# The Future of Death in America

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joint work with Samir Soneji

(talk at the Center for Population and Development Studies, Harvard University, 12/15/08)

# Citations

- Gary King and Samir Soneji. 2008. "The Future of Death in America"
- Gary King and Samir Soneji. 2008. "Eating Away Social Security's Financial Problems"
- Gary King and Federico Girosi. 2008. *Demographic Forecasting*, Princeton University Press.
- copies at `http://gking.harvard.edu`

# The Forecasting Task

- Time series: 25-50 annual mortality rates
- Cross-sections: 1 time series for each age, country, cause, sex, etc.
- Goal: Forecast each time series 25 years
- Challenges: reducing error by:
  - Pooling cross-sections
  - Including demographic knowledge (smooth over time and age)
  - Including biological knowledge (smoking, obesity)

# How (Some) Existing Mortality Forecasts Work

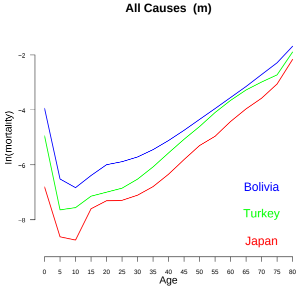
## Procedures:

- Develop private forecasts qualitatively (i.e., informally)
- Adopt a ‘toy’ statistical model
- Get data; produce tentative forecasts with the model
- Adjust model until forecasts fit private views
- Present forecasts, with statistical model as your “method”

## Meaning of procedures

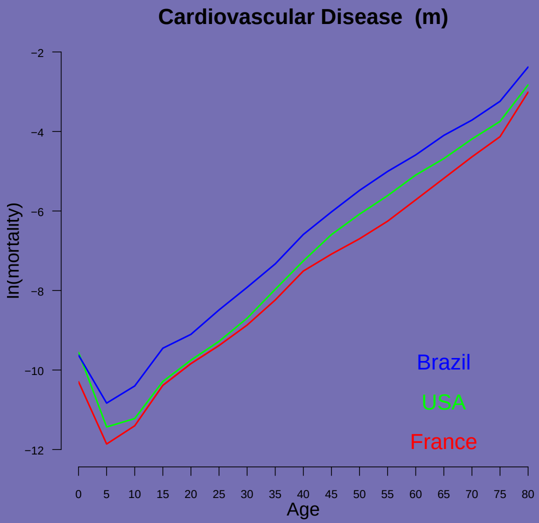
- Forecasts use qualitative information (good!)
- Statistical models add little (bad!)
- Method is invulnerable to being proven wrong
- We bring statistics to demography

# Existing Method 1: Parameterize the Age Profile

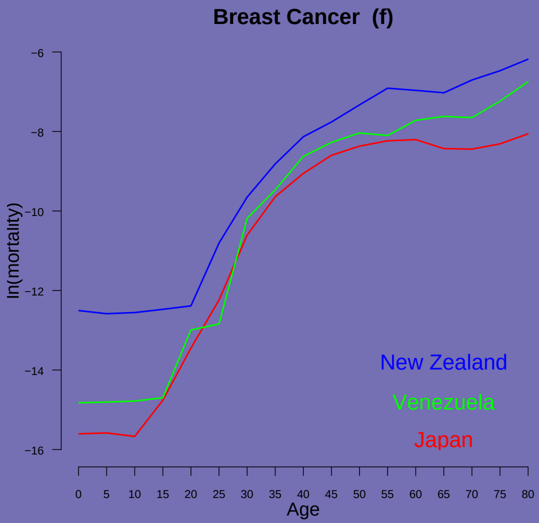



- Gompertz (1825): log-mortality is linear in age after age 20
  - Reduce age-specific rates to 2 parameters ($\mu_{\text{age}} = \gamma_1 + \gamma_2 \times \text{age}$)
  - Forecast only these 2 parameters ($\gamma_1, \gamma_2$)
  - Reduces variance, constrains forecasts
- Dozens of more general functional forms proposed since 1825
- But does it fit anything else?

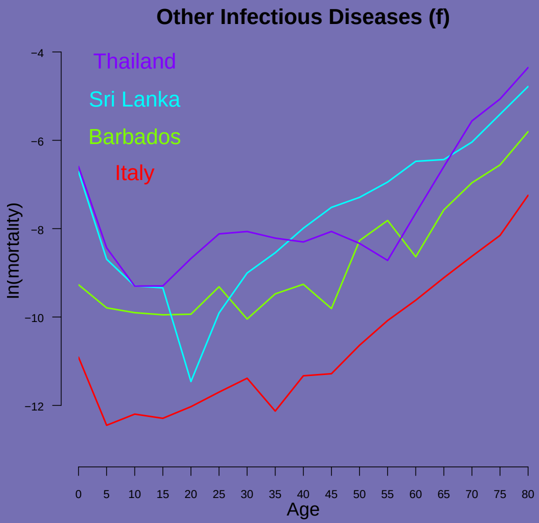
# Mortality Age Profile: The Same Pattern?



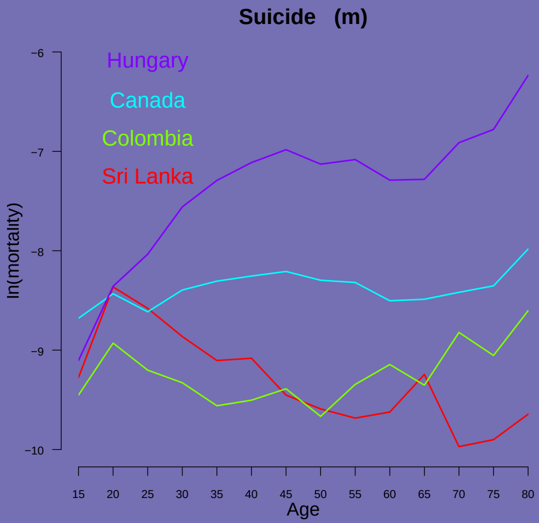
# Mortality Age Profile: The Same Pattern?



# Mortality Age Profile: The Same Pattern?



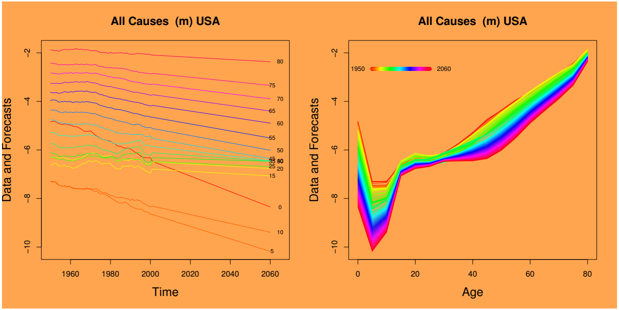
# Mortality Age Profile: The Same Pattern?



# Parameterizing Age Profiles Does Not Work

- No mathematical form fits all or even most age profiles
- Out-of-sample age profiles often unrealistic
- The key empirical patterns are qualitative:
    - Adjacent age groups have similar mortality rates
    - Age profiles are more variable for younger ages
    - We don't know much about levels or exact shapes
- Ignores covariate information

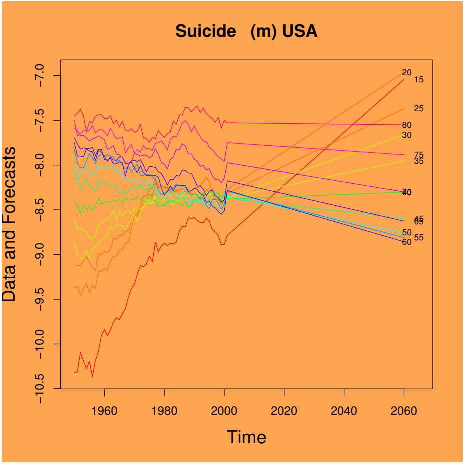
# Existing Method 2: Deterministic Projections

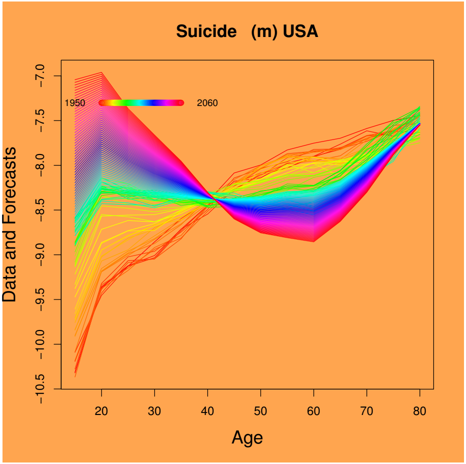



- Random walk with drift; Lee-Carter; least squares on linear trend
- Pros: simple, fast, works well in appropriate data
- Cons: omits covariates; forecasts fan out;
  age profile becomes less smooth
- Does it fit elsewhere?

