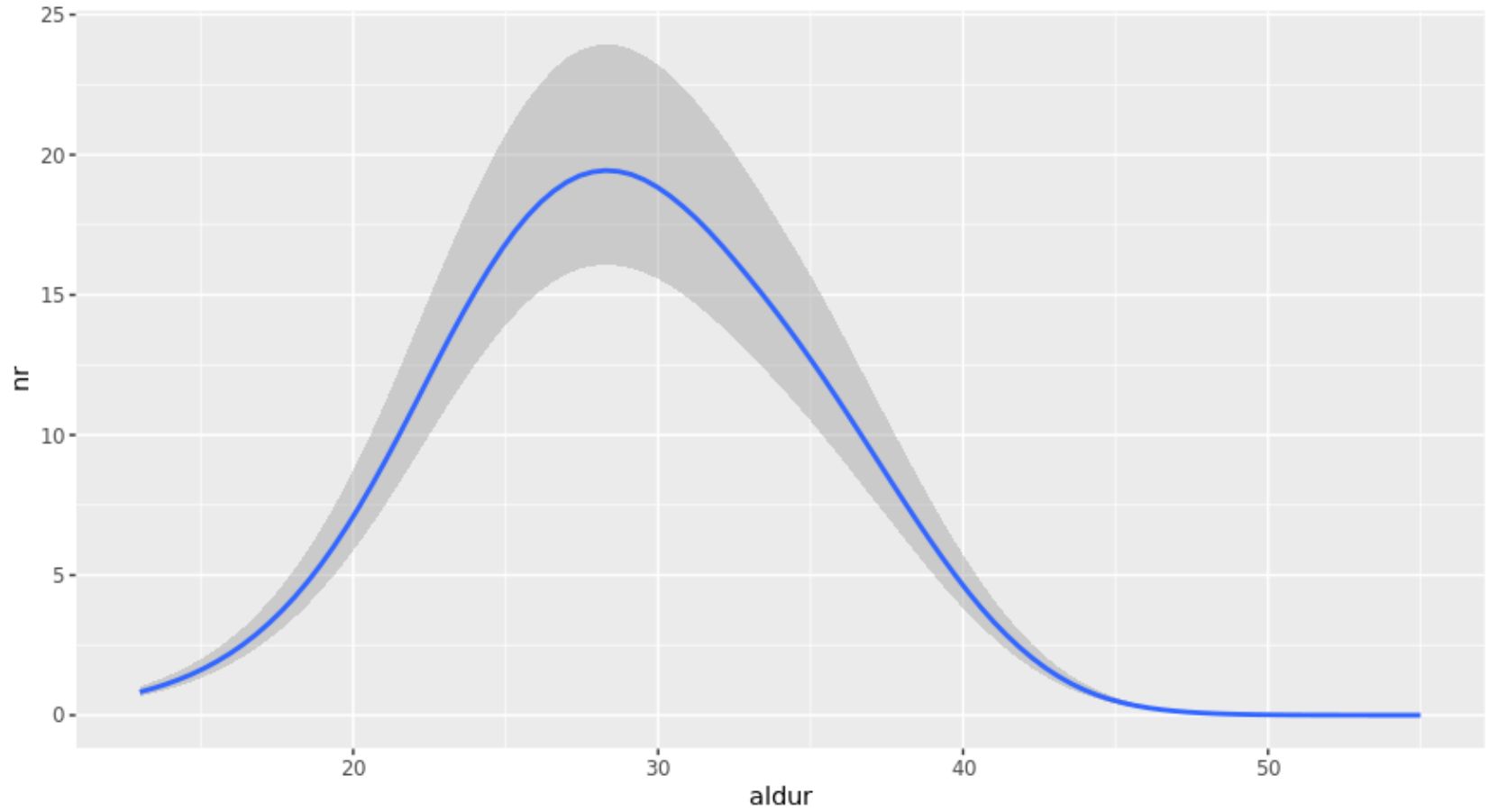
50
aldur

Counts/rates *models: all migration categories (f_em_ut)*

