

# Forecasting the age structure of the scientific workforce in Australia

Rob J Hyndman & Kelly Nguyen

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# Ideal labour force model

$$P_{x+1,t+1} = P_{x,t} - D_{x,t} - R_{x,t} + G_{x,t} - C_{x,t} + N_{x,t}$$

$x$  = Age  
 $t$  = Year

$P_{x,t}$  = number of equivalent full-time workers

$D_{x,t}$  = number of deaths

$R_{x,t}$  = number of retirements

$G_{x,t}$  = number of graduates who work in science

$C_{x,t}$  = net number of people who have a career change

$N_{x,t}$  = net number of migrants

# Pragmatic labour force model

$$P_{x+1,t+1} = P_{x,t}(1 - q_{x,t} - r_x) + g_x G_t + E_{x,t}$$

$x$  = Age  
 $t$  = Year

$P_{x,t}$  = number of equivalent full-time workers

$q_{x,t}$  = probability of death

$r_x$  = probability of retirement

$g_x$  = proportion of graduates by age

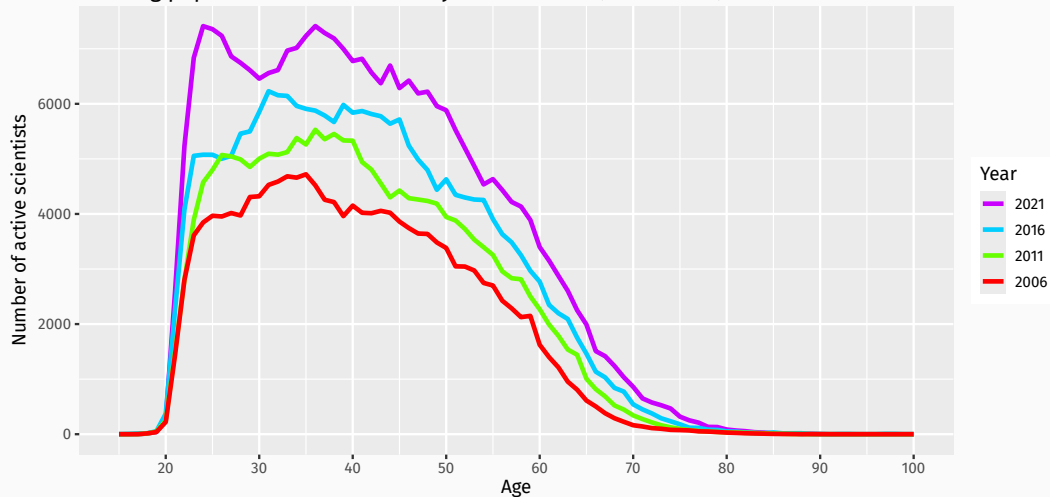
$G_t$  = total number of graduates in science

$E_{x,t}$  = remainder

# Working population: $P_{x,t}$

$$P_{x+1,t+1} = P_{x,t}(1 - q_{x,t} - r_x) + g_x G_t + E_{x,t}$$

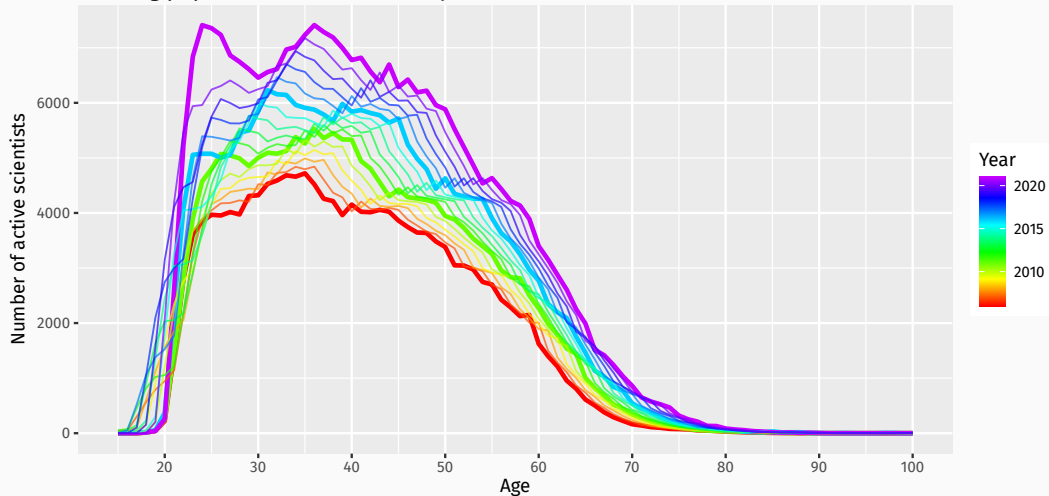
Working population: Natural and Physical Sciences (2006 - 2021)



# Working population: $P_{x,t}$

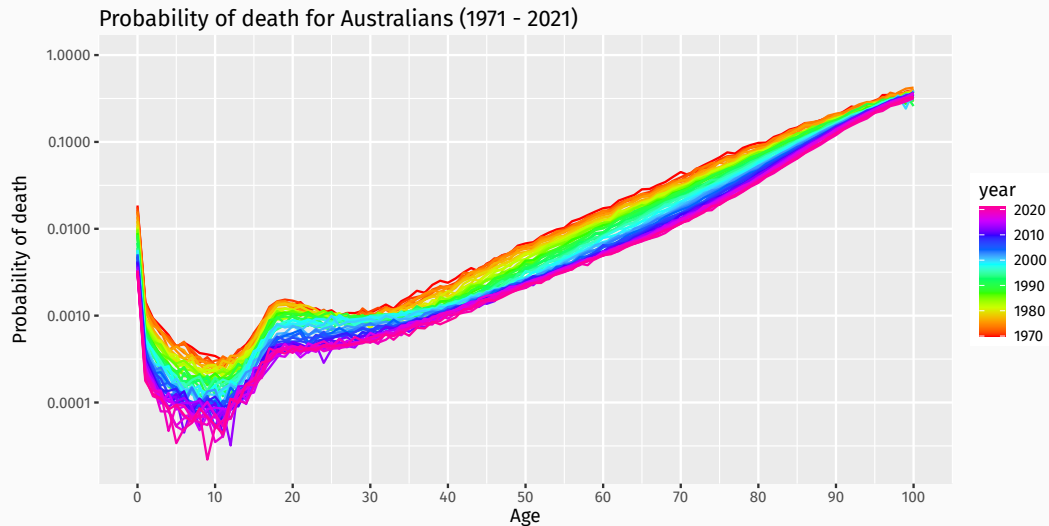
$$P_{x+1,t+1} = P_{x,t}(1 - q_{x,t} - r_x) + g_x G_t + E_{x,t}$$

Working population: Natural and Physical Sciences (2006 - 2021)



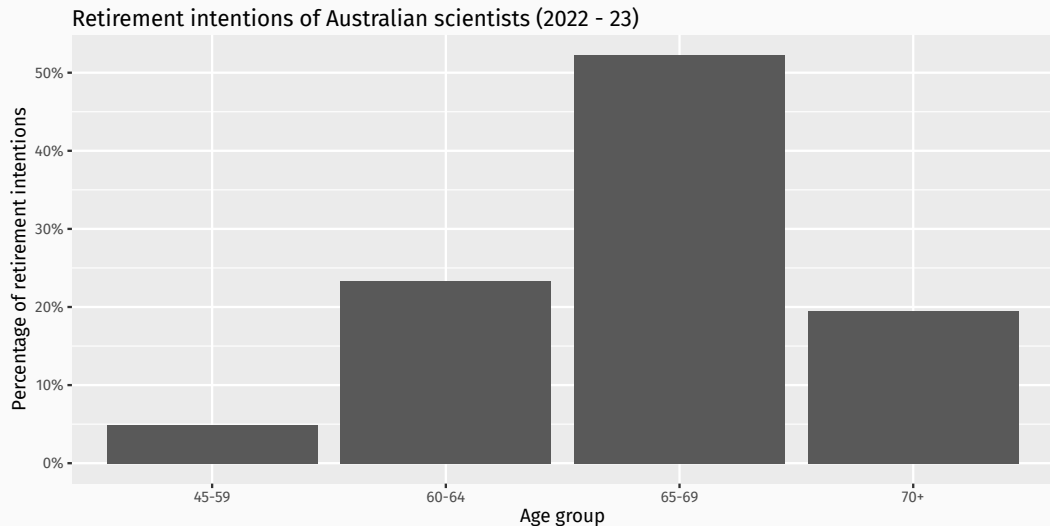
# Death probability: $q_{x,t}$

$$P_{x+1,t+1} = P_{x,t}(1 - q_{x,t} - r_x) + g_x G_t + E_{x,t}$$



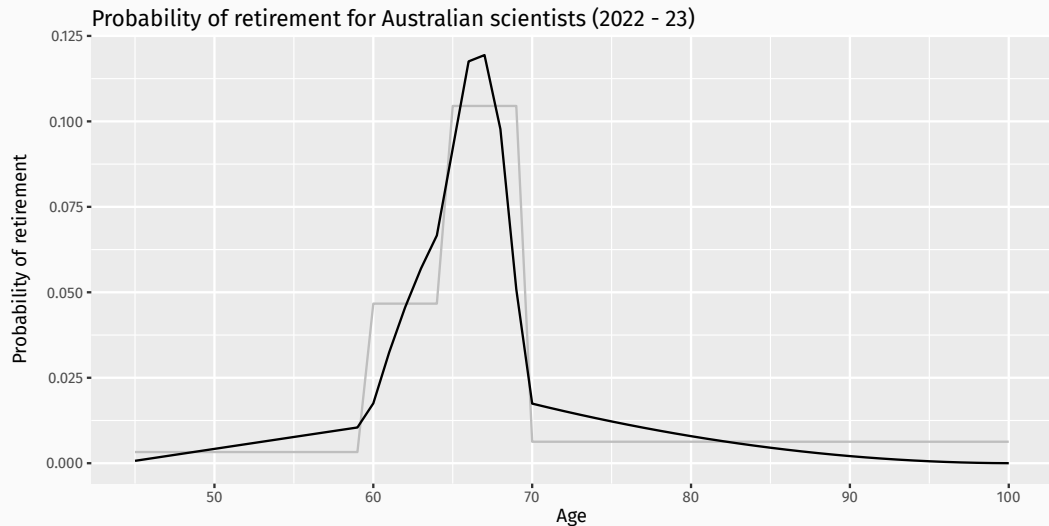
# Retirement rates: $r_x$

$$P_{x+1,t+1} = P_{x,t}(1 - q_{x,t} - r_x) + g_x G_t + E_{x,t}$$



# Retirement rates: $r_x$

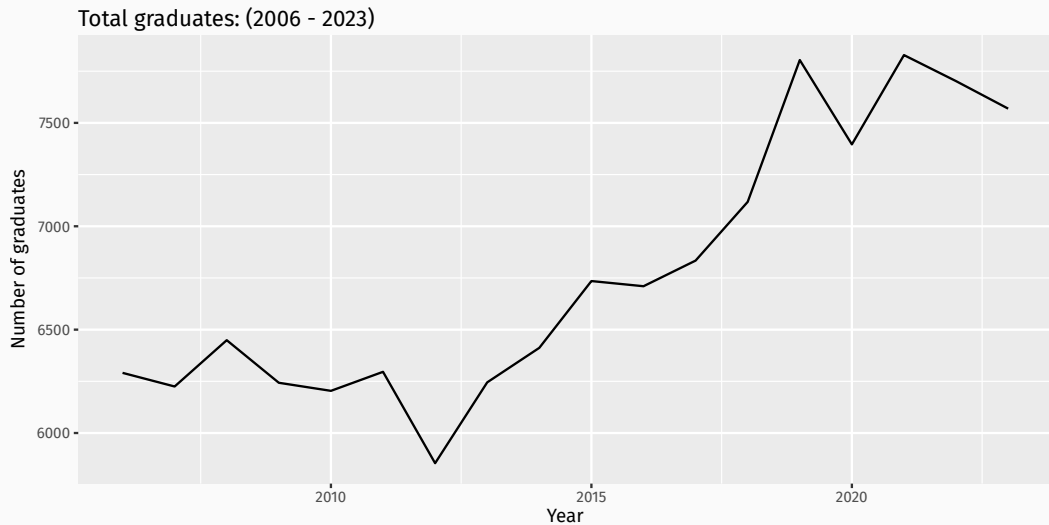
$$P_{x+1,t+1} = P_{x,t}(1 - q_{x,t} - r_x) + g_x G_t + E_{x,t}$$





# Graduate completions: $G_t$

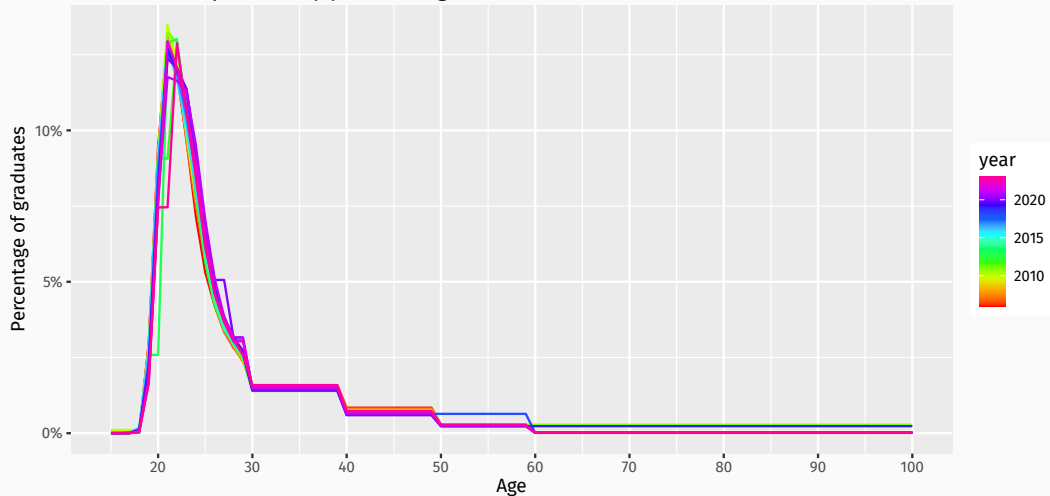
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# Graduate completions: $g_x$