# The same pattern?

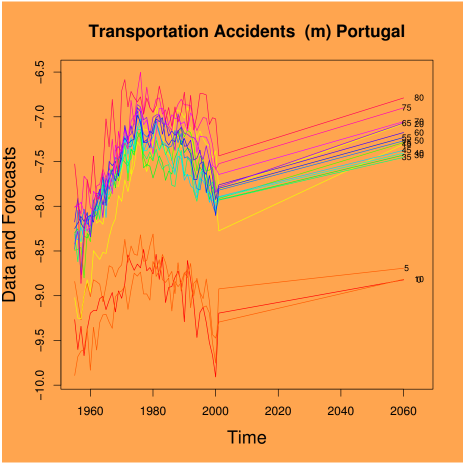
## Random Walk with Drift ≈ Lee-Carter ≈ Least Squares

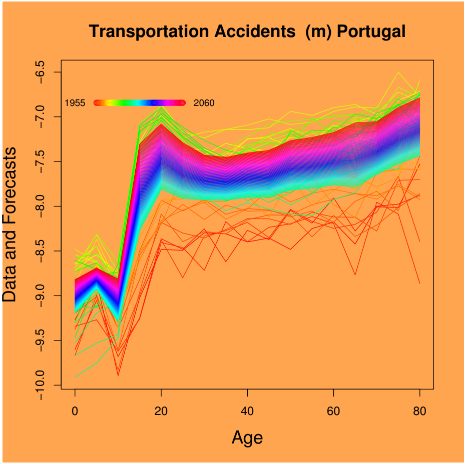


# The same pattern?

## Random Walk with Drift ≈ Lee-Carter ≈ Least Squares



# Deterministic Projections Do Not Work

- Linearity does not fit most time series data
- Out-of-sample age profiles become unrealistic over time

# Existing Method 3: Stacked Regression
(Murray and Lopez, 1996)

- Model mortality over countries ($c$) and ages ($a$) as:

$$m_{cat} = \mathbf{Z}_{ca,t-\ell}\boldsymbol{\beta}_{ca} + \epsilon_{cat} \quad , \quad t = 1, \ldots, T$$

- $\mathbf{Z}_{ca,t-\ell}$ : covariates lagged $\ell$ years.
- $\boldsymbol{\beta}_{ca}$ : coefficients to be estimated
- Equation by equation estimation: huge variances
- Pool over countries: $\boldsymbol{\beta}_{ca} \Rightarrow \boldsymbol{\beta}_{a}$
  - Small variance (due to large $n$)
  - large biases (due to restrictive pooling over countries),
  - considerable information lost (due to no pooling over ages)
  - same covariates required in all cross-sections
- (It always seems ok to pool over variables outside your own field.)

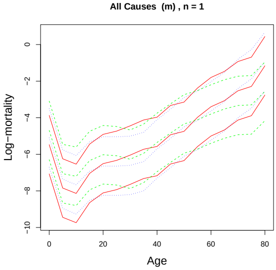
# The New Approach

- Start with separate equation-by-equation regressions
- Use Bayesian priors to smooth across age, time, age$\times$time, etc.
- Put priors on E(mortality), not coefficients
- No arbitrary normalizations
- Different covariates allowed in each regression
- Only one smoothing parameter to represent demographic information
- $\rightsquigarrow$ An easy-to-use software program, YourCast

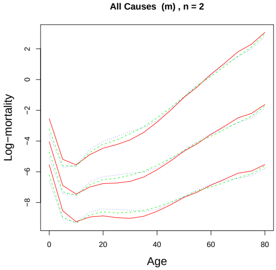
# Formalizing (Prior) Indifference (so no cooking the books)

equal color = equal probability

Level indifference

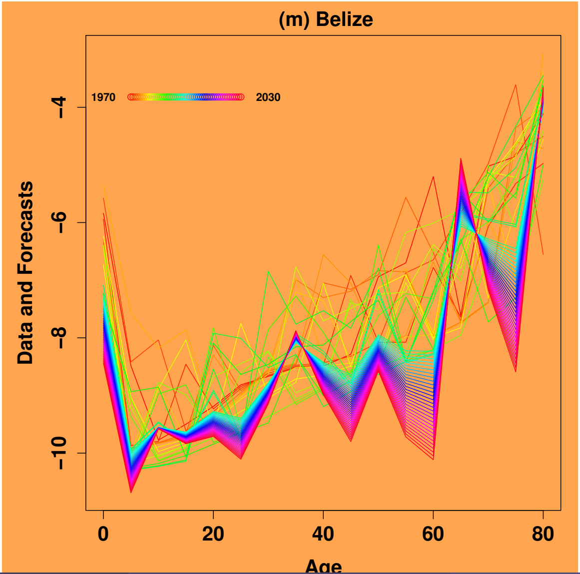



Level and slope indifference



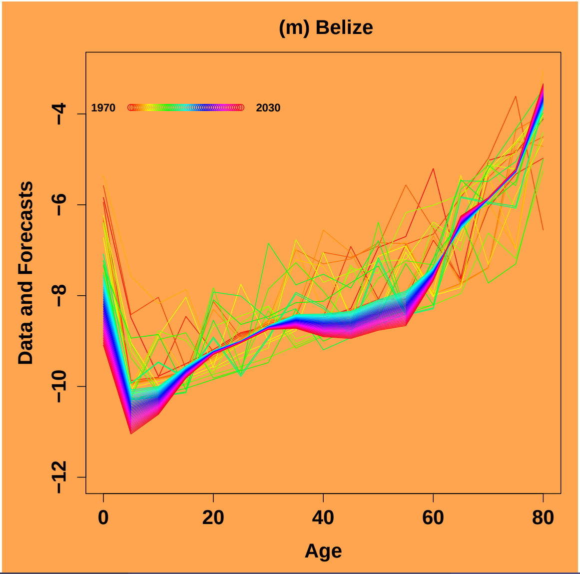
# Mortality from Respiratory Infections, Males

## Least Squares



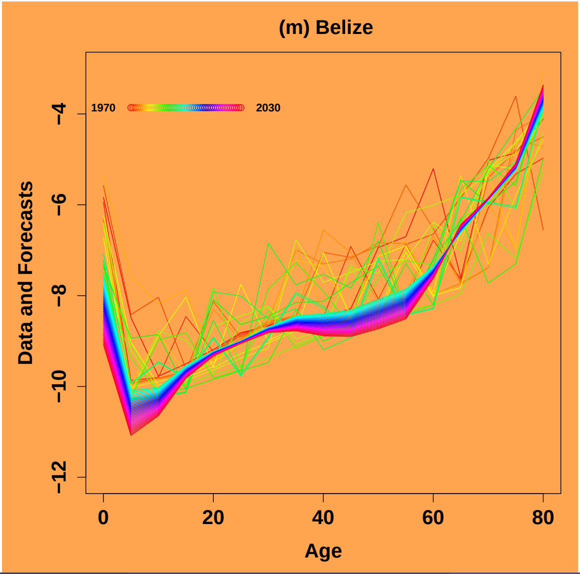
# Mortality from Respiratory Infections, males, $\sigma = 2.00$

## Smoothing over Age Groups



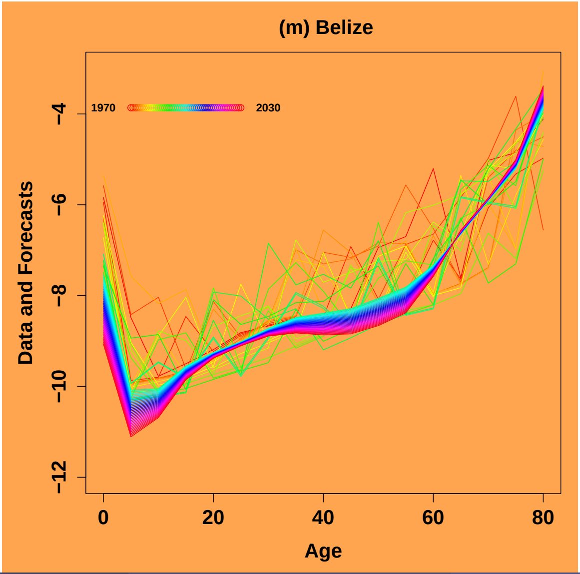
# Mortality from Respiratory Infections, males, $\sigma = 1.51$