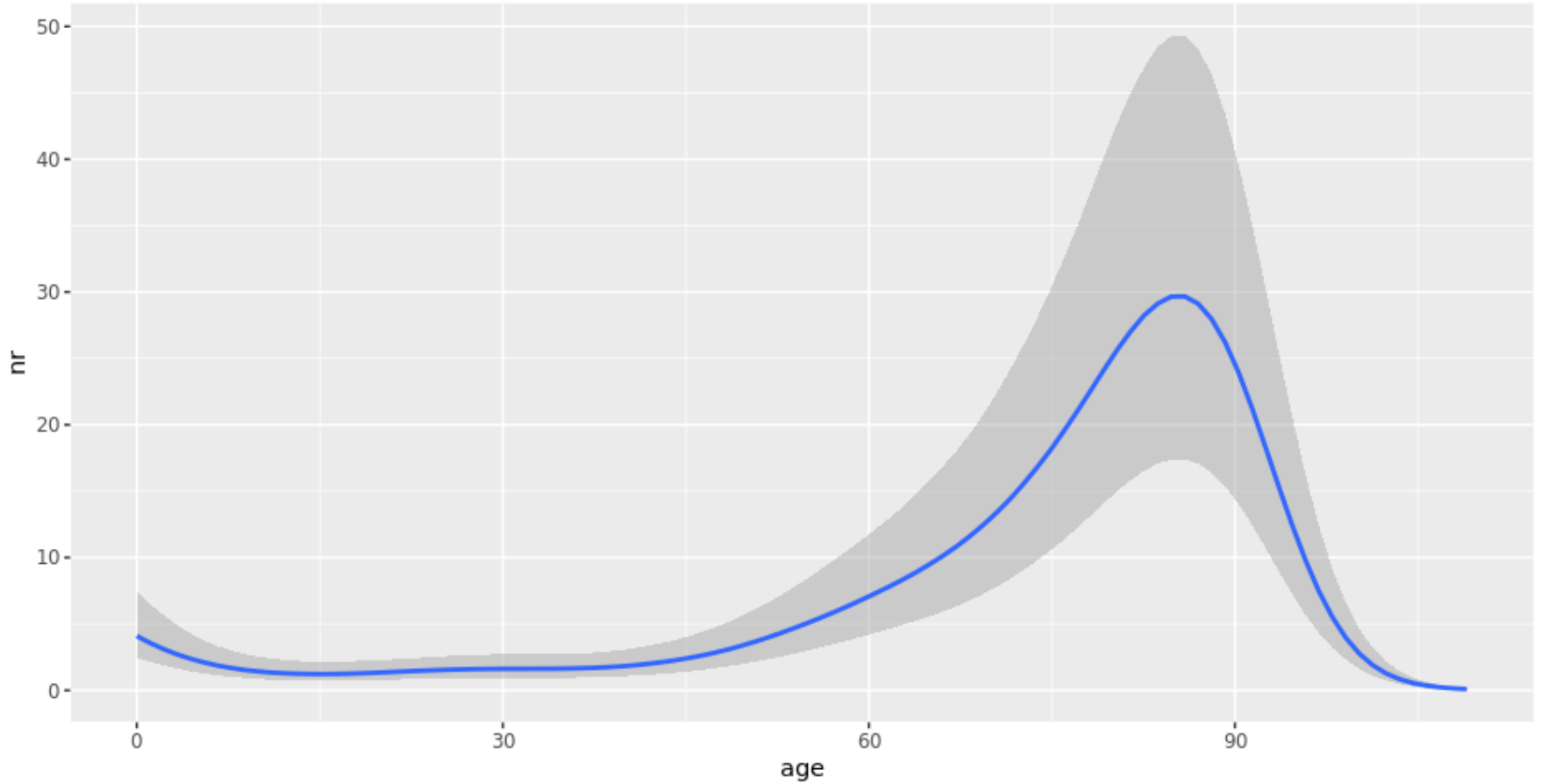
https://cran.r-project.org/web/packages/brms/index.html