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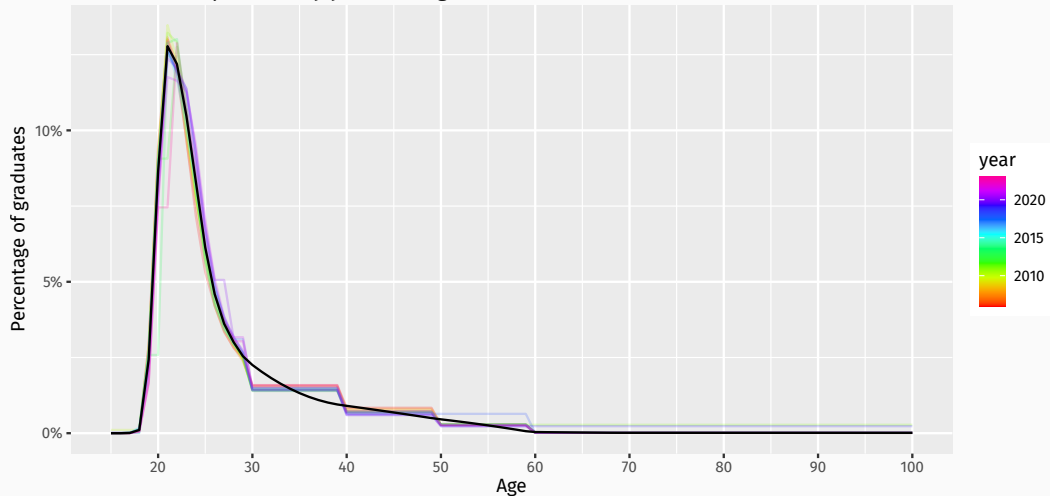
Graduate completions by year and age (2006 - 2023)



# Graduate completions: $g_x$

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Graduate completions by year and age (2006 - 2023)



**Remainder:**  $E_{x,t}$

$$P_{x+1,t+1} = P_{x,t}(1 - q_{x,t} - r_x) + g_x G_t + E_{x,t}$$

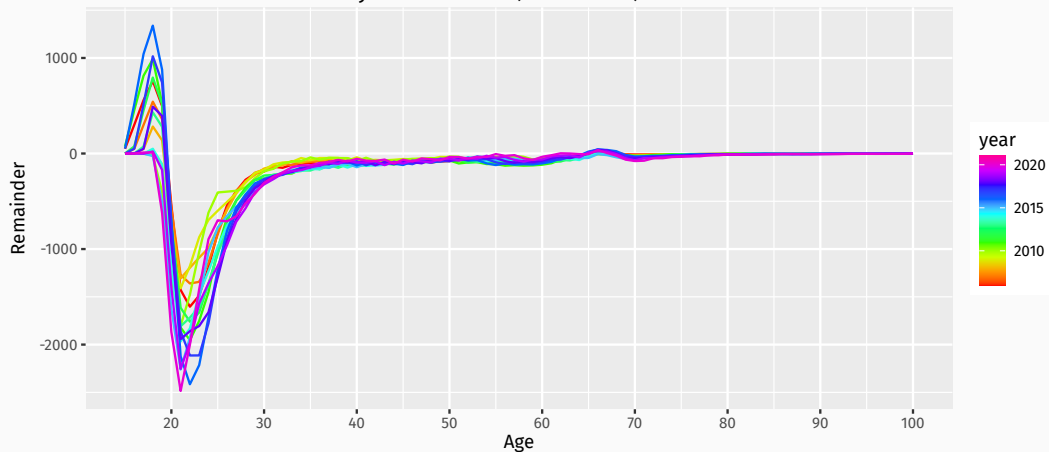
$$E_{x,t} = P_{x+1,t+1} - P_{x,t}(1 - q_{x,t} - r_x) - g_x G_t$$

# Remainder: $E_{x,t}$

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Remainder: Natural and Physical Sciences (2006 - 2021)



$$P_{x+1,t+1} = P_{x,t}(1 - q_{x,t} - r_x) + g_x G_t + E_{x,t}$$

- $G_t$  ARIMA model of total graduates by year
- $q_{x,t}$  functional time series model
- $E_{x,t}$  functional time series model

$$P_{x+1,t+1} = P_{x,t}(1 - q_{x,t} - r_x) + g_x G_t + E_{x,t}$$

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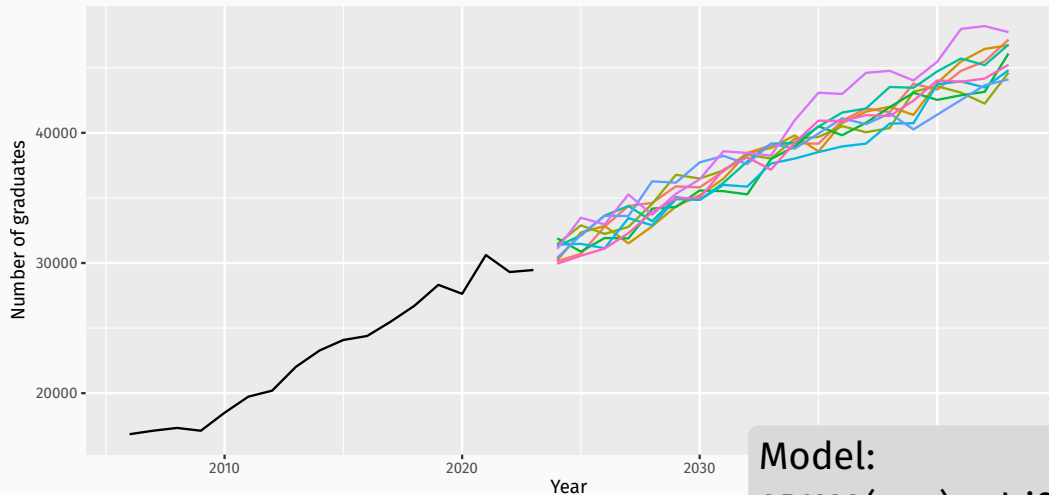
$E_{x,t}$  functional time series model

- Future sample paths of all components simulated to obtain probabilistic forecasts of  $P_{x,t}$

# Forecasting models: $G_t$

$$P_{x+1,t+1} = P_{x,t}(1 - q_{x,t} - r_x) + g_x G_t + E_{x,t}$$

Total Science Graduates: Australia

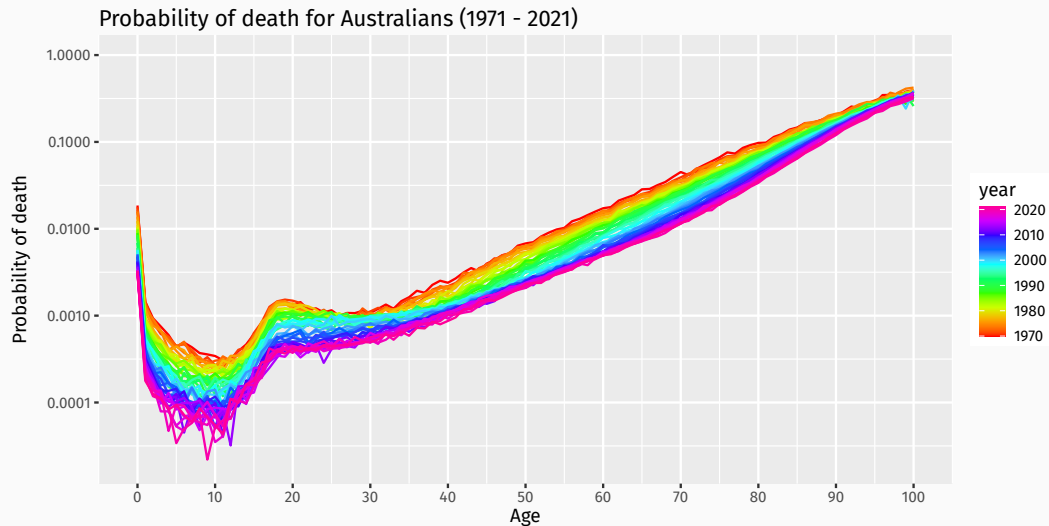


Model:  
ARIMA(0,1,1) + drift



# Forecasting models: $q_{x,t}$

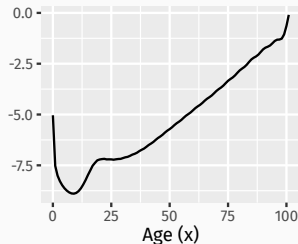
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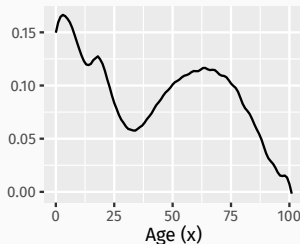
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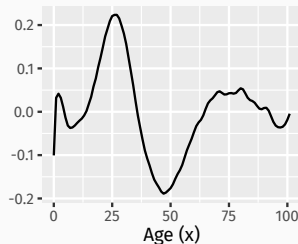
$\mu(x)$



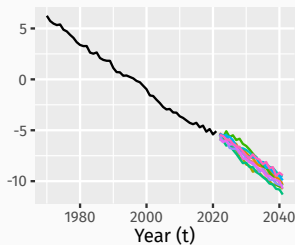
$\phi_1(x)$



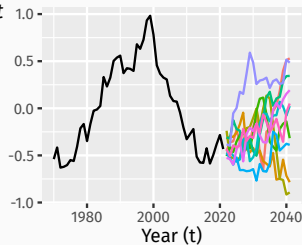
$\phi_2(x)$



$\beta_{1,t}$



$\beta_{2,t}$



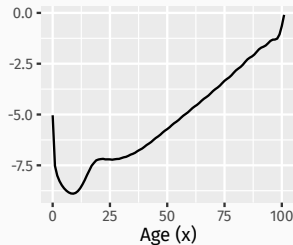
$$q_{x,t} = \mu(x) + \sum_{k=1}^6 \beta_{k,t} \phi_k(x) + \varepsilon_t(x)$$

$\beta_{k,t} \sim \text{ARIMA}$

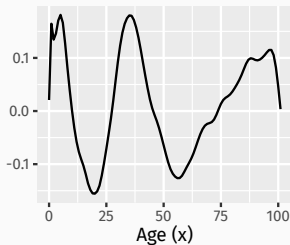
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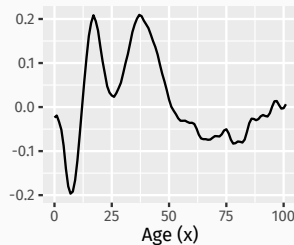
$\mu(x)$



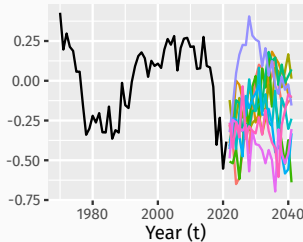
$\phi_3(x)$



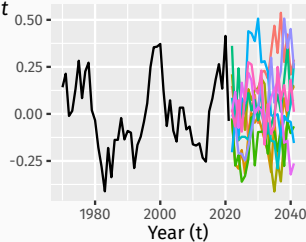
$\phi_4(x)$



$\beta_{3,t}$



$\beta_{4,t}$



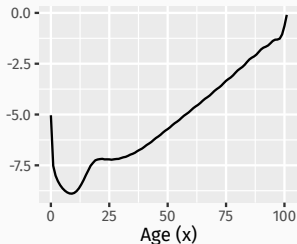
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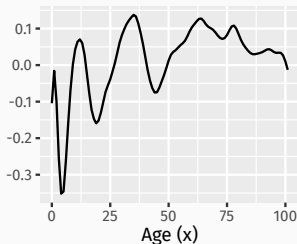
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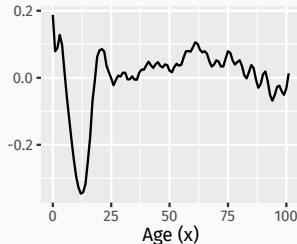
$\mu(x)$