## Smoothing over Age Groups



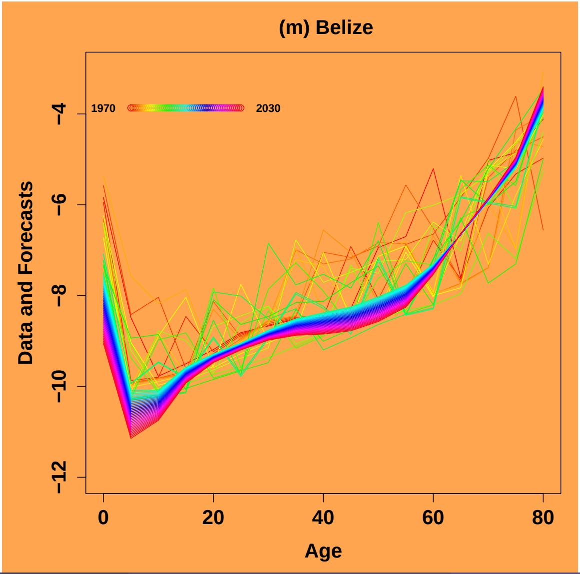
# Mortality from Respiratory Infections, males, $\sigma = 1.15$

## Smoothing over Age Groups



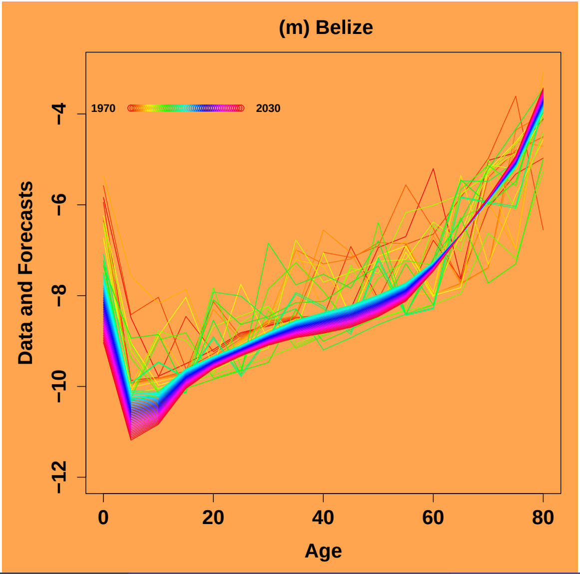
# Mortality from Respiratory Infections, males, $\sigma = 0.87$

## Smoothing over Age Groups



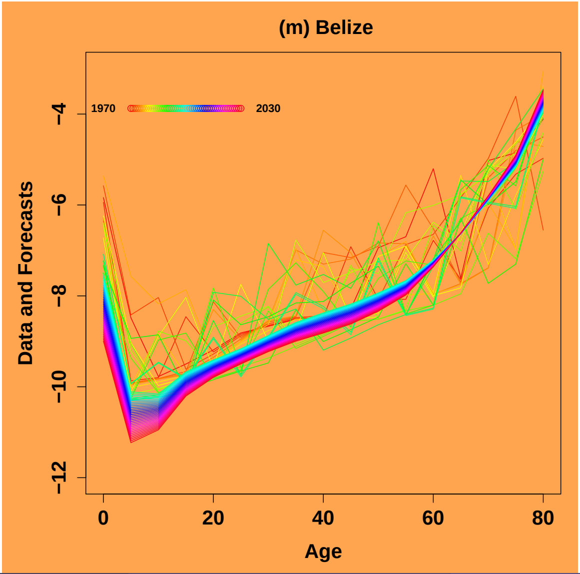
# Mortality from Respiratory Infections, males, $\sigma = 0.66$

## Smoothing over Age Groups



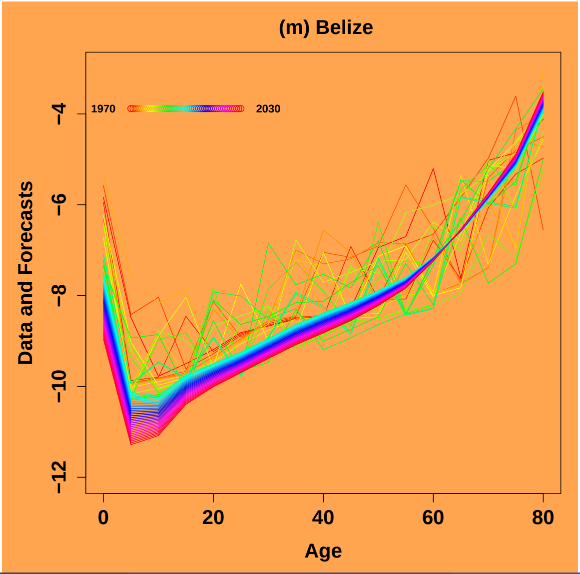
# Mortality from Respiratory Infections, males, $\sigma = 0.50$

## Smoothing over Age Groups



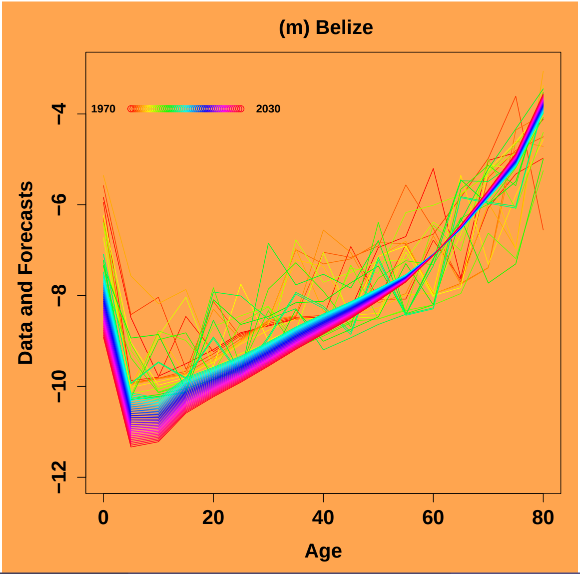
# Mortality from Respiratory Infections, males, $\sigma = 0.38$

## Smoothing over Age Groups



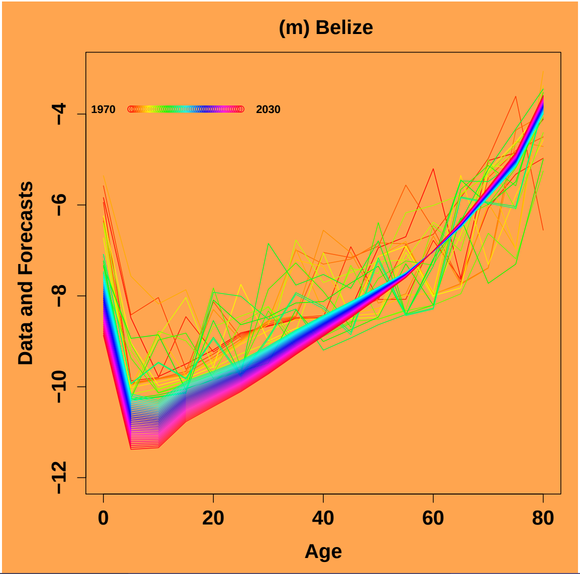
# Mortality from Respiratory Infections, males, $\sigma = 0.28$

## Smoothing over Age Groups



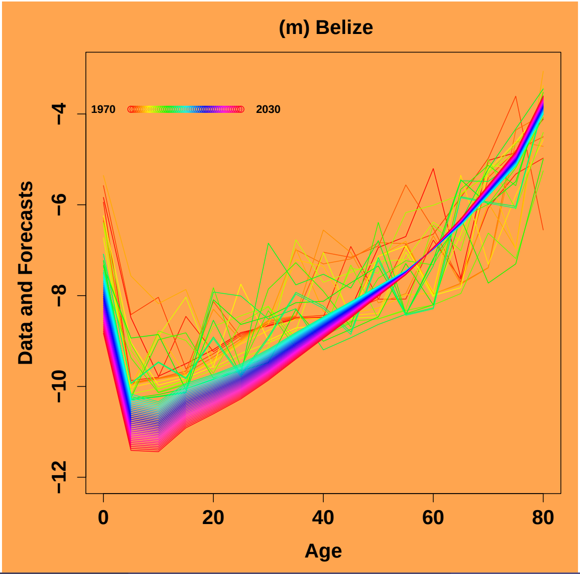
# Mortality from Respiratory Infections, males, $\sigma = 0.21$

## Smoothing over Age Groups



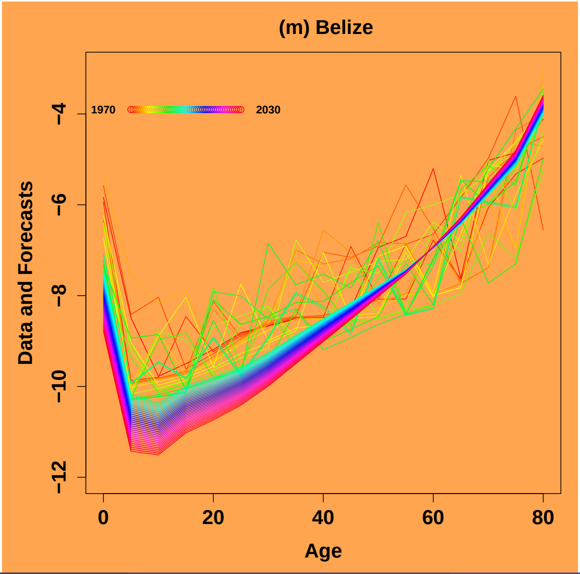
# Mortality from Respiratory Infections, males, $\sigma = 0.16$

