

World Population Projections in R

Hana Ševčíková

Center for Statistics and the Social Sciences
University of Washington
hanas@uw.edu

Joint work with Adrian Raftery & his team
and the United Nations Population Division

Project website: bayespop.csss.washington.edu

Cascadia R Conference, Portland, OR, June 3rd
Research supported by NICHD

Motivation

- ▶ Every two years the United Nations (UN) publish updated population estimates and projections for all countries of the world

Motivation

- ▶ Every two years the United Nations (UN) publish updated population estimates and projections for all countries of the world
→ *World Population Prospects* (WPP), latest revision WPP 2015

Motivation

- ▶ Every two years the United Nations (UN) publish updated population estimates and projections for all countries of the world
→ *World Population Prospects* (WPP), latest revision WPP 2015 (WPP 2017 to be released soon)

Motivation

- ▶ Every two years the United Nations (UN) publish updated population estimates and projections for all countries of the world
→ *World Population Prospects* (WPP), latest revision WPP 2015 (WPP 2017 to be released soon)
- ▶ Used among others by WHO, UNAIDS, IPCC, national governments, researchers, private sector.

Motivation

- ▶ Every two years the United Nations (UN) publish updated population estimates and projections for all countries of the world
→ *World Population Prospects* (WPP), latest revision WPP 2015 (WPP 2017 to be released soon)
- ▶ Used among others by WHO, UNAIDS, IPCC, national governments, researchers, private sector.
- ▶ As a measure of uncertainty until recently the UN Population Division (UNPD) produced High, Medium and Low variants of the projections.

Motivation

- ▶ Every two years the United Nations (UN) publish updated population estimates and projections for all countries of the world
→ *World Population Prospects* (WPP), latest revision WPP 2015 (WPP 2017 to be released soon)
- ▶ Used among others by WHO, UNAIDS, IPCC, national governments, researchers, private sector.
- ▶ As a measure of uncertainty until recently the UN Population Division (UNPD) produced High, Medium and Low variants of the projections.
- ▶ These are scenarios and lack probabilistic interpretation.

Motivation

- ▶ Every two years the United Nations (UN) publish updated population estimates and projections for all countries of the world
→ *World Population Prospects* (WPP), latest revision WPP 2015 (WPP 2017 to be released soon)
- ▶ Used among others by WHO, UNAIDS, IPCC, national governments, researchers, private sector.
- ▶ As a measure of uncertainty until recently the UN Population Division (UNPD) produced High, Medium and Low variants of the projections.
- ▶ These are scenarios and lack probabilistic interpretation.
- ▶ In our collaboration with the UNPD, methods for *probabilistic population projections* were developed, including uncertainty about fertility and life expectancy for all countries.

Motivation

- ▶ Every two years the United Nations (UN) publish updated population estimates and projections for all countries of the world
→ *World Population Prospects* (WPP), latest revision WPP 2015 (WPP 2017 to be released soon)
- ▶ Used among others by WHO, UNAIDS, IPCC, national governments, researchers, private sector.
- ▶ As a measure of uncertainty until recently the UN Population Division (UNPD) produced High, Medium and Low variants of the projections.
- ▶ These are scenarios and lack probabilistic interpretation.
- ▶ In our collaboration with the UNPD, methods for *probabilistic population projections* were developed, including uncertainty about fertility and life expectancy for all countries.
- ▶ The UN used the new methods to produce WPP 2015 (& 2017)

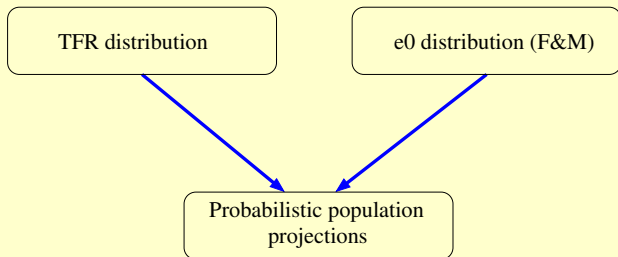
Motivation

- ▶ Every two years the United Nations (UN) publish updated population estimates and projections for all countries of the world
→ *World Population Prospects* (WPP), latest revision WPP 2015 (WPP 2017 to be released soon)
- ▶ Used among others by WHO, UNAIDS, IPCC, national governments, researchers, private sector.
- ▶ As a measure of uncertainty until recently the UN Population Division (UNPD) produced High, Medium and Low variants of the projections.
- ▶ These are scenarios and lack probabilistic interpretation.
- ▶ In our collaboration with the UNPD, methods for *probabilistic population projections* were developed, including uncertainty about fertility and life expectancy for all countries.
- ▶ The UN used the new methods to produce WPP 2015 (& 2017)
- ▶ The new methods were implemented as *R packages*.