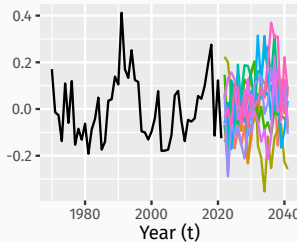
$\phi_5(x)$



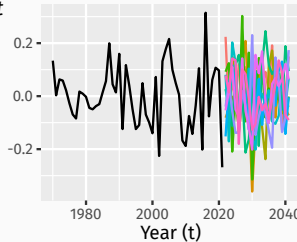
$\phi_6(x)$



$\beta_{5,t}$



$\beta_{6,t}$

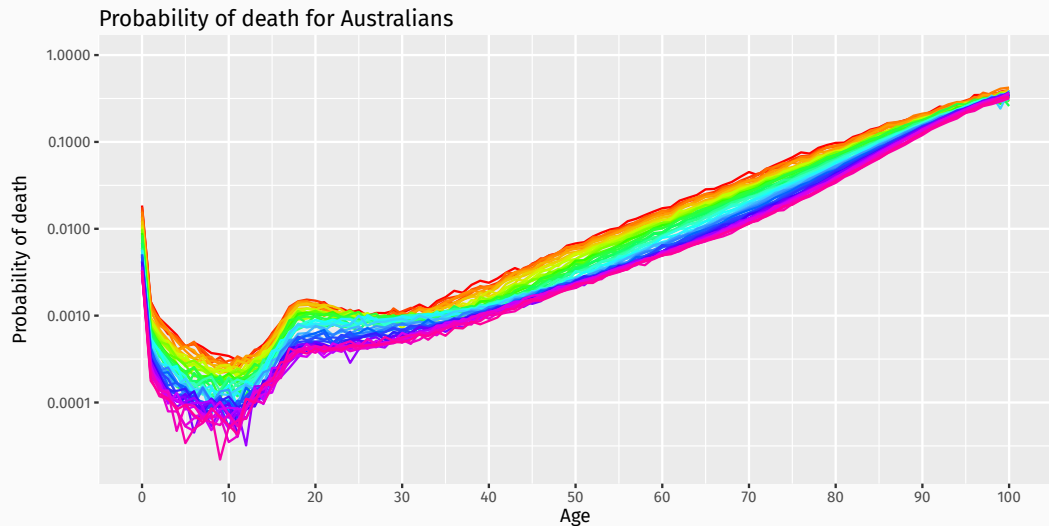


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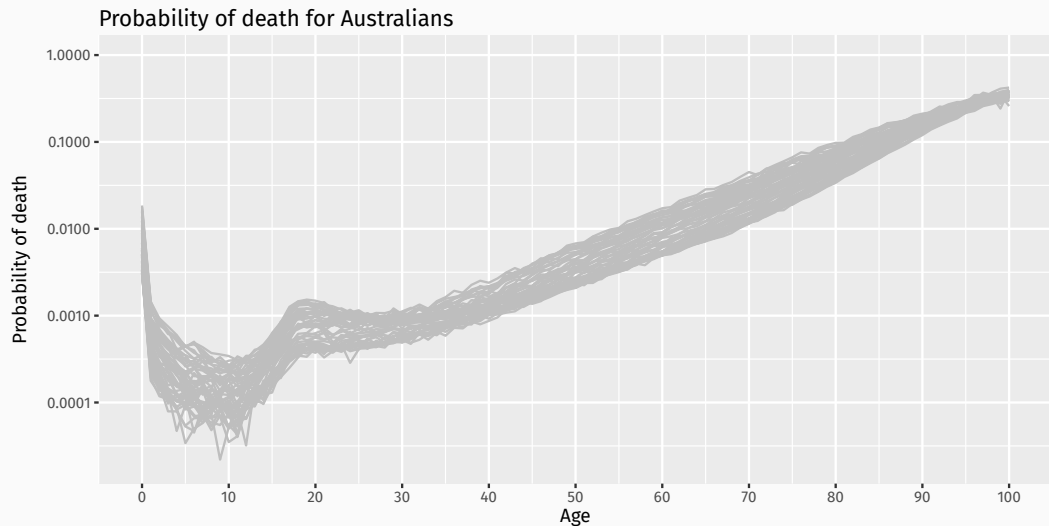
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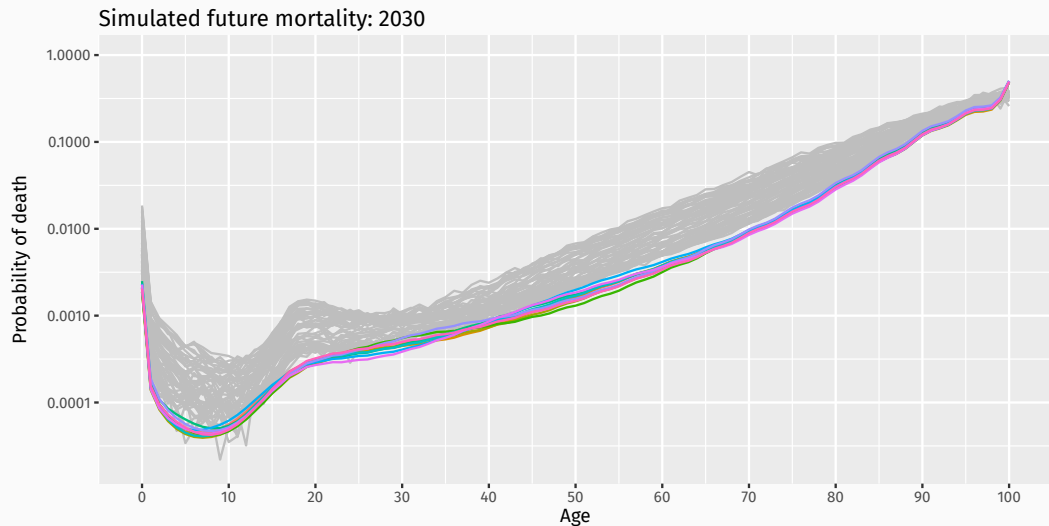
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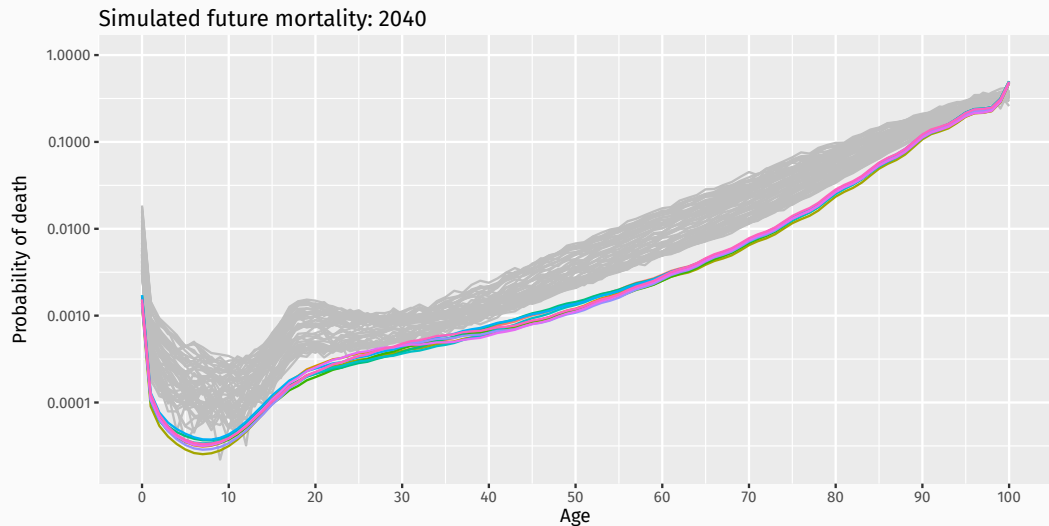
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# Forecasting models: $q_{x,t}$

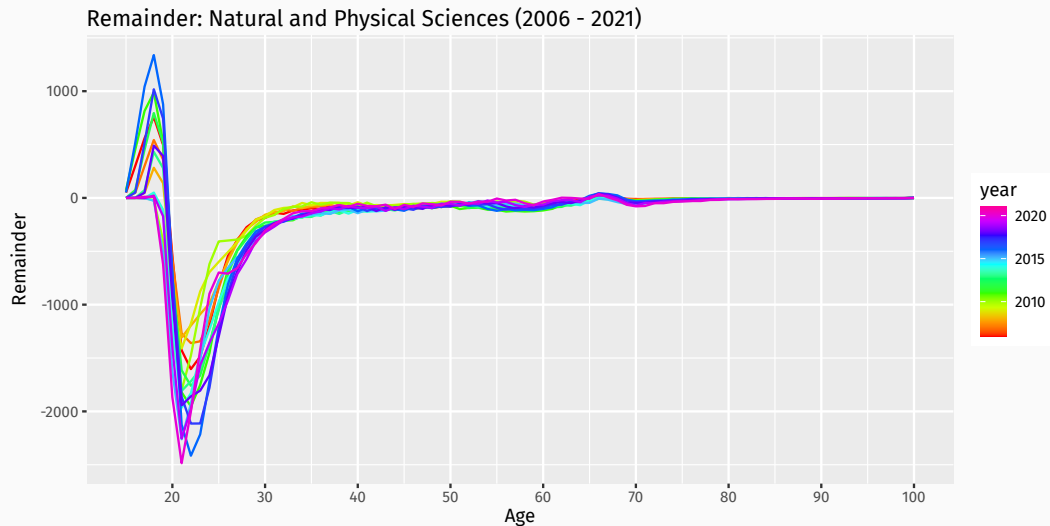
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# Remainder: $E_{x,t}$

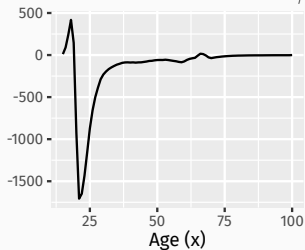
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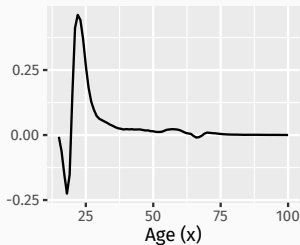
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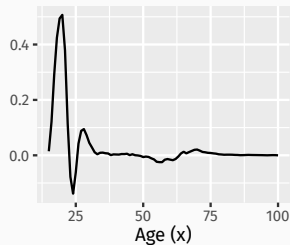
$\mu(x)$



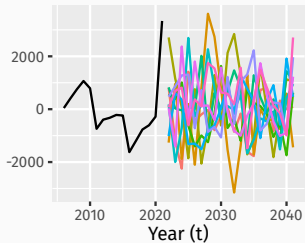
$\phi_1(x)$



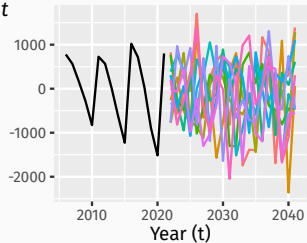
$\phi_2(x)$



$\beta_{1,t}$



$\beta_{2,t}$



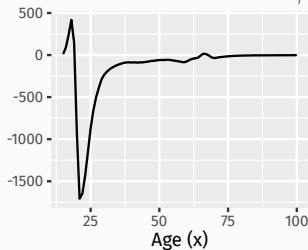
$$E_{x,t} = \mu(x) + \sum_{k=1}^6 \beta_{k,t} \phi_k(x) + \varepsilon_t(x)$$

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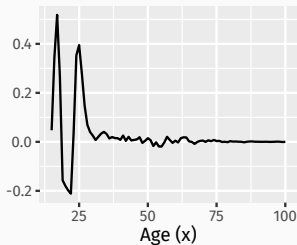
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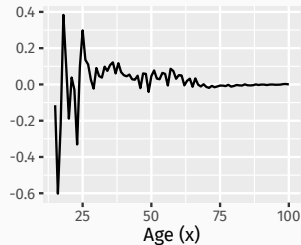
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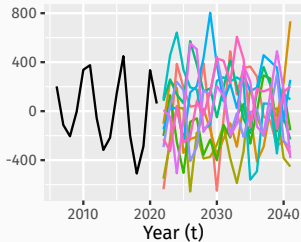
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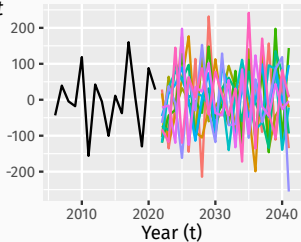
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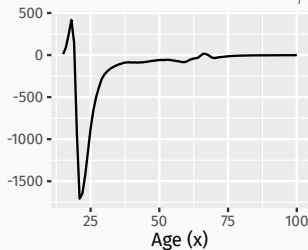
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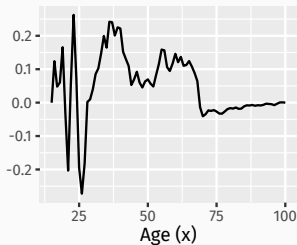
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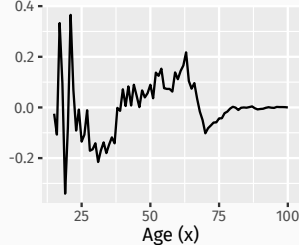
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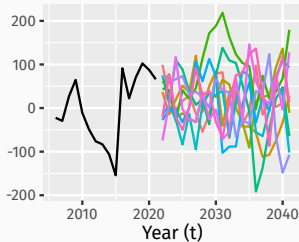
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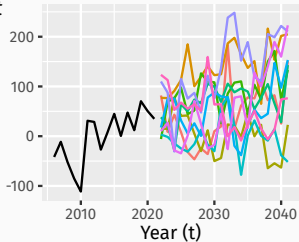
$\phi_6(x)$