## Smoothing over Age Groups



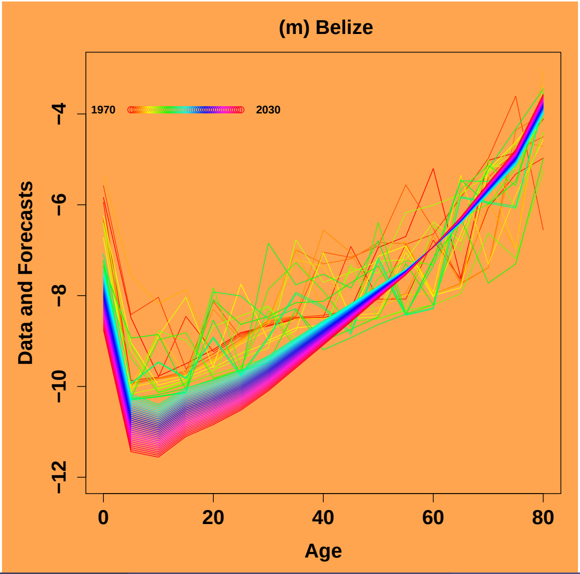
# Mortality from Respiratory Infections, males, $\sigma = 0.12$

## Smoothing over Age Groups



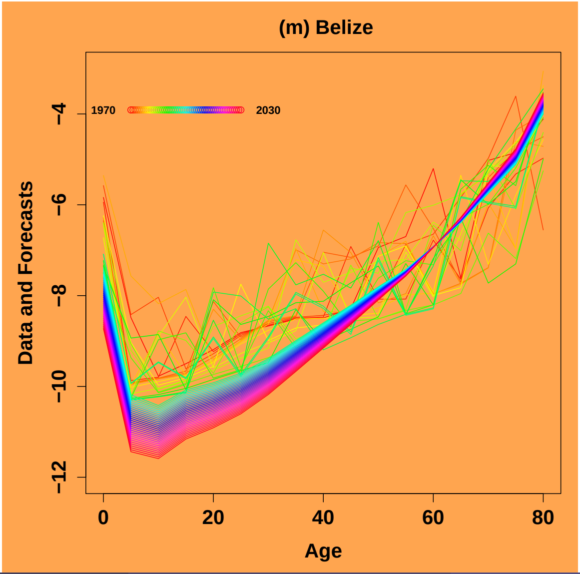
# Mortality from Respiratory Infections, males, $\sigma = 0.09$

## Smoothing over Age Groups



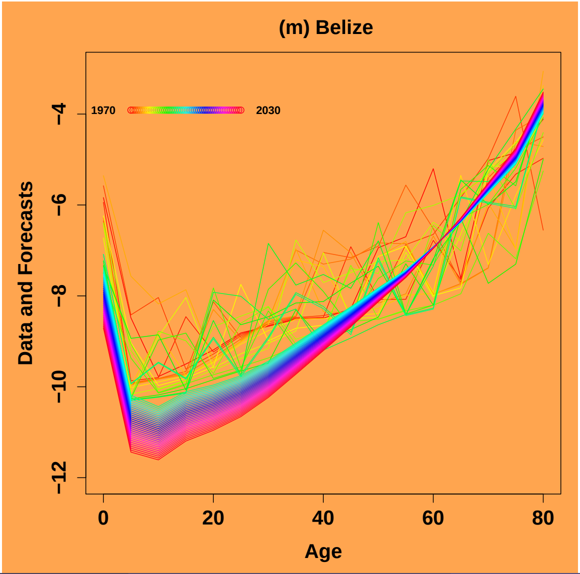
# Mortality from Respiratory Infections, males, $\sigma = 0.07$

Smoothing over Age Groups



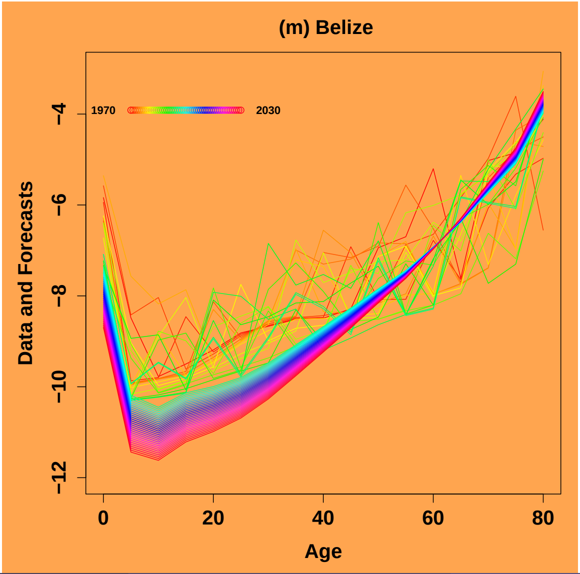
# Mortality from Respiratory Infections, males, $\sigma = 0.05$

## Smoothing over Age Groups



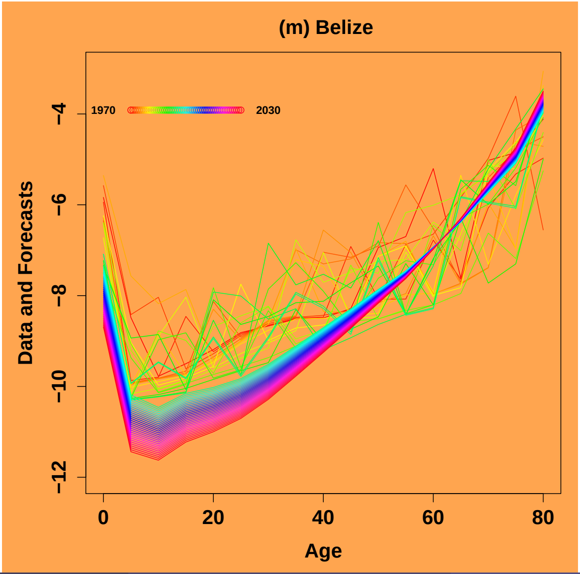
# Mortality from Respiratory Infections, males, $\sigma = 0.04$

## Smoothing over Age Groups



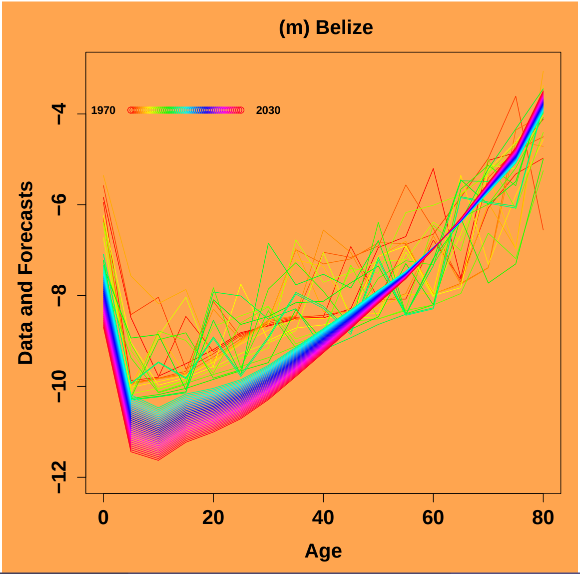
# Mortality from Respiratory Infections, males, $\sigma = 0.03$

## Smoothing over Age Groups



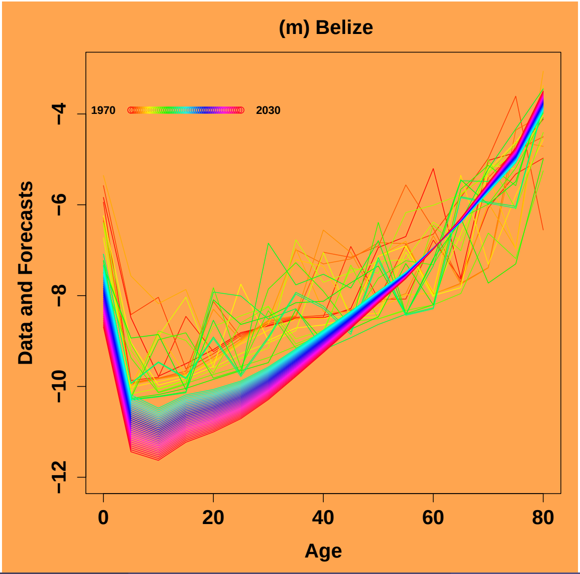
# Mortality from Respiratory Infections, males, $\sigma = 0.02$