Counts/rates: fertility models



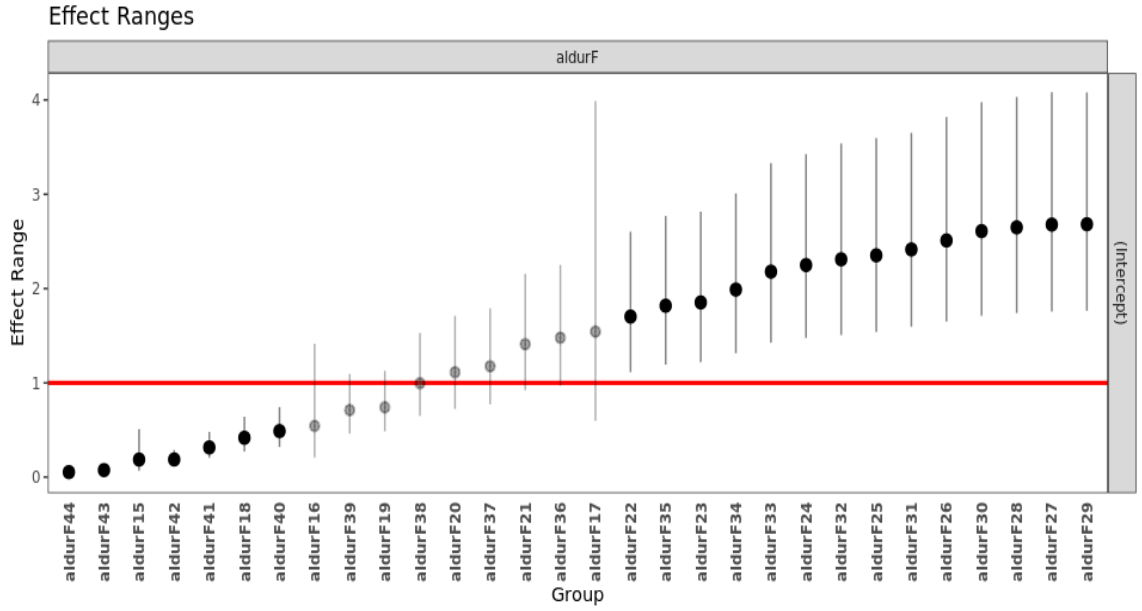
***Counts/rates**: mortality models (addit, s)*