$\beta_{5,t}$



$\beta_{6,t}$

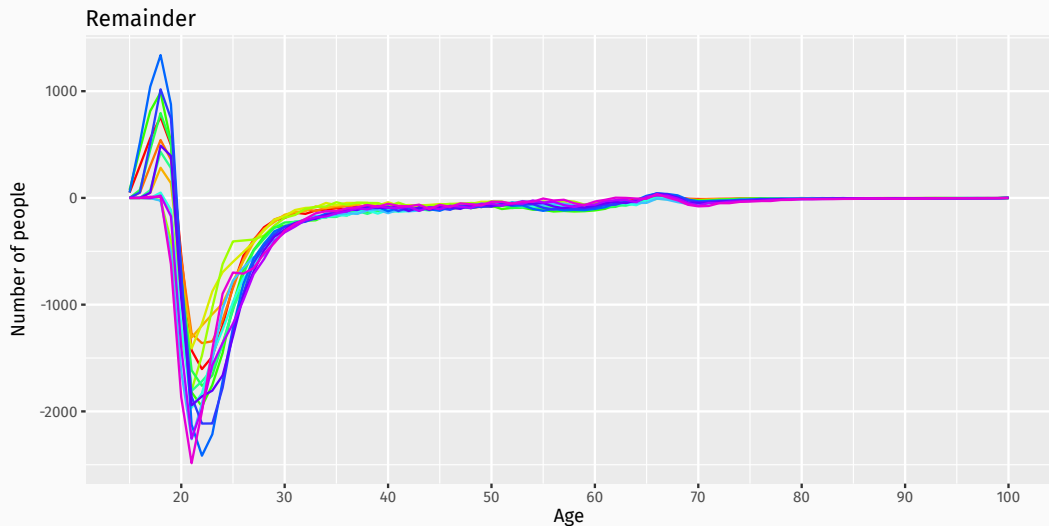


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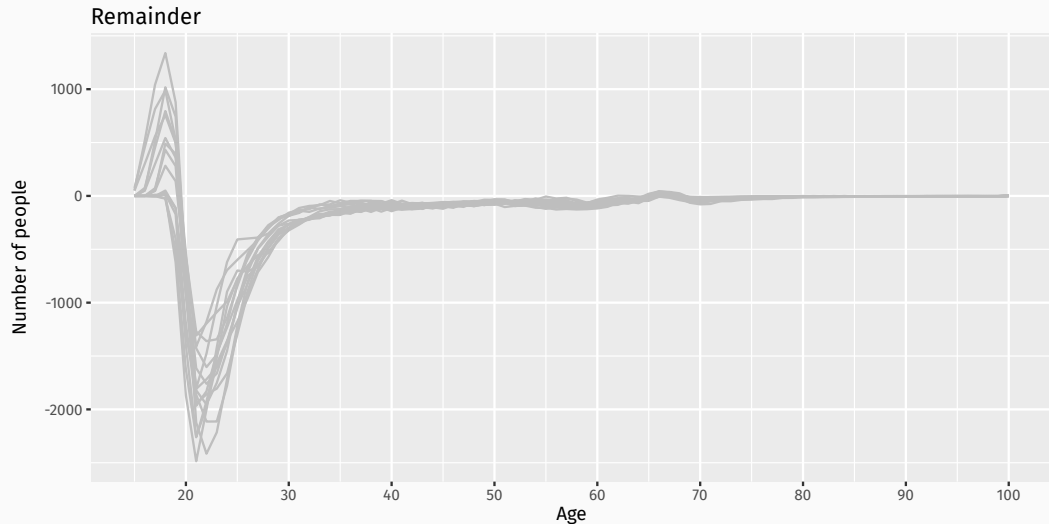
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# Forecasting models: $E_{x,t}$

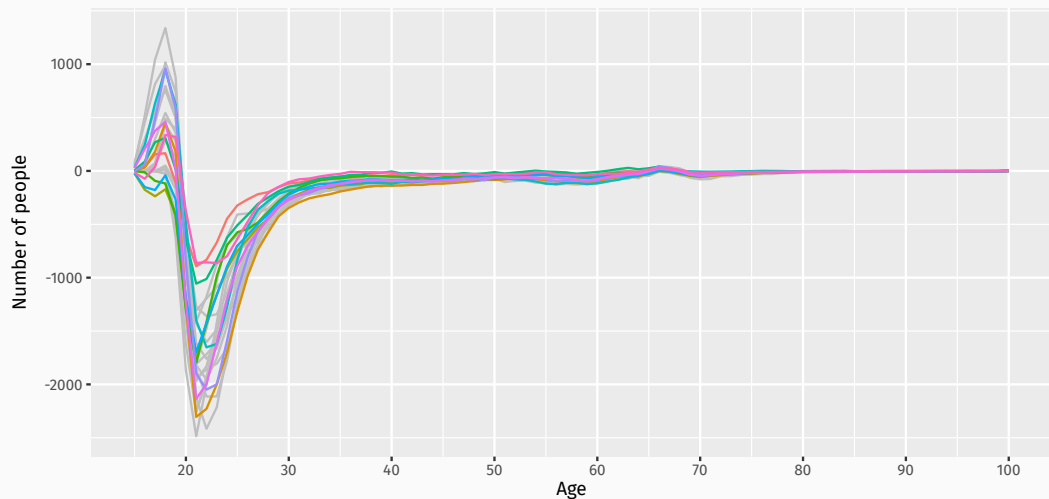
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# Forecasting models: $E_{x,t}$

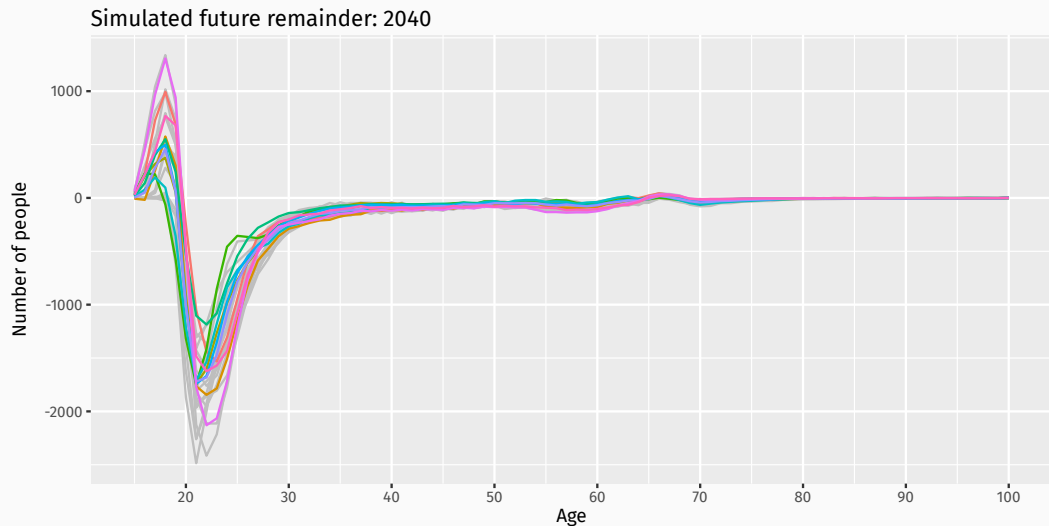
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Simulated future remainder: 2030



# Forecasting models: $E_{x,t}$

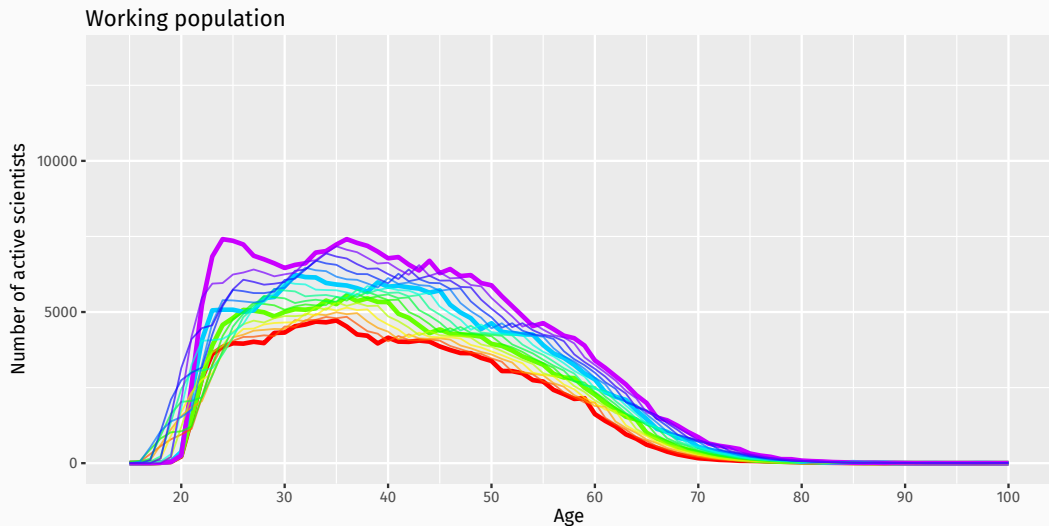
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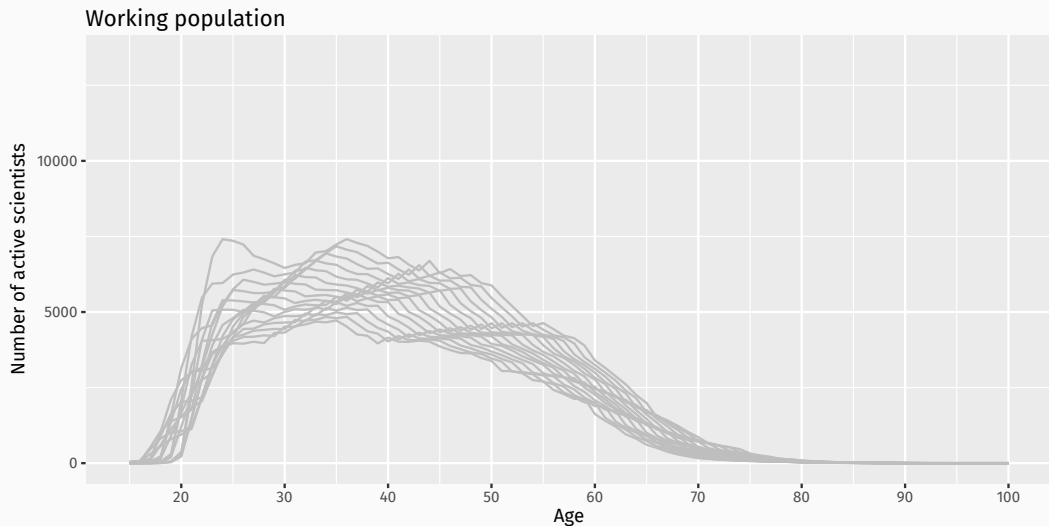
# Final forecasts: $P_{x,t}$

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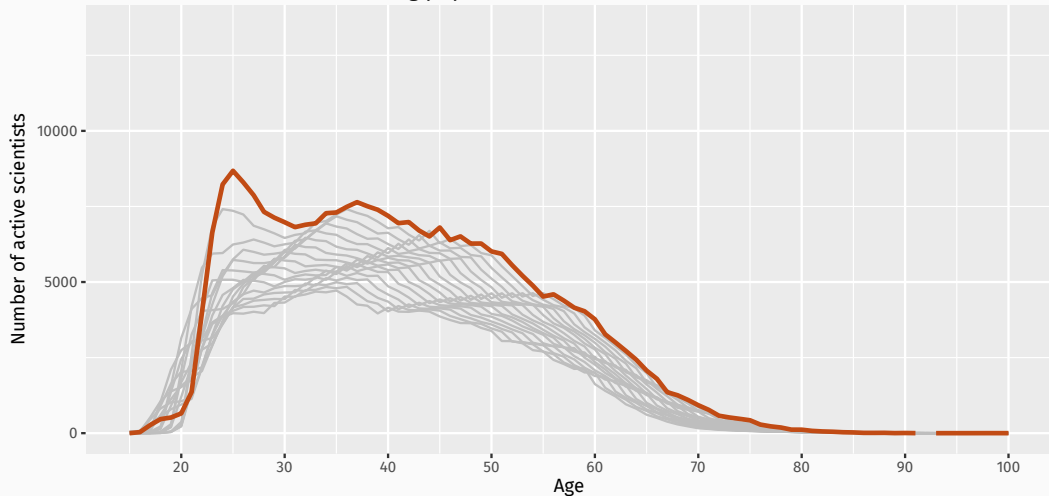
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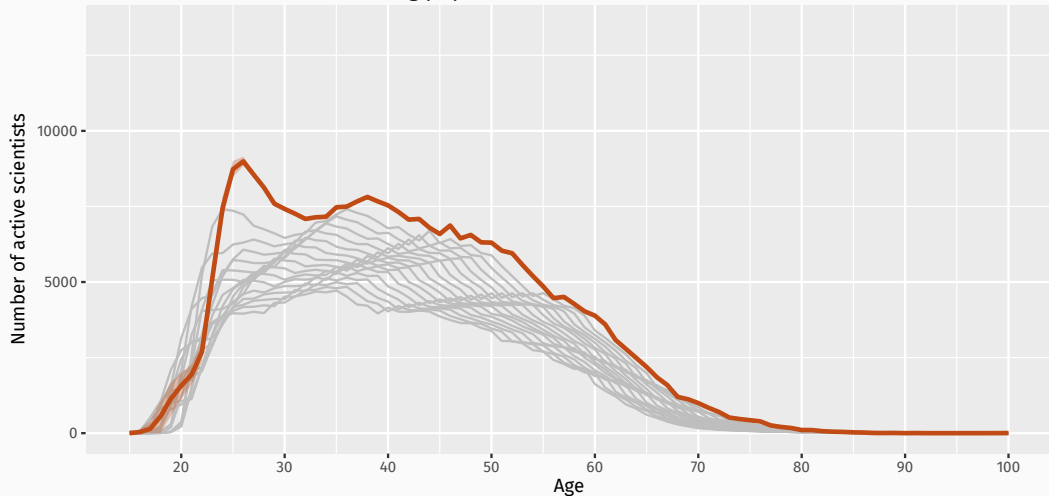
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90% forecast interval for working population: 2022



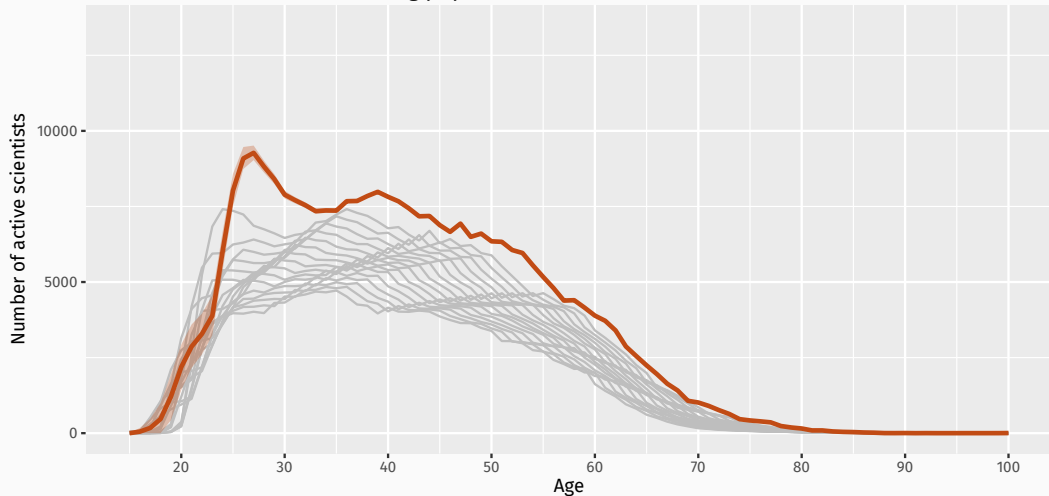
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90% forecast interval for working population: 2023