## Smoothing over Age Groups



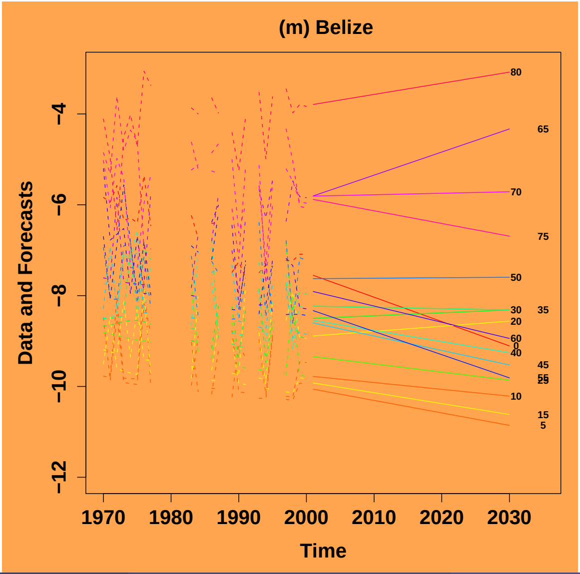
# Mortality from Respiratory Infections, males, $\sigma = 0.01$

## Smoothing over Age Groups



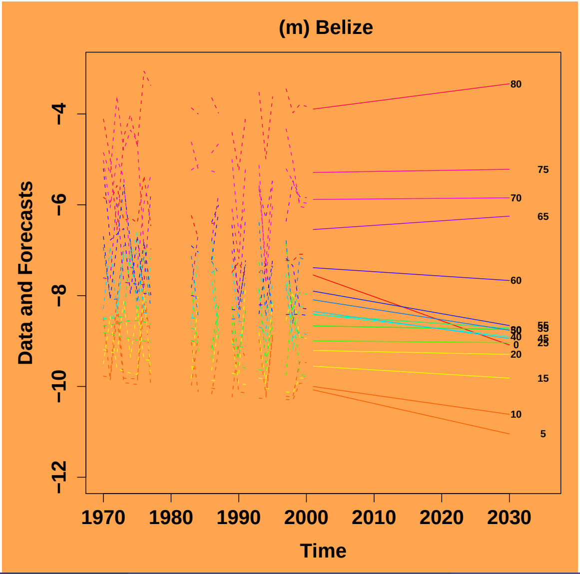
# Mortality from Respiratory Infections, males

## Least Squares



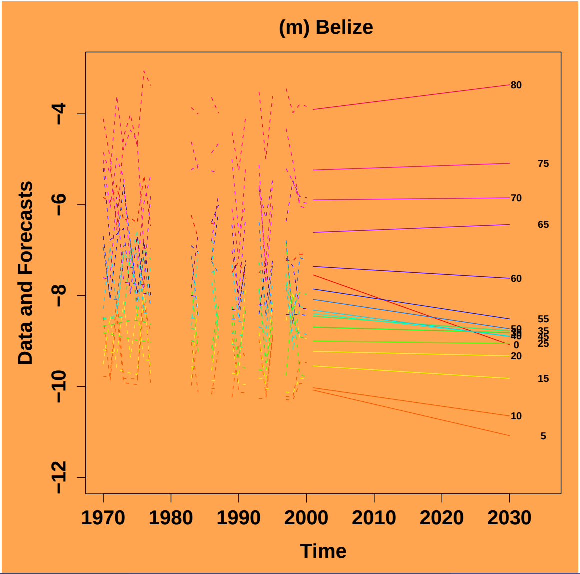
# Mortality from Respiratory Infections, males, $\sigma = 2.00$

## Smoothing over Age Groups



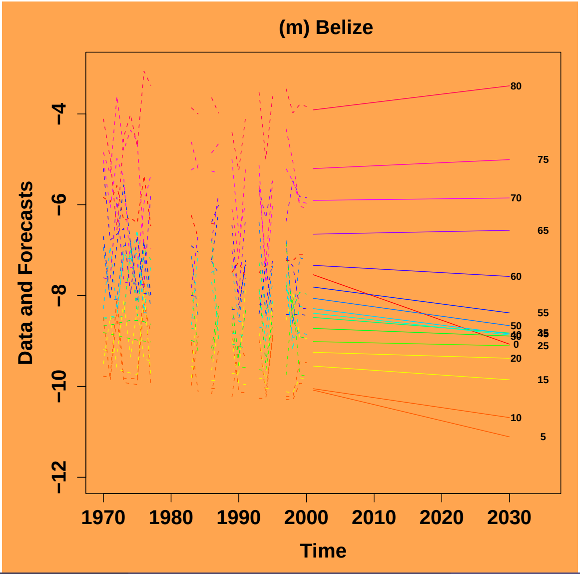
# Mortality from Respiratory Infections, males, $\sigma = 1.51$

## Smoothing over Age Groups



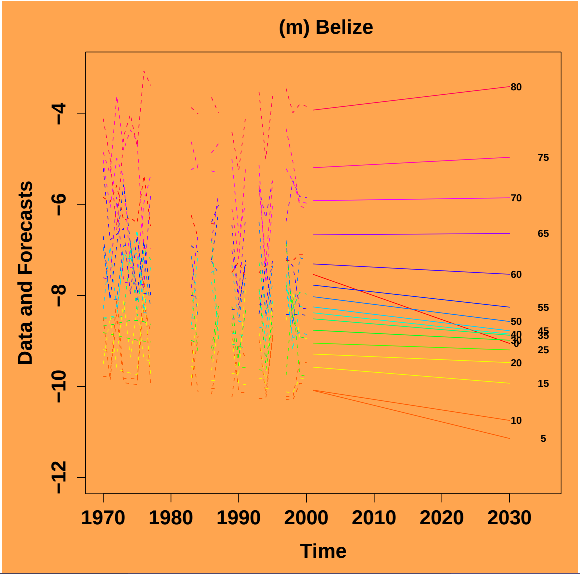
# Mortality from Respiratory Infections, males, $\sigma = 1.15$

## Smoothing over Age Groups



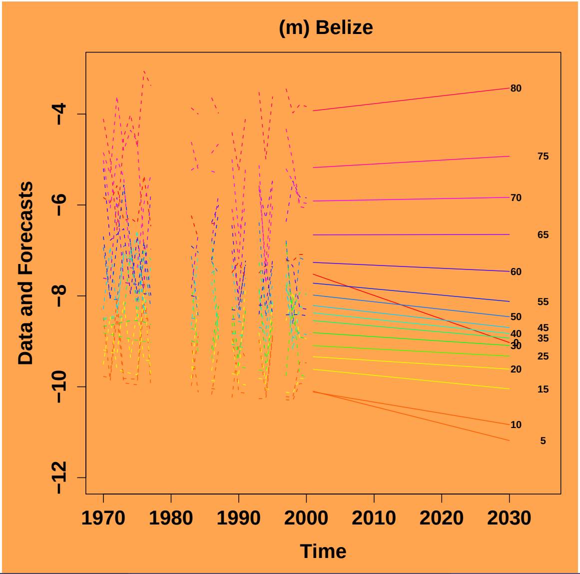
# Mortality from Respiratory Infections, males, $\sigma = 0.87$

## Smoothing over Age Groups



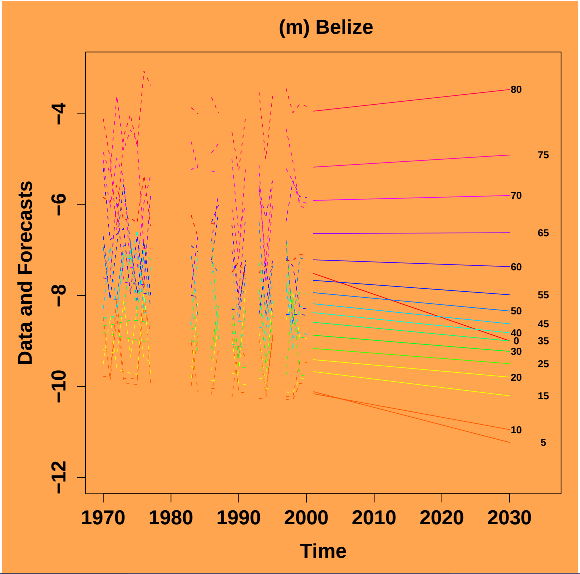
# Mortality from Respiratory Infections, males, $\sigma = 0.66$