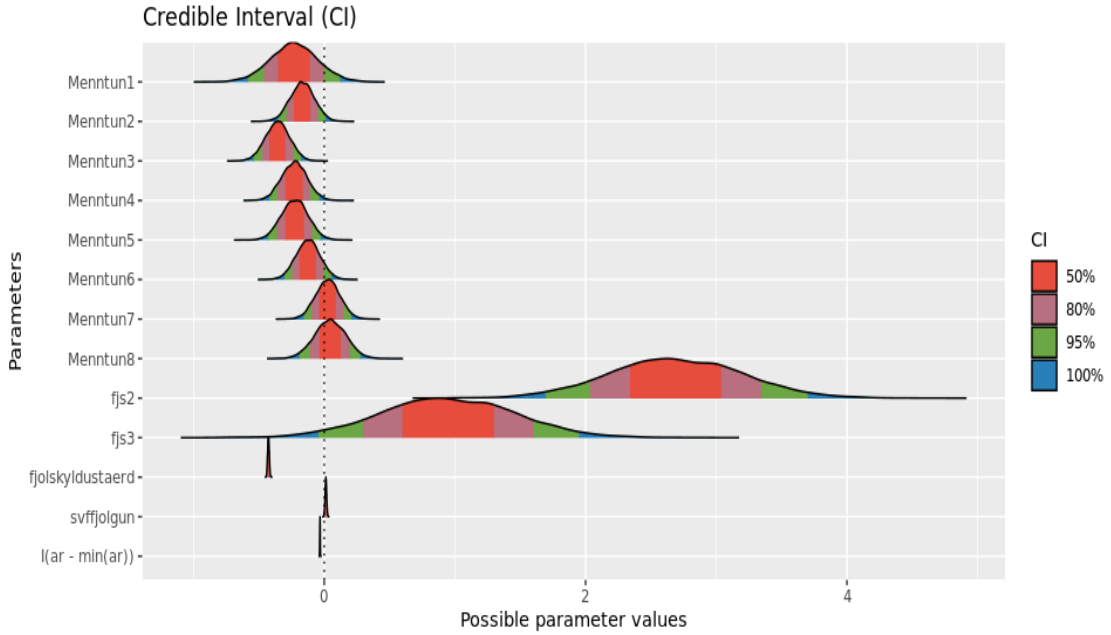
V2. Microdata input

Example 1. Significance of effects for:

Age group effect on fertility (o.r. units)