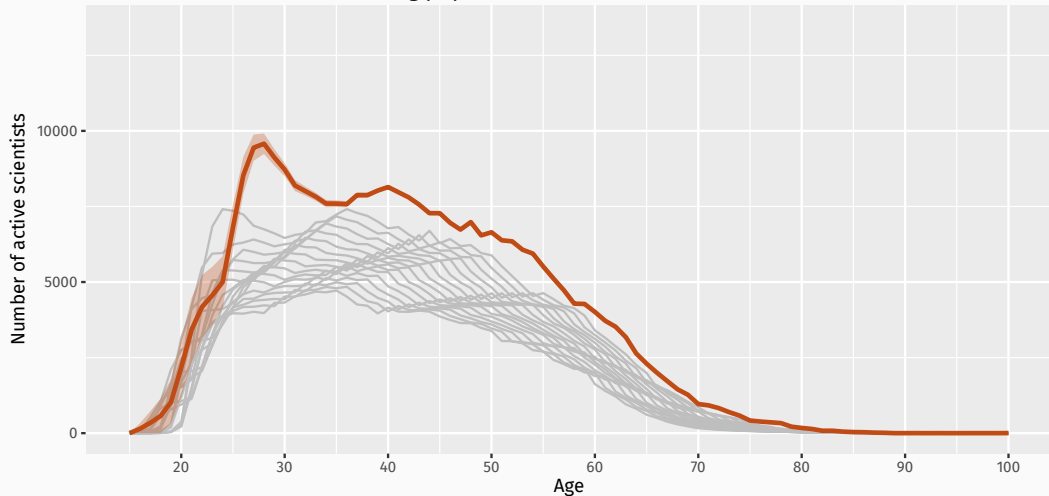
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90% forecast interval for working population: 2024



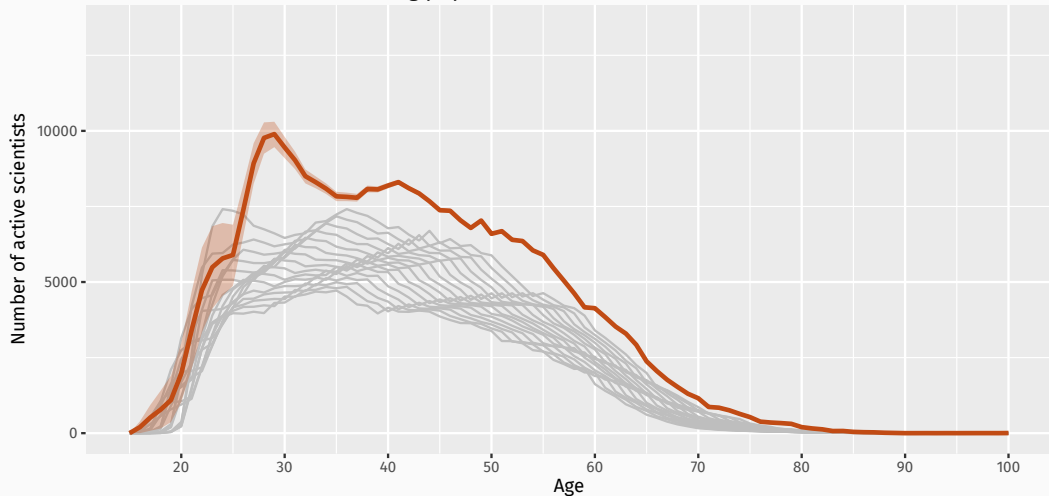
$$P_{x+1,t+1} = P_{x,t}(1 - q_{x,t} - r_x) + g_x G_t + E_{x,t}$$

90% forecast interval for working population: 2025



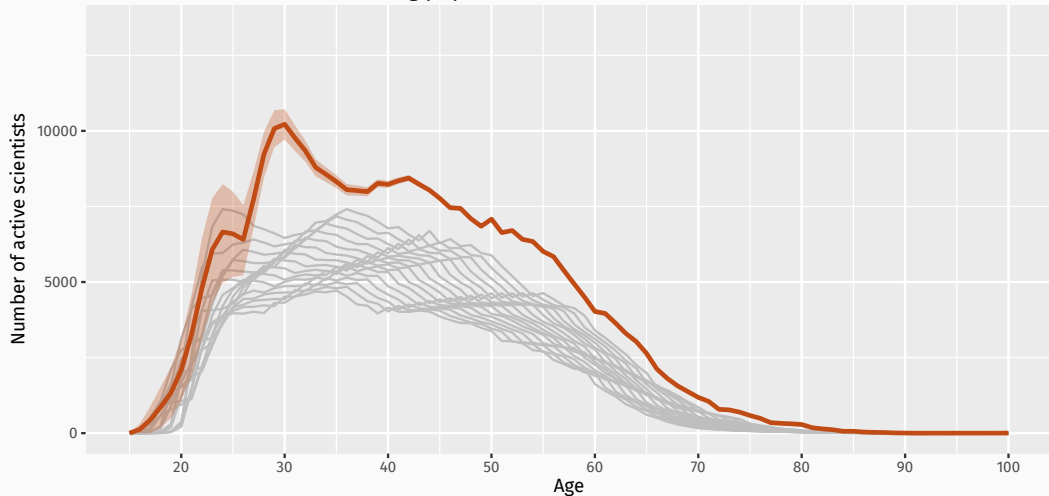
$$P_{x+1,t+1} = P_{x,t}(1 - q_{x,t} - r_x) + g_x G_t + E_{x,t}$$

90% forecast interval for working population: 2026



$$P_{x+1,t+1} = P_{x,t}(1 - q_{x,t} - r_x) + g_x G_t + E_{x,t}$$

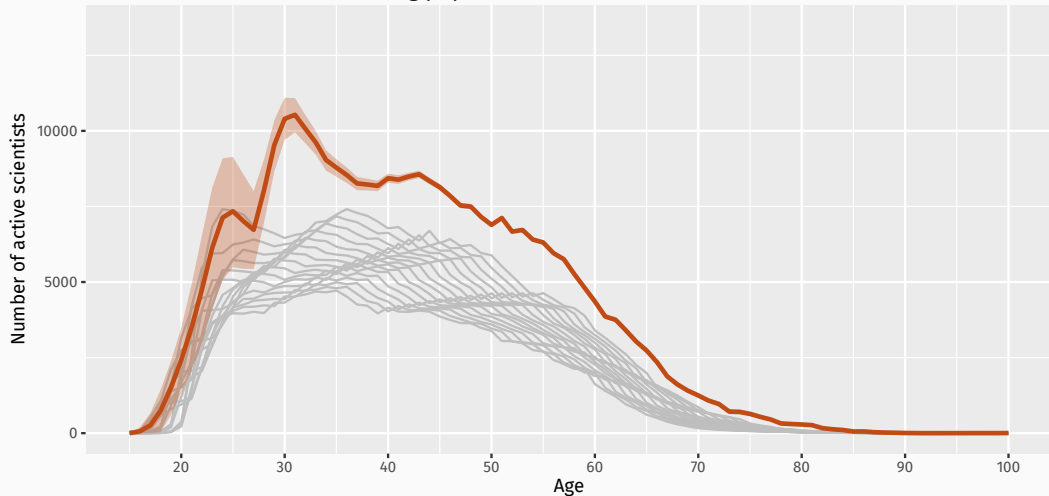
90% forecast interval for working population: 2027





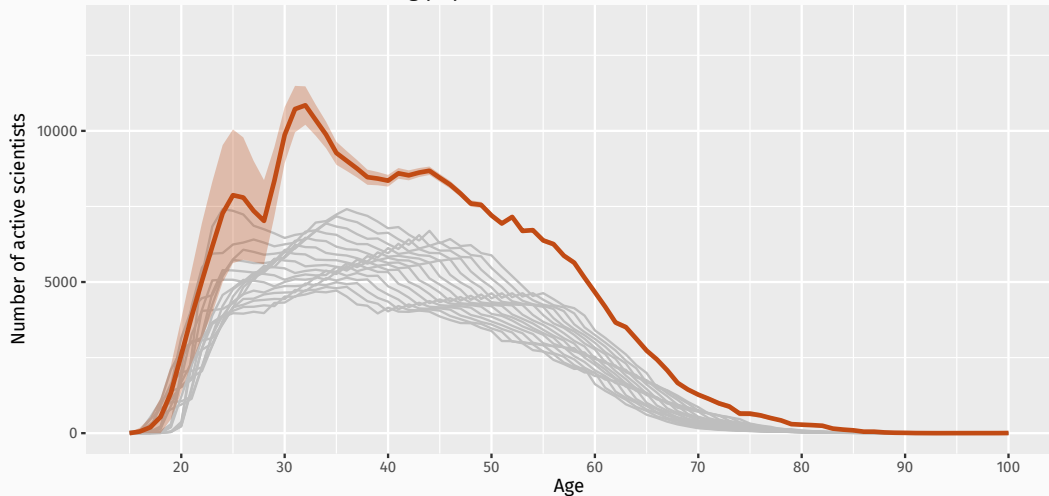
$$P_{x+1,t+1} = P_{x,t}(1 - q_{x,t} - r_x) + g_x G_t + E_{x,t}$$

90% forecast interval for working population: 2028



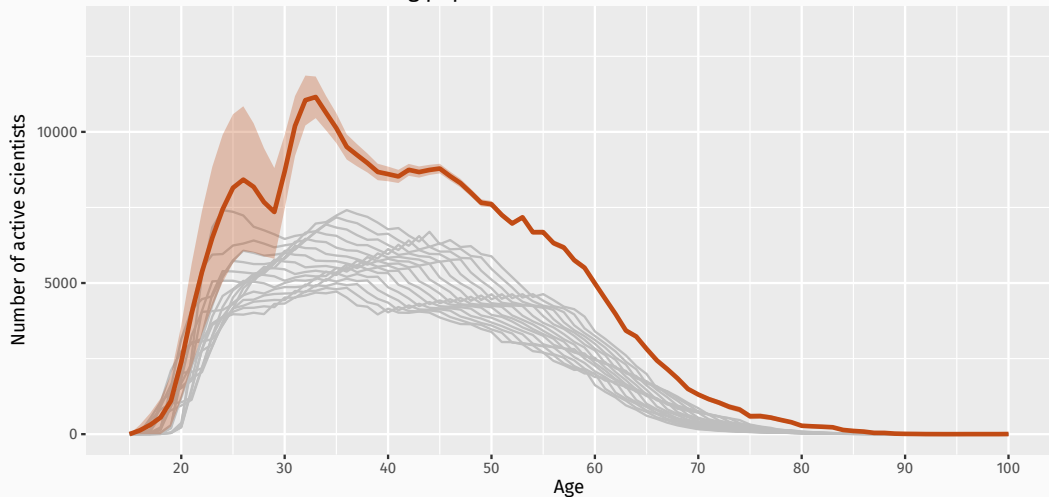
$$P_{x+1,t+1} = P_{x,t}(1 - q_{x,t} - r_x) + g_x G_t + E_{x,t}$$

90% forecast interval for working population: 2029



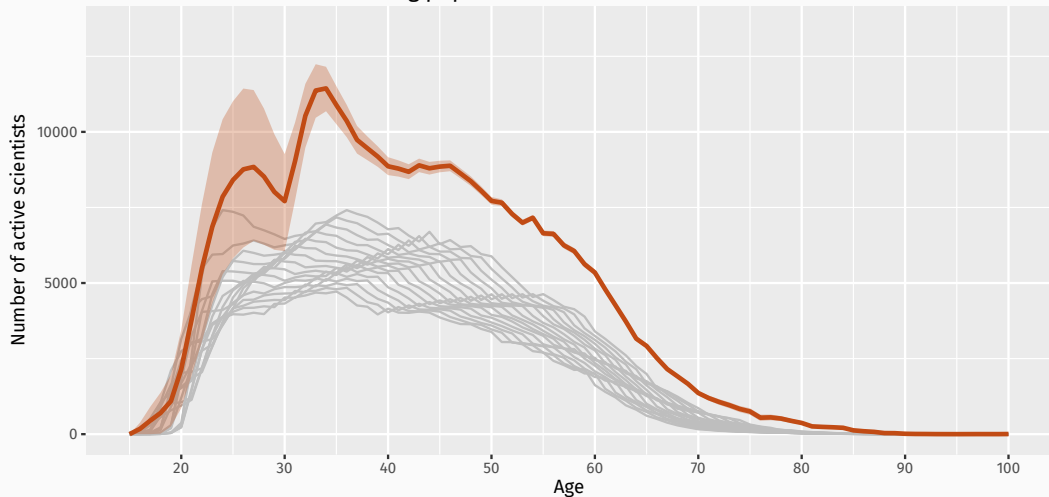
$$P_{x+1,t+1} = P_{x,t}(1 - q_{x,t} - r_x) + g_x G_t + E_{x,t}$$