## Smoothing over Age Groups



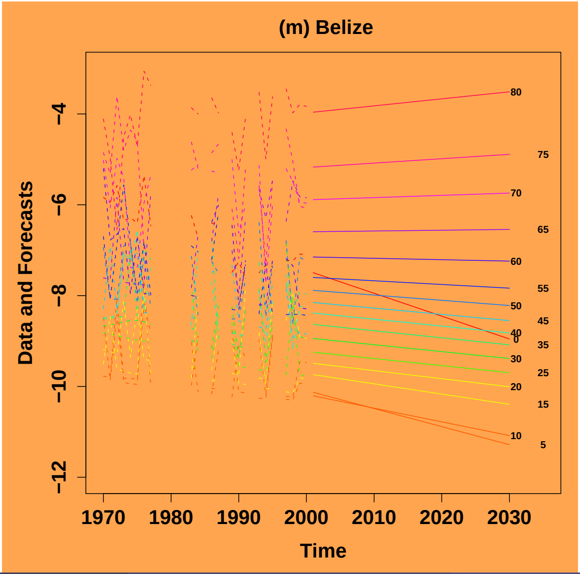
# Mortality from Respiratory Infections, males, $\sigma = 0.50$

## Smoothing over Age Groups



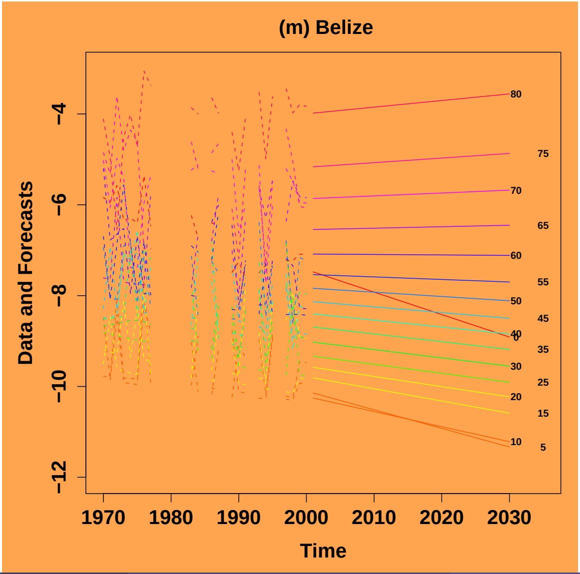
# Mortality from Respiratory Infections, males, $\sigma = 0.38$

## Smoothing over Age Groups



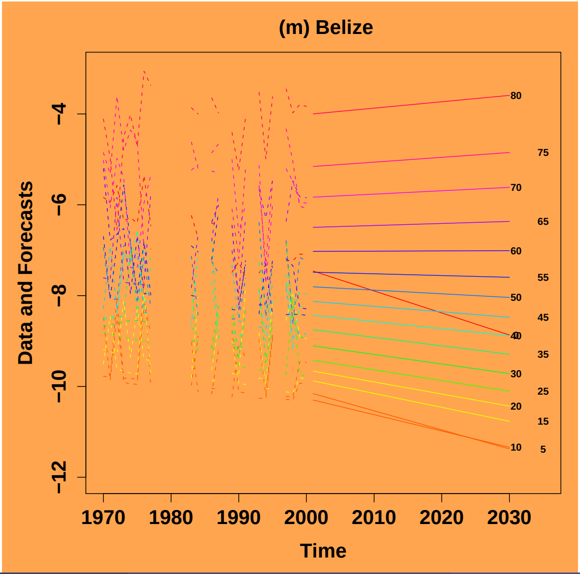
# Mortality from Respiratory Infections, males, $\sigma = 0.28$

## Smoothing over Age Groups



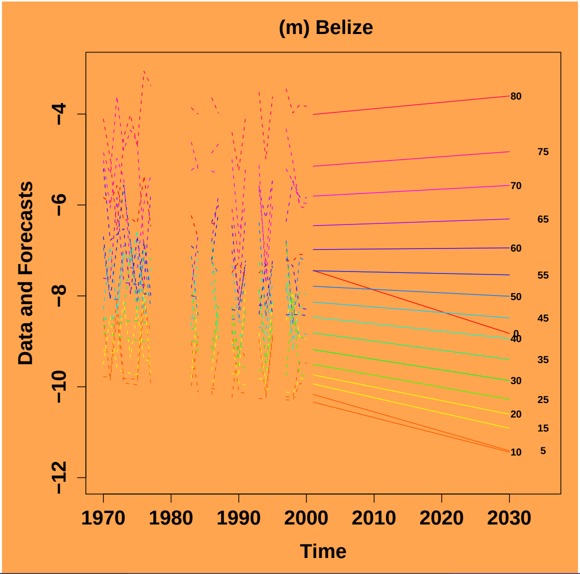
# Mortality from Respiratory Infections, males, $\sigma = 0.21$

## Smoothing over Age Groups



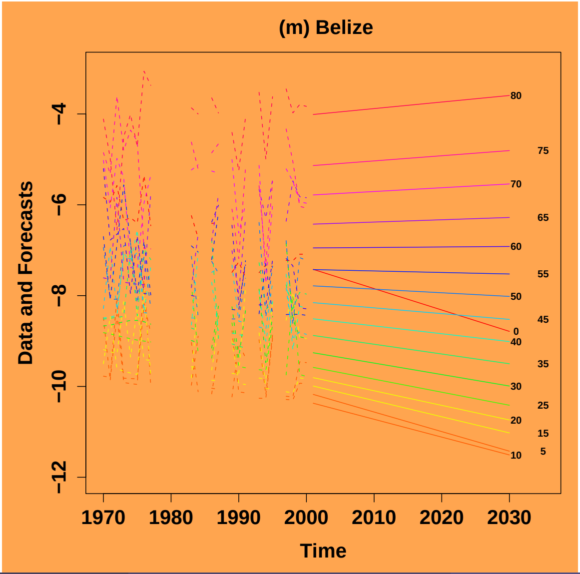
# Mortality from Respiratory Infections, males, $\sigma = 0.16$

## Smoothing over Age Groups



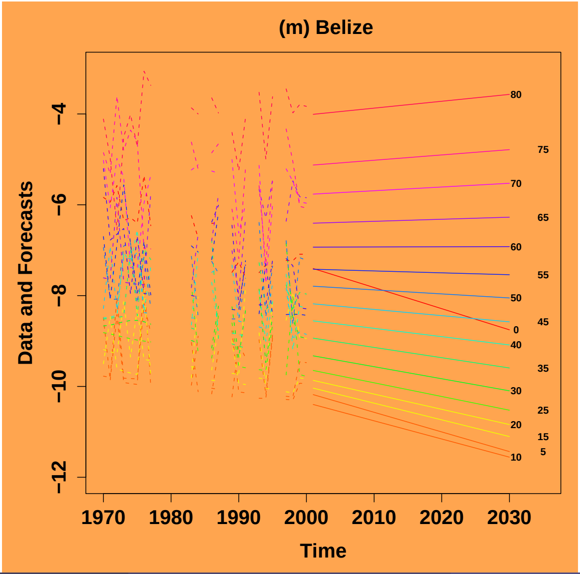
# Mortality from Respiratory Infections, males, $\sigma = 0.12$

## Smoothing over Age Groups



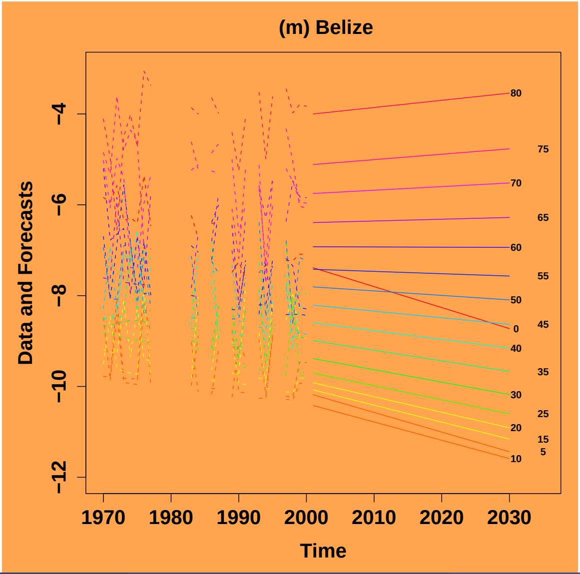
# Mortality from Respiratory Infections, males, $\sigma = 0.09$

## Smoothing over Age Groups



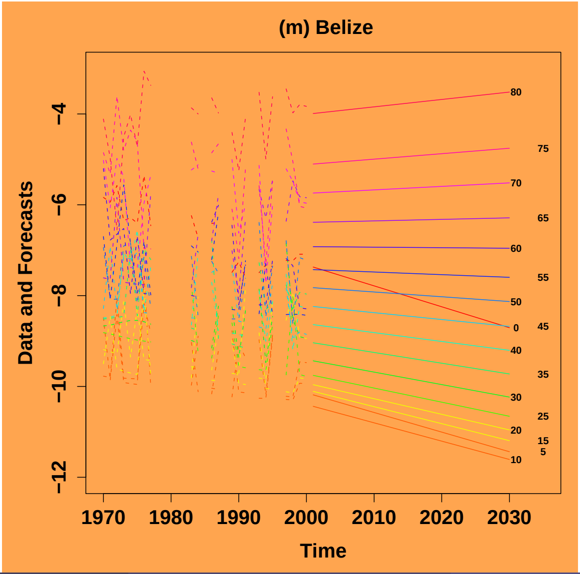
# Mortality from Respiratory Infections, males, $\sigma = 0.07$