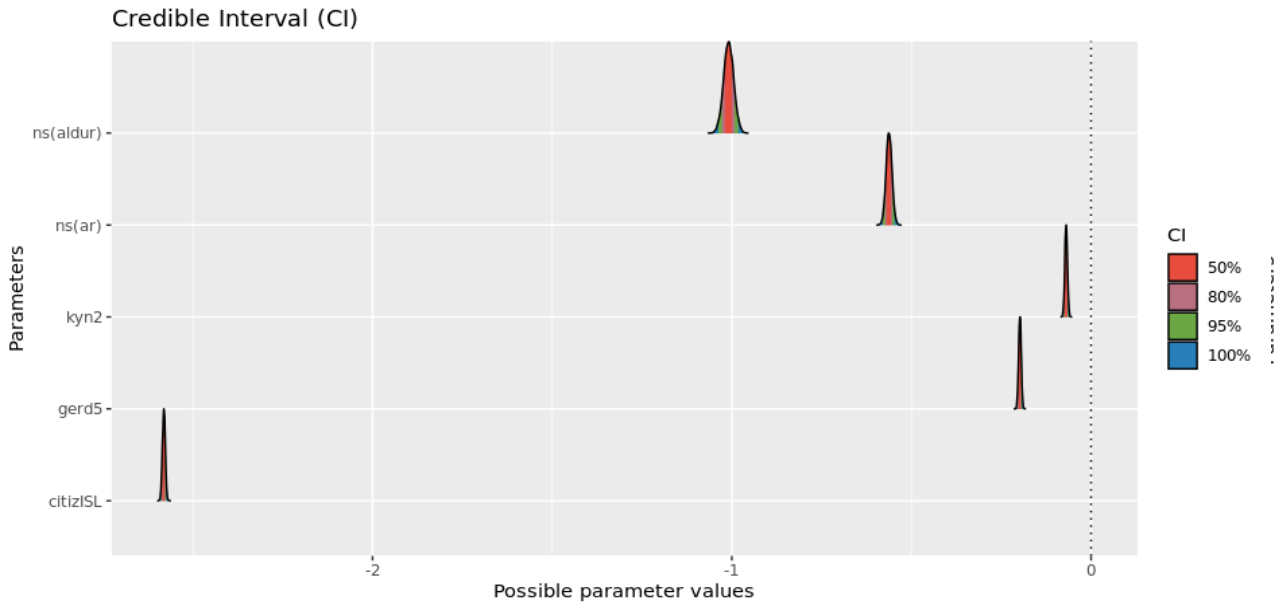
Characteristics‘ effects on fertility



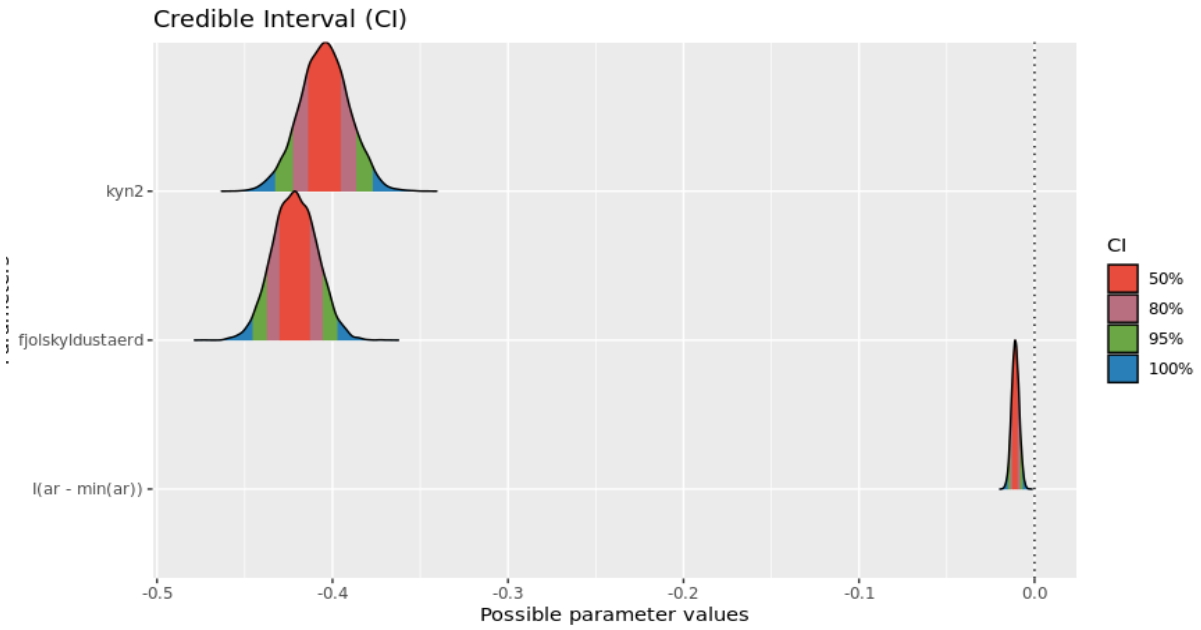
Microdata input

Example 2. Characteristics' effects on:

Migration

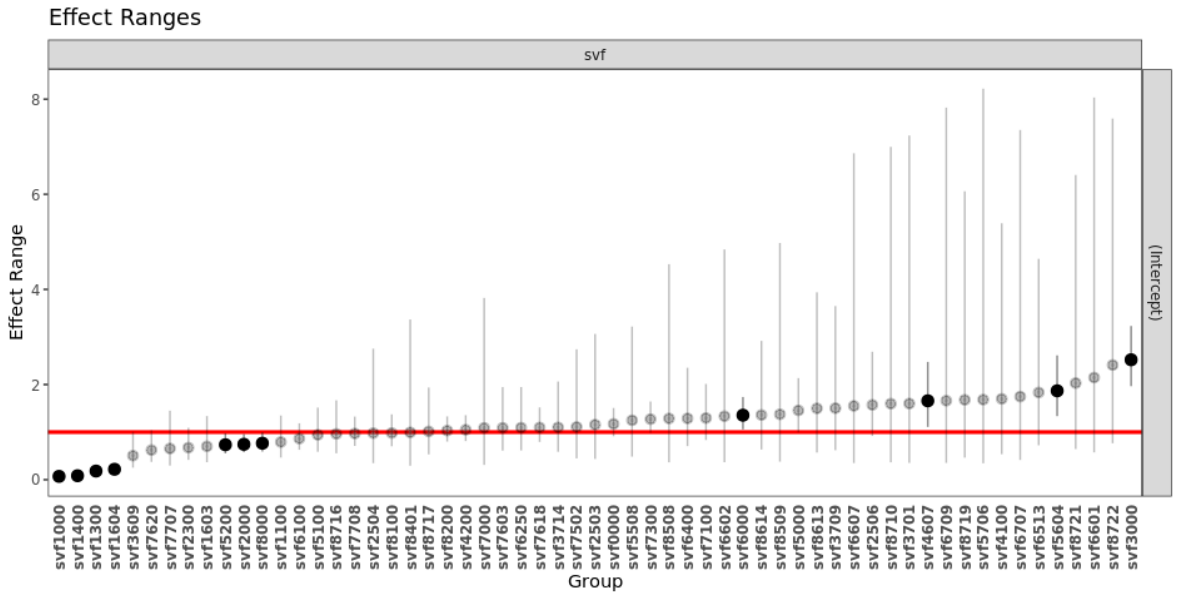


Mortality

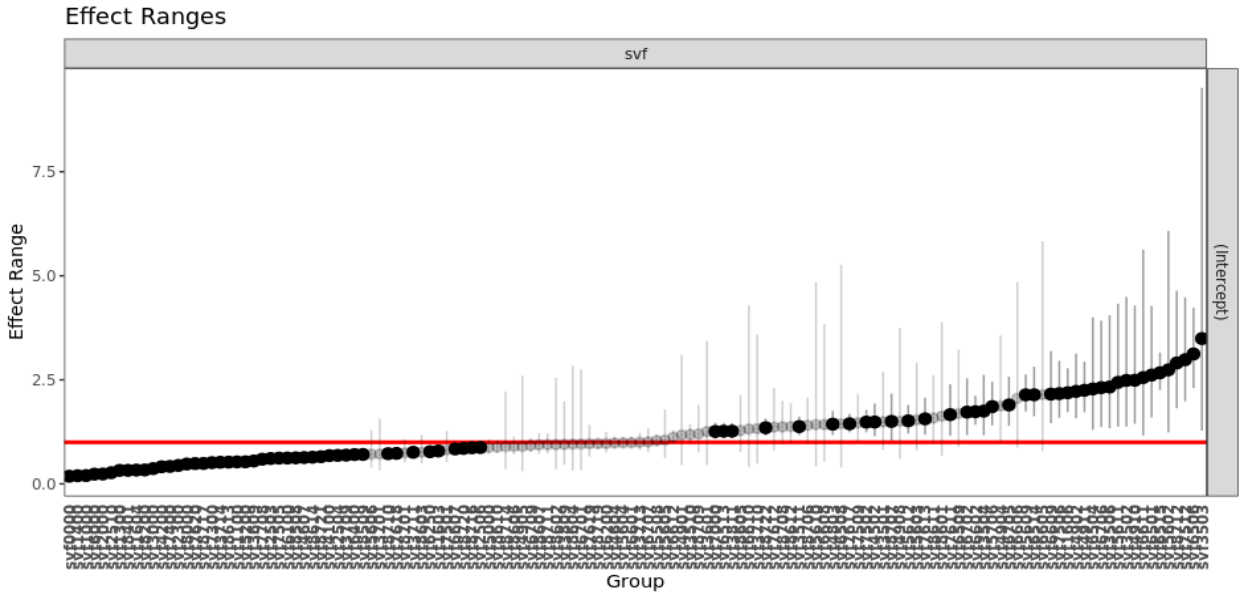


*One more example: testing for location effects (although not with **mrf** yet!)*

municipality - effect on fertility



municipality – effect on migration



Future/work in progress/*

- finalise stochastic *population* predictions by combining high number of values sampled from the posterior distributions of the demographic components (migration, fertility, mortality) as in *ccpm*
- finalise the model *testing*
- forecasting with multiple *model averaging**

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Thank you!