90% forecast interval for working population: 2030



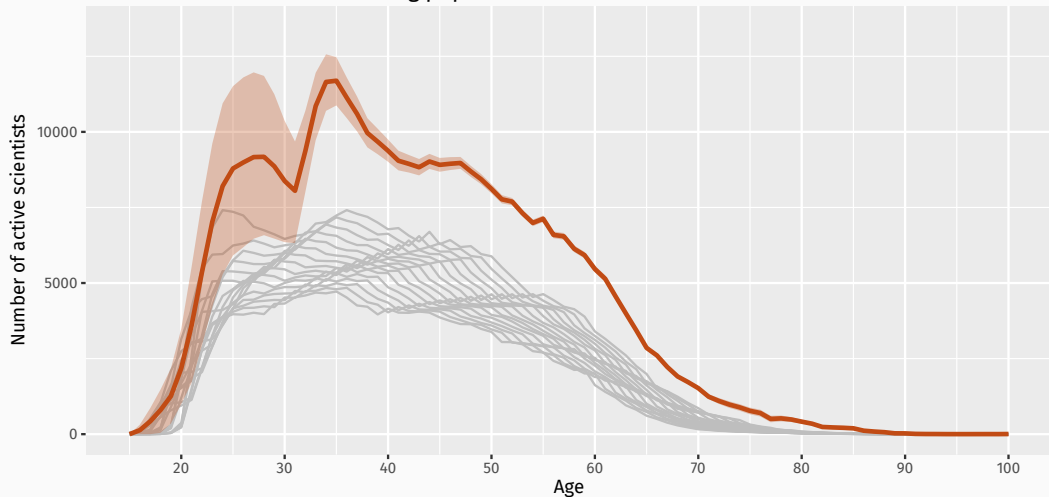
$$P_{x+1,t+1} = P_{x,t}(1 - q_{x,t} - r_x) + g_x G_t + E_{x,t}$$

90% forecast interval for working population: 2031



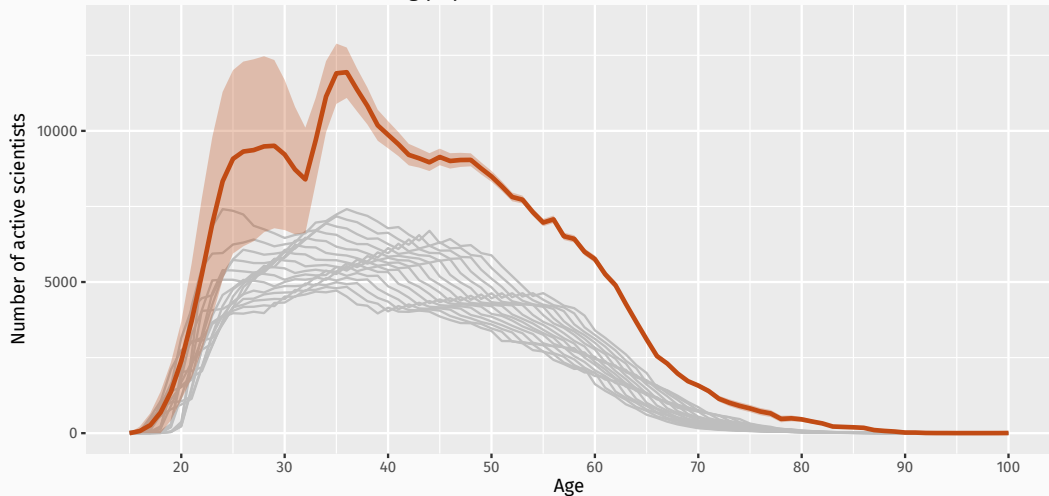
$$P_{x+1,t+1} = P_{x,t}(1 - q_{x,t} - r_x) + g_x G_t + E_{x,t}$$

90% forecast interval for working population: 2032



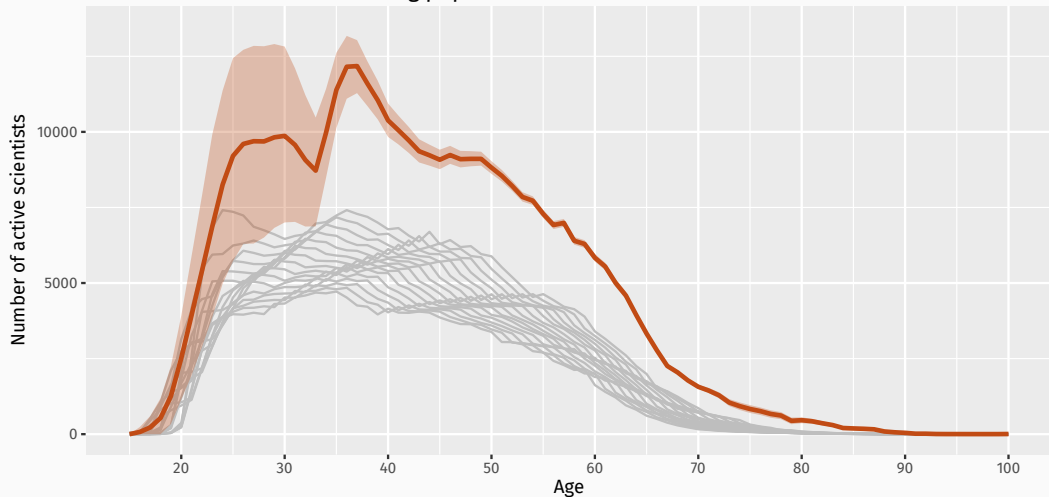
$$P_{x+1,t+1} = P_{x,t}(1 - q_{x,t} - r_x) + g_x G_t + E_{x,t}$$

90% forecast interval for working population: 2033



$$P_{x+1,t+1} = P_{x,t}(1 - q_{x,t} - r_x) + g_x G_t + E_{x,t}$$

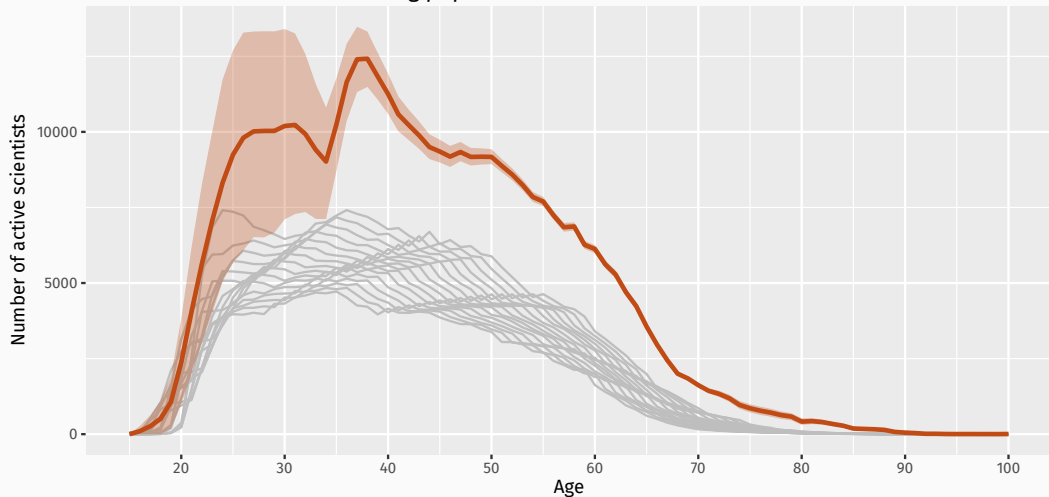
90% forecast interval for working population: 2034



# Forecasts: $P_{x,t}$

$$P_{x+1,t+1} = P_{x,t}(1 - q_{x,t} - r_x) + g_x G_t + E_{x,t}$$

90% forecast interval for working population: 2035

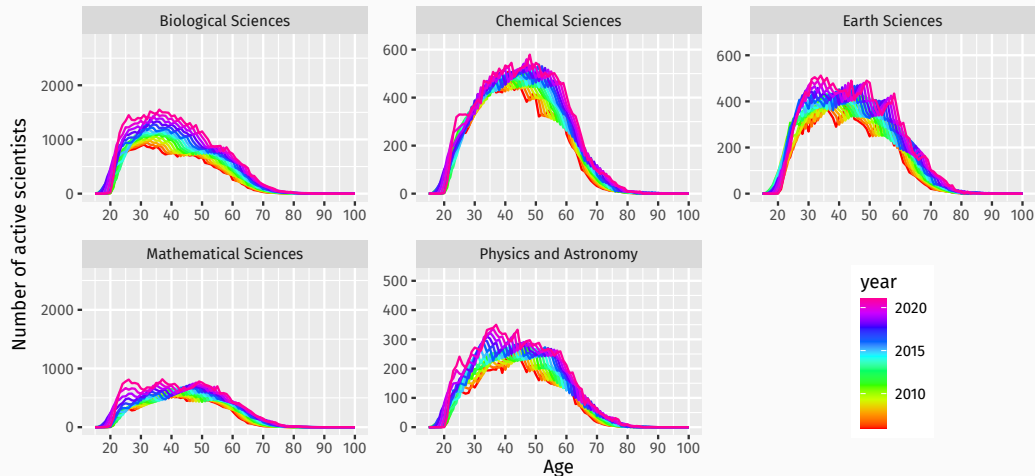




# Population by discipline

$$P_{x+1,t+1,i} = P_{x,t,i}(1 - q_{x,t} - r_x) + g_x G_{t,i} + E_{x,t,i}$$

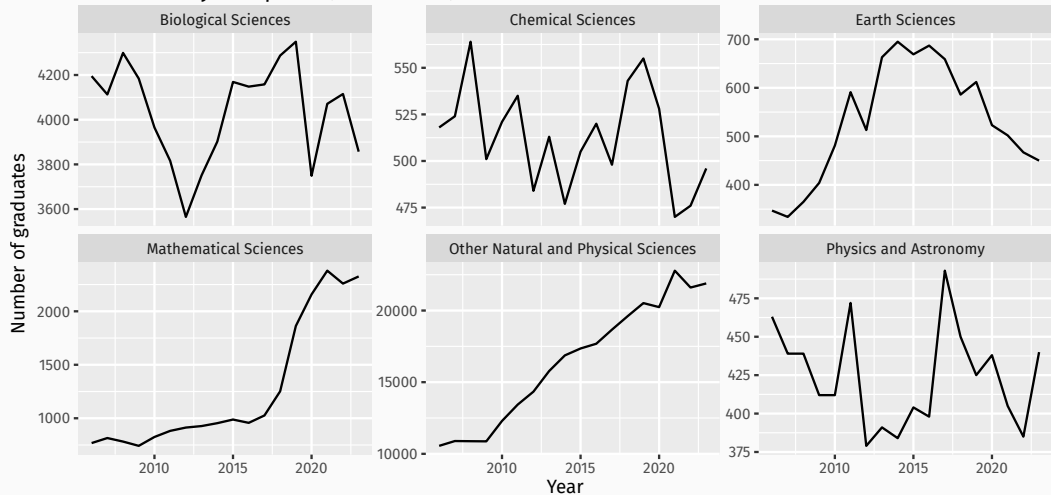
## Working population by discipline



# Graduates by discipline

$$P_{x+1,t+1,i} = P_{x,t,i}(1 - q_{x,t} - r_x) + g_x G_{t,i} + E_{x,t,i}$$

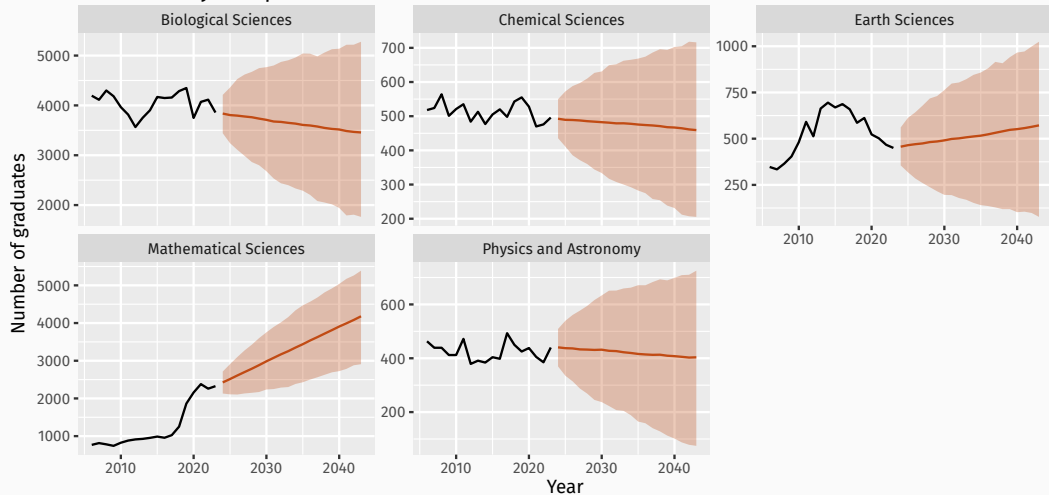
Graduates by discipline: (2006 - 2023)