## Smoothing over Age Groups



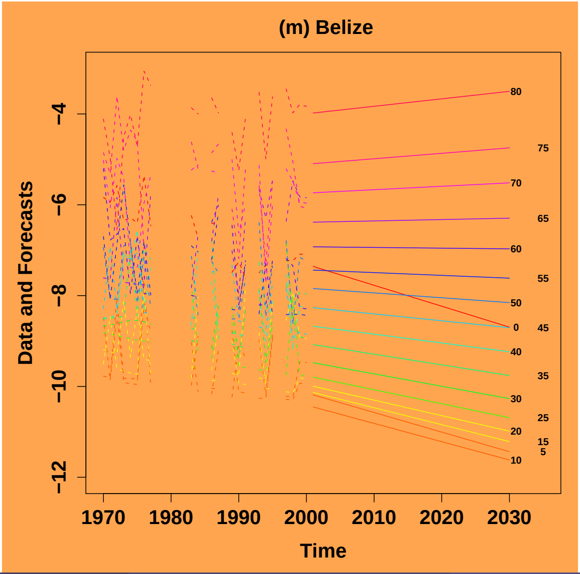
# Mortality from Respiratory Infections, males, $\sigma = 0.05$

## Smoothing over Age Groups



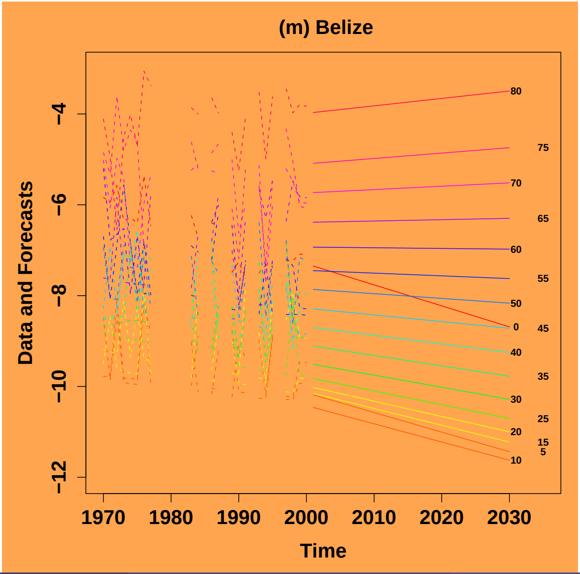
# Mortality from Respiratory Infections, males, $\sigma = 0.04$

## Smoothing over Age Groups



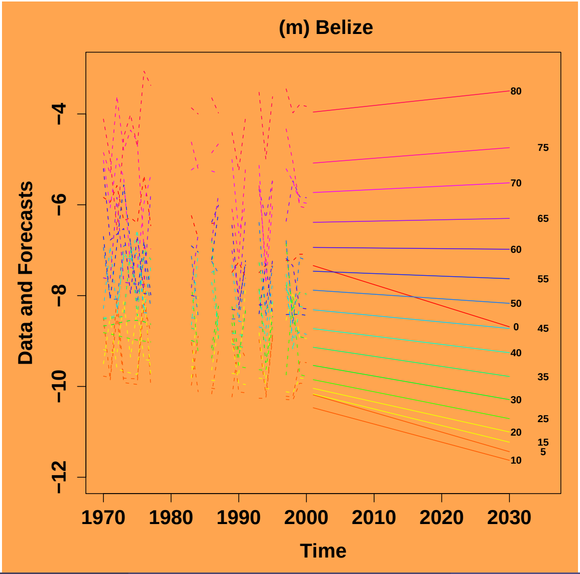
# Mortality from Respiratory Infections, males, $\sigma = 0.03$

## Smoothing over Age Groups



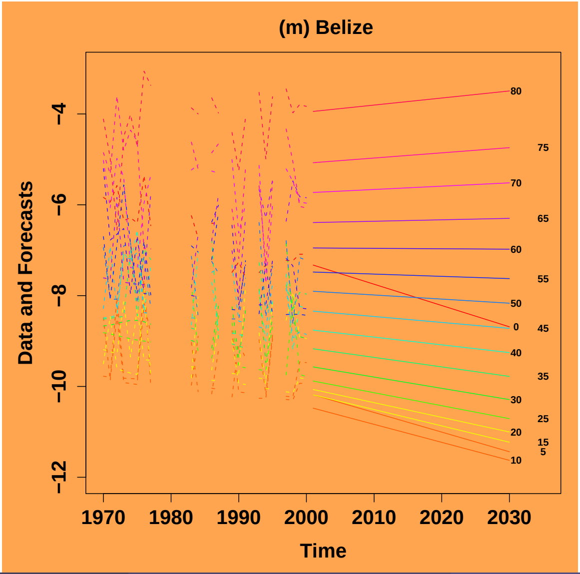
# Mortality from Respiratory Infections, males, $\sigma = 0.02$

## Smoothing over Age Groups



# Mortality from Respiratory Infections, males, $\sigma = 0.01$

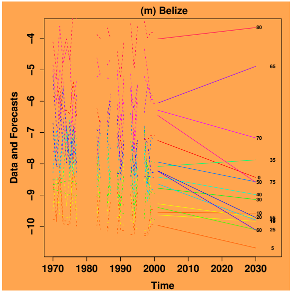
## Smoothing over Age Groups

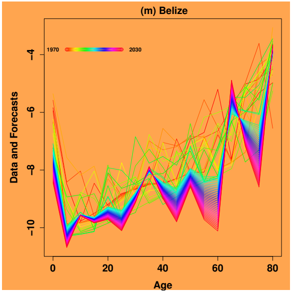


# Smoothing Trends over Age Groups

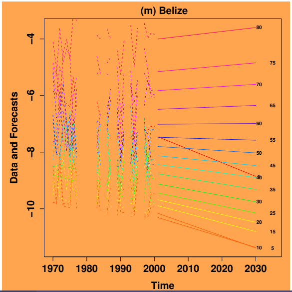
Log-mortality in Belize males from respiratory infections

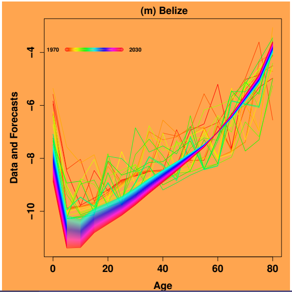
Least Squares




Smoothing
Age Groups

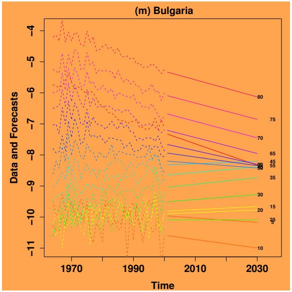


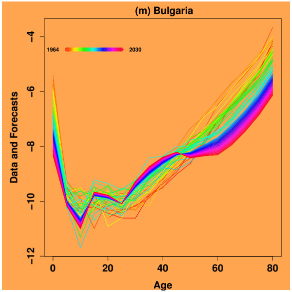



# Smoothing Trends over Age Groups and Time

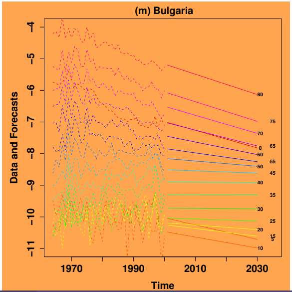
## Log-Mortality in Bulgarian males from respiratory infections