# Graduate forecasts

$$P_{x+1,t+1,i} = P_{x,t,i}(1 - q_{x,t} - r_x) + g_x G_{t,i} + E_{x,t,i}$$

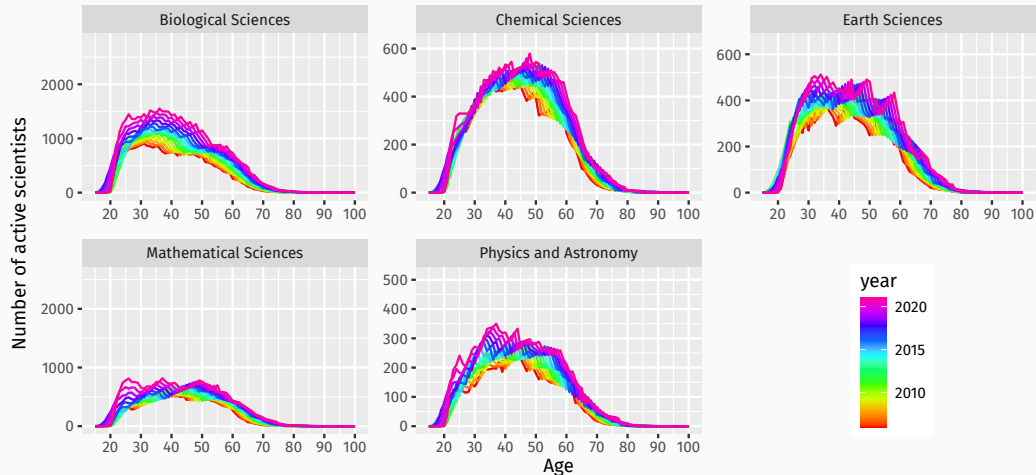
## Graduates by discipline



# Population by discipline

$$P_{x+1,t+1,i} = P_{x,t,i}(1 - q_{x,t} - r_x) + g_x G_{t,i} + E_{x,t,i}$$

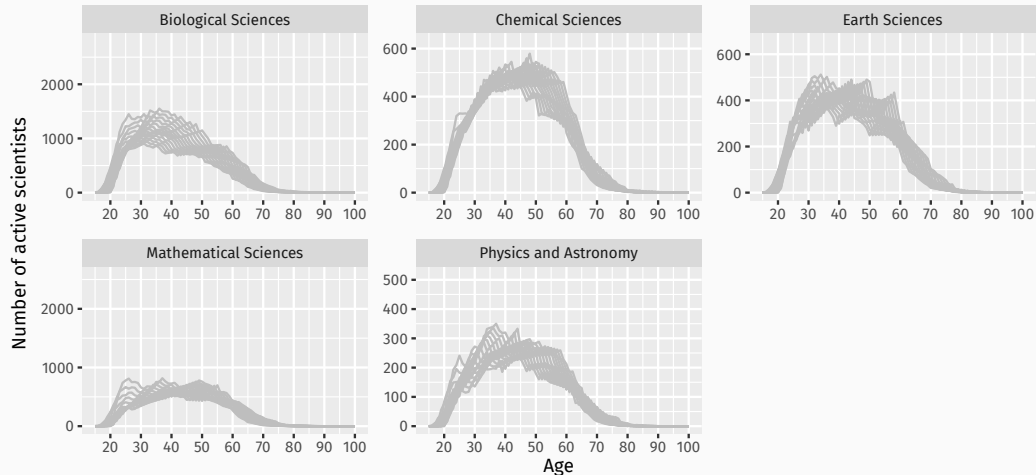
## Working population by discipline



# Population by discipline

$$P_{x+1,t+1,i} = P_{x,t,i}(1 - q_{x,t} - r_x) + g_x G_{t,i} + E_{x,t,i}$$

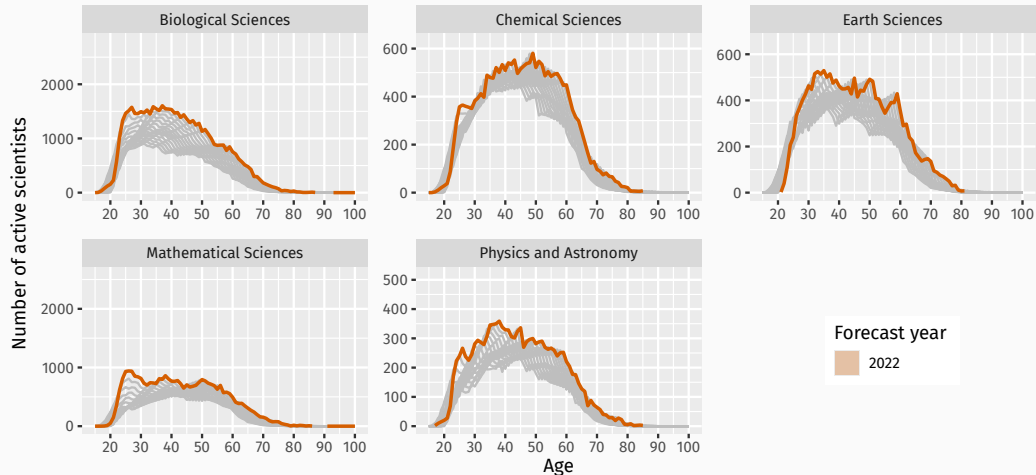
Working population by discipline



# Forecasts by discipline

$$P_{x+1,t+1,i} = P_{x,t,i}(1 - q_{x,t} - r_x) + g_x G_{t,i} + E_{x,t,i}$$

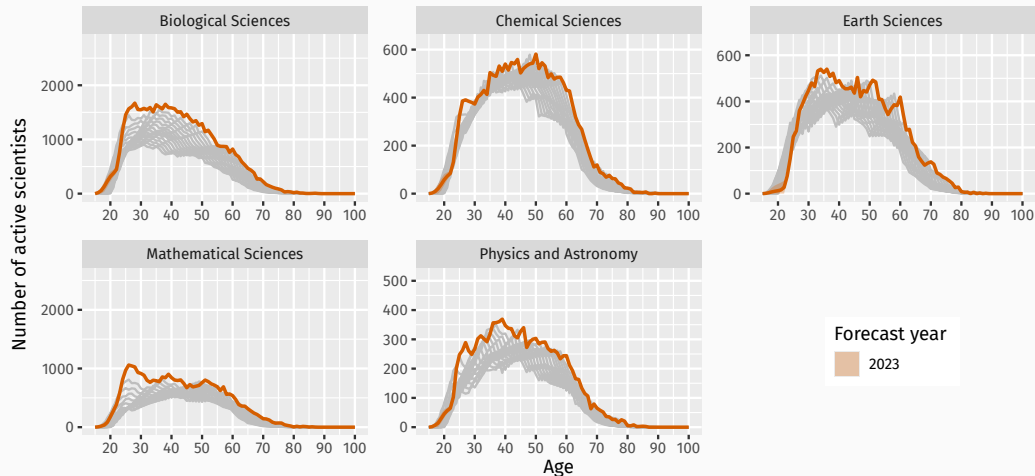
90% forecast interval for working population by discipline



# Forecasts by discipline

$$P_{x+1,t+1,i} = P_{x,t,i}(1 - q_{x,t} - r_x) + g_x G_{t,i} + E_{x,t,i}$$

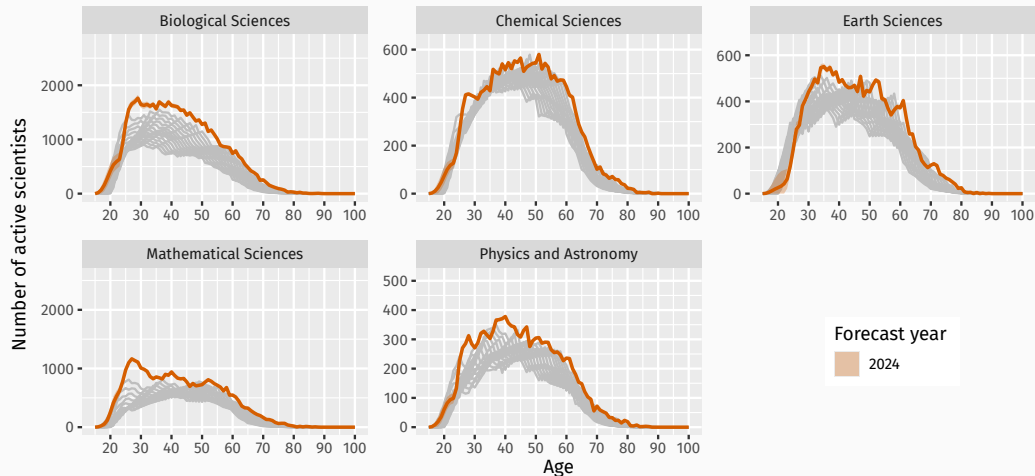
90% forecast interval for working population by discipline



# Forecasts by discipline

$$P_{x+1,t+1,i} = P_{x,t,i}(1 - q_{x,t} - r_x) + g_x G_{t,i} + E_{x,t,i}$$

90% forecast interval for working population by discipline

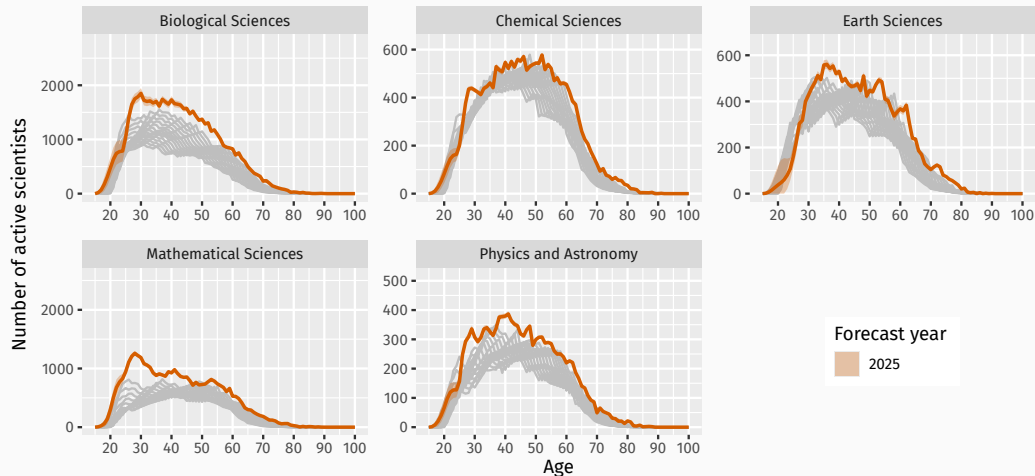




# Forecasts by discipline

$$P_{x+1,t+1,i} = P_{x,t,i}(1 - q_{x,t} - r_x) + g_x G_{t,i} + E_{x,t,i}$$

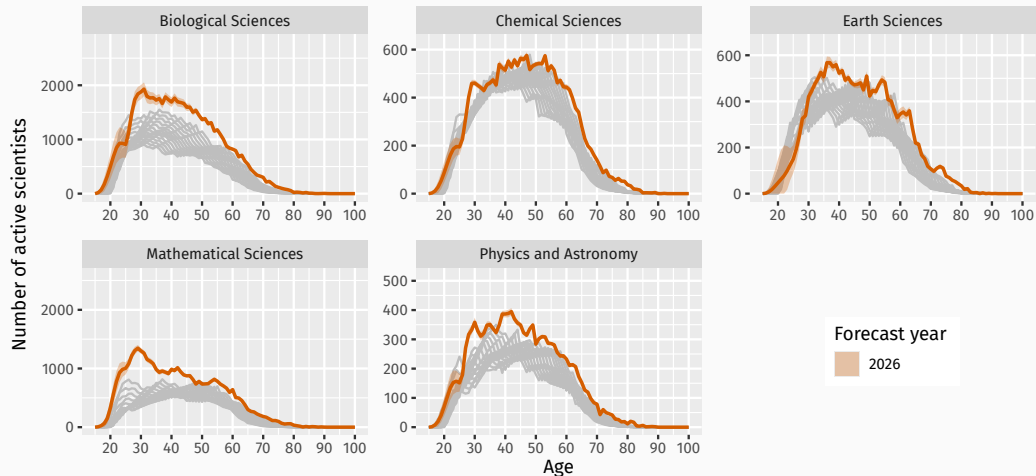
90% forecast interval for working population by discipline



# Forecasts by discipline

$$P_{x+1,t+1,i} = P_{x,t,i}(1 - q_{x,t} - r_x) + g_x G_{t,i} + E_{x,t,i}$$

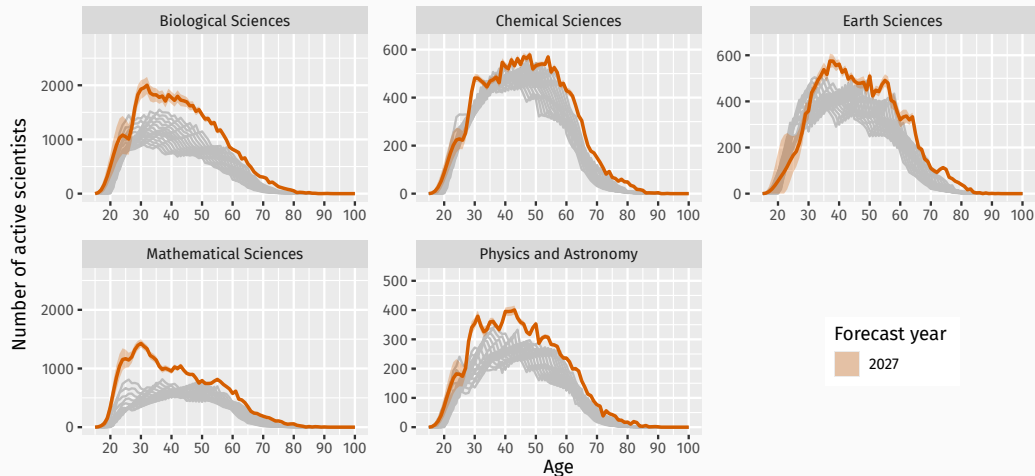
90% forecast interval for working population by discipline



# Forecasts by discipline

$$P_{x+1,t+1,i} = P_{x,t,i}(1 - q_{x,t} - r_x) + g_x G_{t,i} + E_{x,t,i}$$

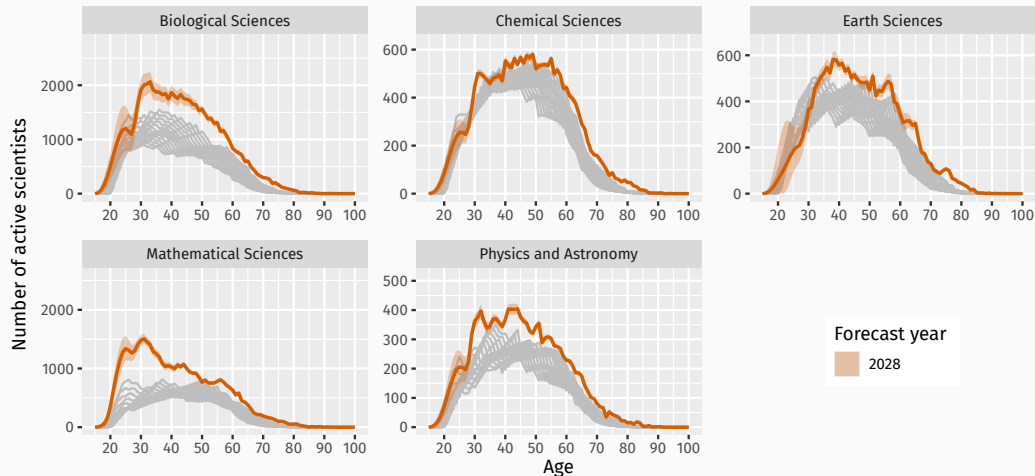
90% forecast interval for working population by discipline



# Forecasts by discipline

$$P_{x+1,t+1,i} = P_{x,t,i}(1 - q_{x,t} - r_x) + g_x G_{t,i} + E_{x,t,i}$$

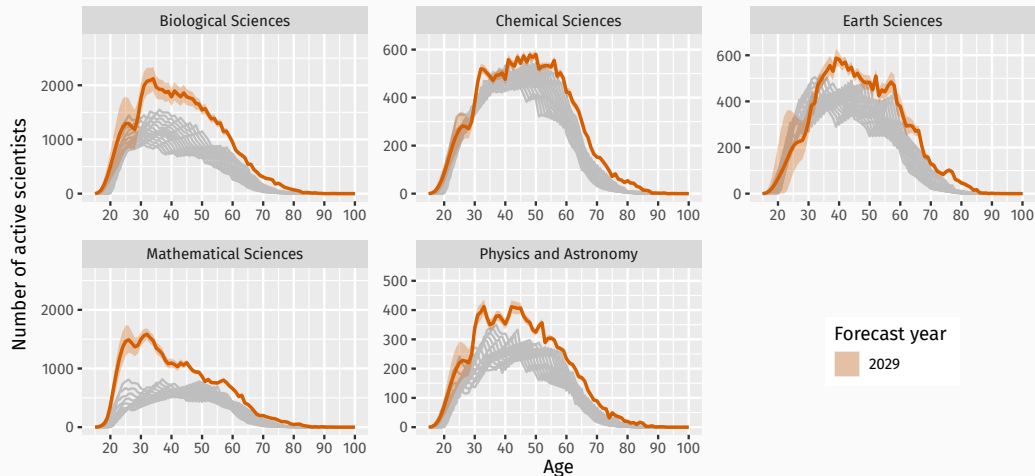
90% forecast interval for working population by discipline



# Forecasts by discipline

$$P_{x+1,t+1,i} = P_{x,t,i}(1 - q_{x,t} - r_x) + g_x G_{t,i} + E_{x,t,i}$$

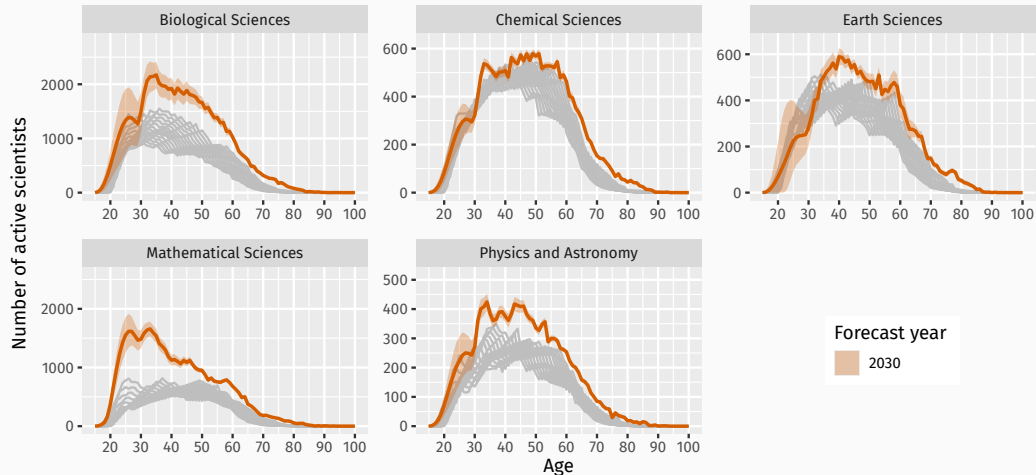
90% forecast interval for working population by discipline



# Forecasts by discipline

$$P_{x+1,t+1,i} = P_{x,t,i}(1 - q_{x,t} - r_x) + g_x G_{t,i} + E_{x,t,i}$$

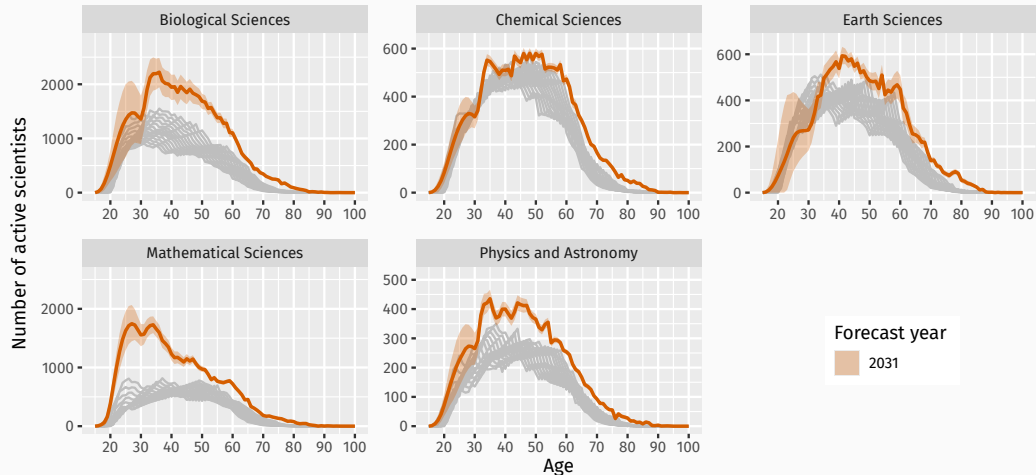
90% forecast interval for working population by discipline



# Forecasts by discipline

$$P_{x+1,t+1,i} = P_{x,t,i}(1 - q_{x,t} - r_x) + g_x G_{t,i} + E_{x,t,i}$$

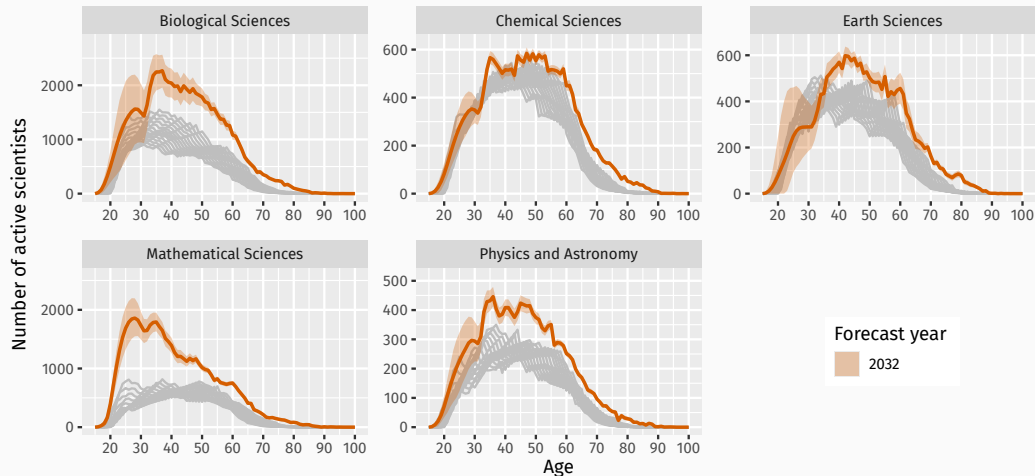
90% forecast interval for working population by discipline



# Forecasts by discipline

$$P_{x+1,t+1,i} = P_{x,t,i}(1 - q_{x,t} - r_x) + g_x G_{t,i} + E_{x,t,i}$$

90% forecast interval for working population by discipline

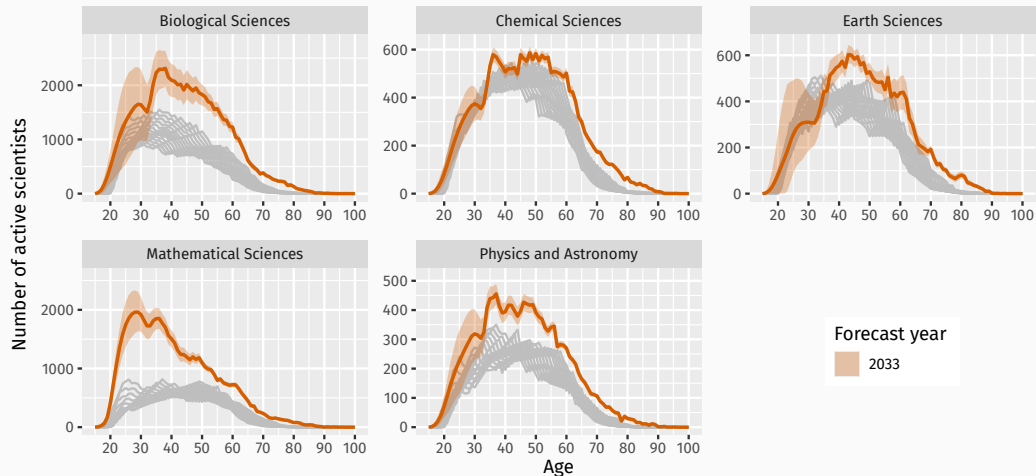




# Forecasts by discipline

$$P_{x+1,t+1,i} = P_{x,t,i}(1 - q_{x,t} - r_x) + g_x G_{t,i} + E_{x,t,i}$$

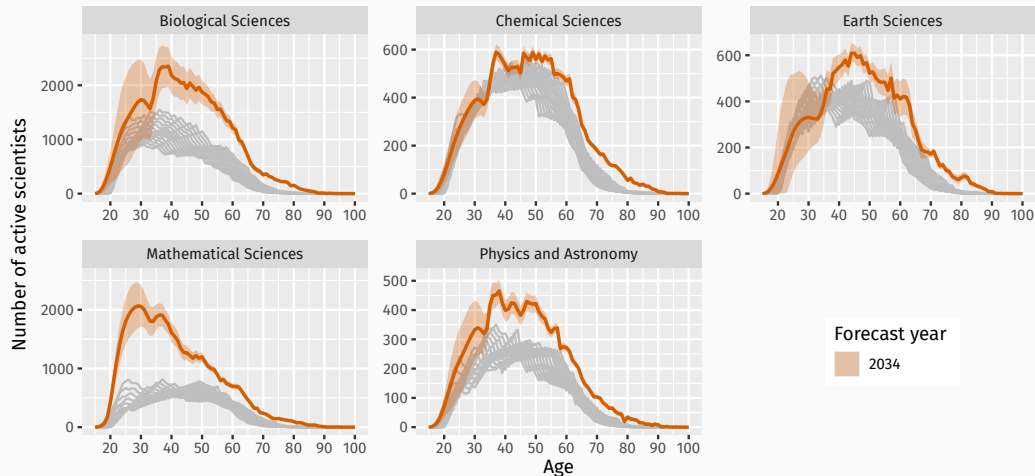
90% forecast interval for working population by discipline



# Forecasts by discipline

$$P_{x+1,t+1,i} = P_{x,t,i}(1 - q_{x,t} - r_x) + g_x G_{t,i} + E_{x,t,i}$$

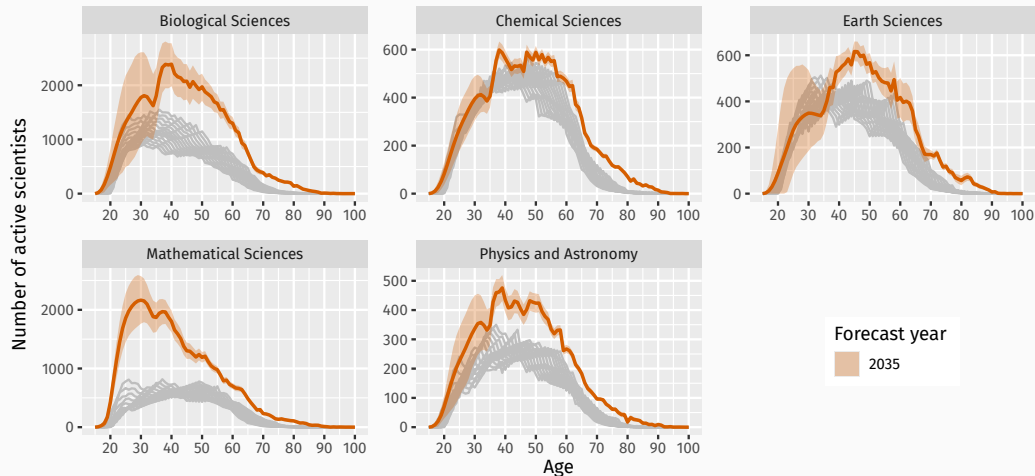
90% forecast interval for working population by discipline



# Forecasts by discipline

$$P_{x+1,t+1,i} = P_{x,t,i}(1 - q_{x,t} - r_x) + g_x G_{t,i} + E_{x,t,i}$$

90% forecast interval for working population by discipline



## More information

**[robjhyndman.com/isf2025](http://robjhyndman.com/isf2025)**

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