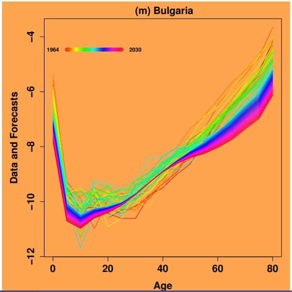
Least Squares




Smoothing
Age and Time

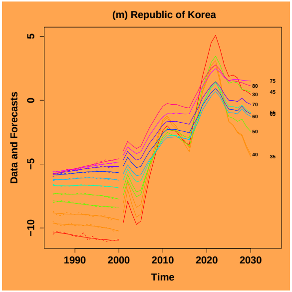


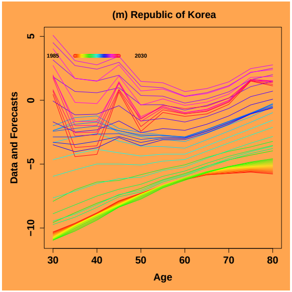



# Using Covariates (GDP, tobacco, trend, log trend)

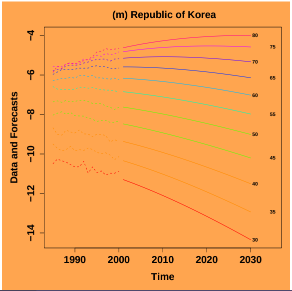
## Lung cancer in Korean Males

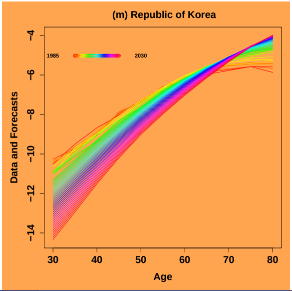
Least Squares




Smooth over age, time, age/time

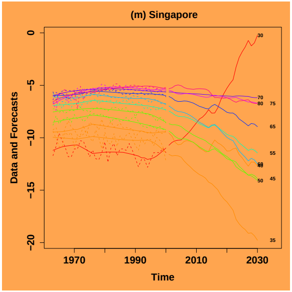


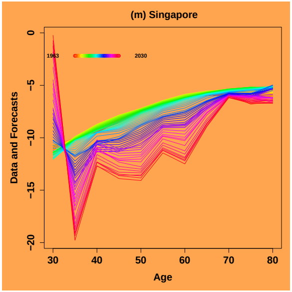



# Using Covariates (GDP, tobacco, trend, log trend)

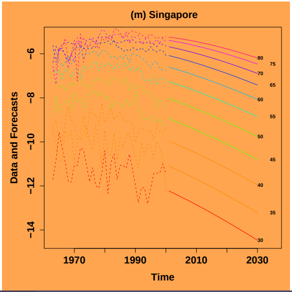
## Lung cancer in Males, Singapore

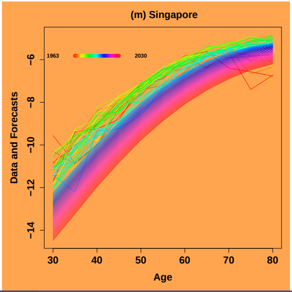
Least Squares



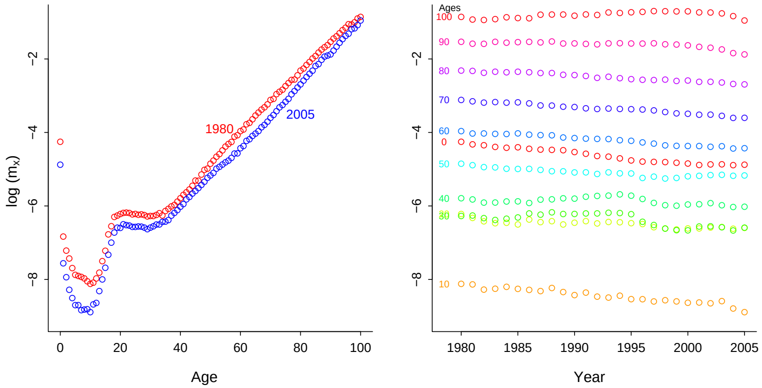

Smooth over age, time, age/time



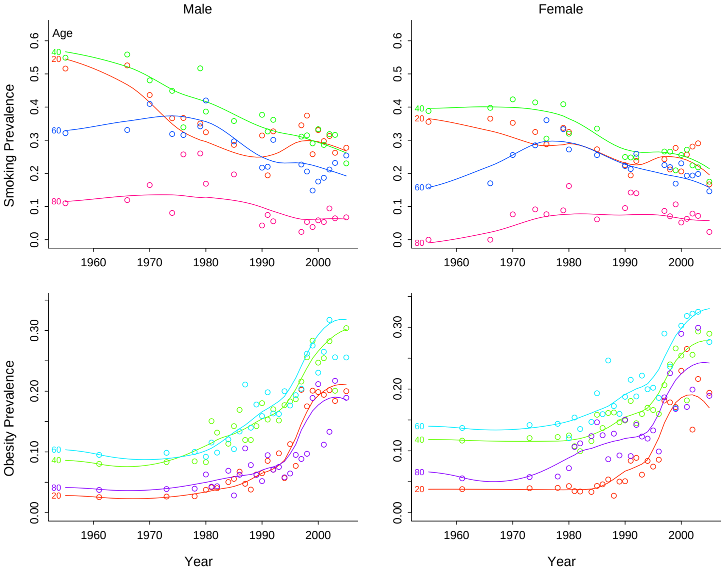



# U.S. Male Mortality over Age and Time

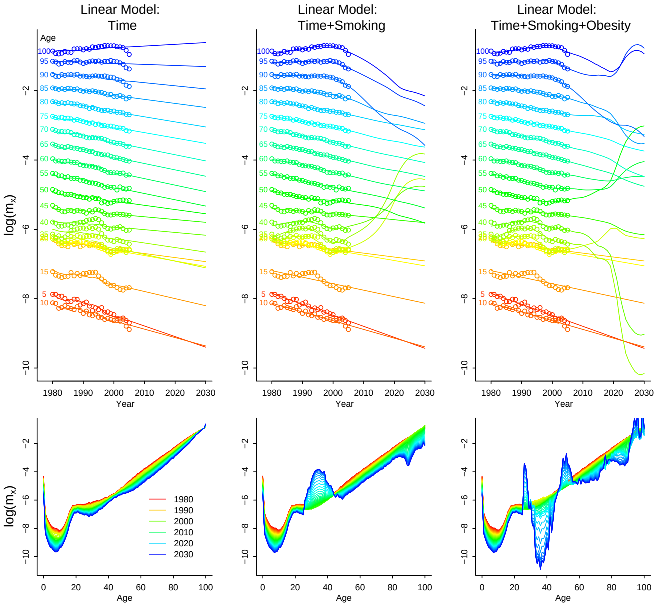
## Demographic Facts: Smoothness in both dimensions



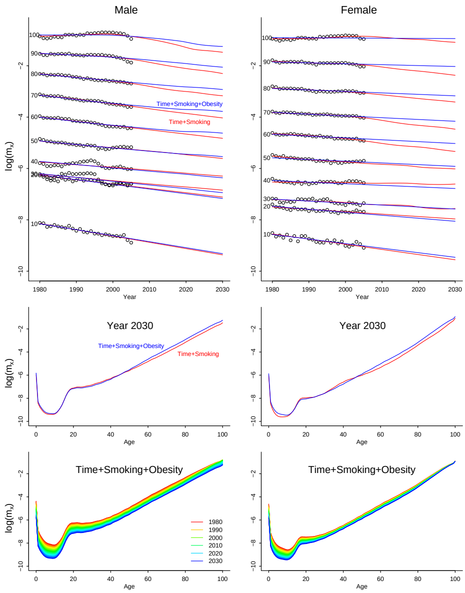
# Biological Risk Factors in U.S. Data



# Linear Models: Biology vs. Demography

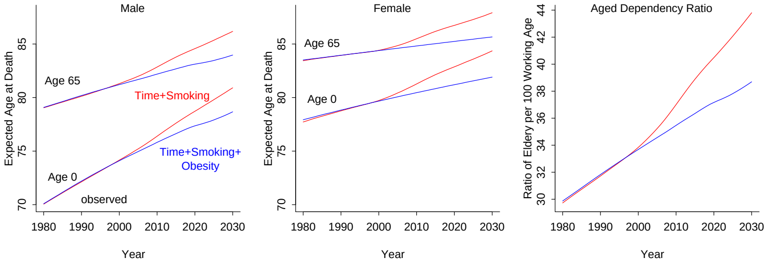


# Forecasts: Biology *and* Demography




- Forecasts retain smoothness over age and time
- After age 50, age-specific mortality increases when adding obesity.
- 2030 forecast for 70-year-olds (per 100,000PYs). Males: 2,290 deaths with obesity; 1,775 without; Females: 1,558 with, 1,144 without.
- At ages over 90, model forecasts converge faster for females than males.

# Life Expectancy and Aged Dependency Ratios




- Male Life Expectancy (±25 years)
  - Past: +5.1 years ⇝ 75.2
  - Future: +5.7 years ⇝ 80.9 (excluding obesity)
  - Future: +3.5 years ⇝ 78.7 (a 35% drop)
- Female Life Expectancy (±25 years)
  - Past: +2.7 years ⇝ 80.4
  - Future: +3.9 years ⇝ 84.4 (excluding obesity)
  - Future: +1.8 years ⇝ 81.9 (a 53% drop)
- ⇝ 1/2 trillion dollar difference for Social Security

# For papers, software, etc.

http://GKing.Harvard.edu