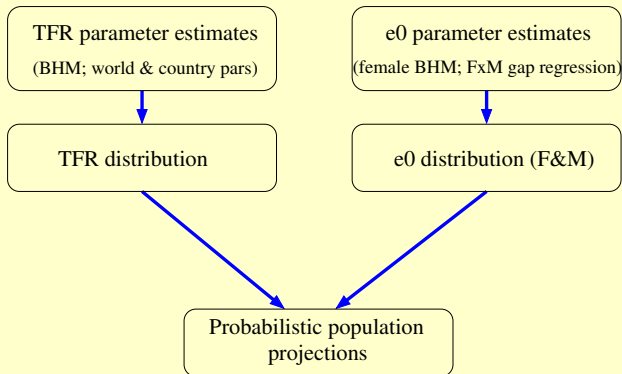
Motivation

- ▶ Every two years the United Nations (UN) publish updated population estimates and projections for all countries of the world
→ *World Population Prospects* (WPP), latest revision WPP 2015 (WPP 2017 to be released soon)
- ▶ Used among others by WHO, UNAIDS, IPCC, national governments, researchers, private sector.
- ▶ As a measure of uncertainty until recently the UN Population Division (UNPD) produced High, Medium and Low variants of the projections.
- ▶ These are scenarios and lack probabilistic interpretation.
- ▶ In our collaboration with the UNPD, methods for *probabilistic population projections* were developed, including uncertainty about fertility and life expectancy for all countries.
- ▶ The UN used the new methods to produce WPP 2015 (& 2017)
- ▶ The new methods were implemented as *R packages*.
- ▶ Provides *transparency* to the UNPD products and allows *reproducibility*.

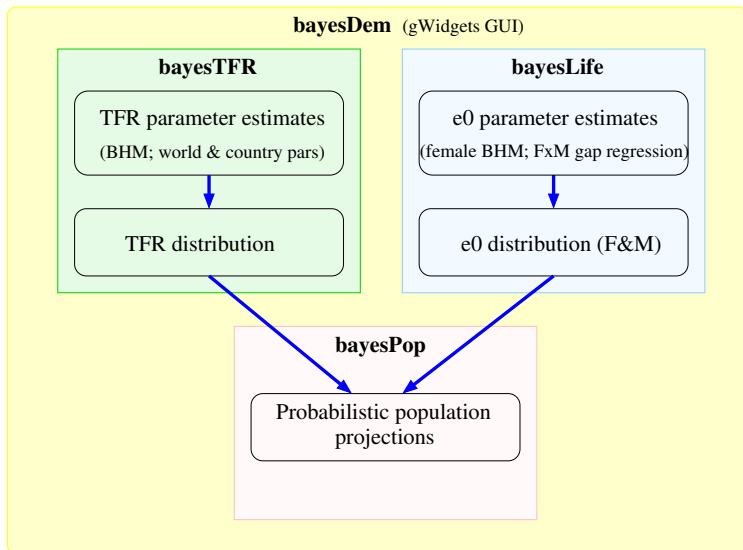
Software Overview



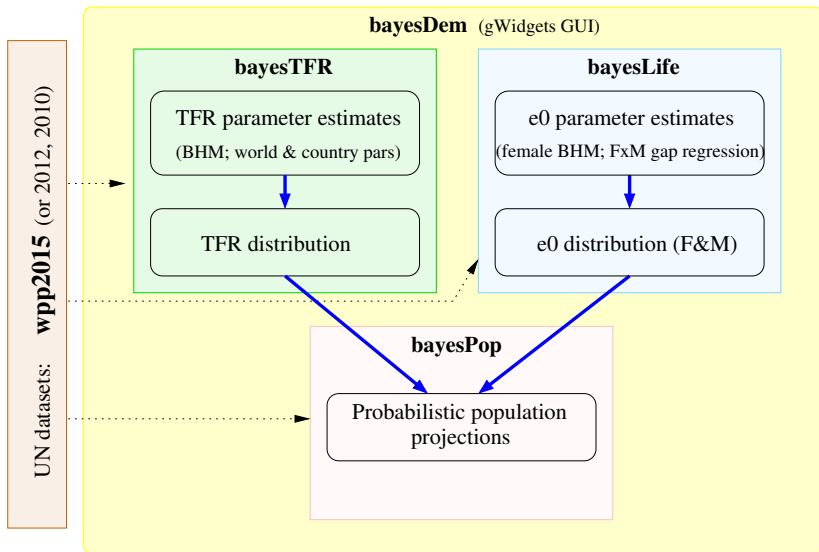
Software Overview



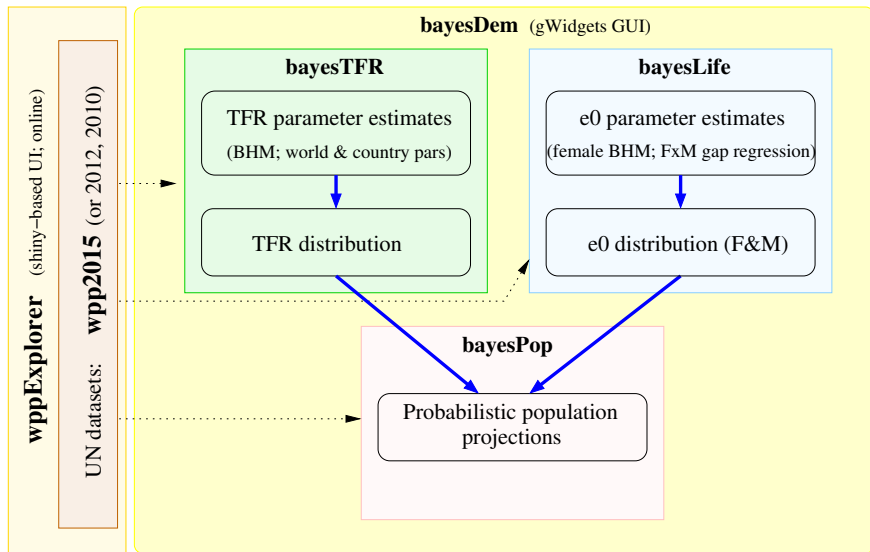
Software Overview



Software Overview



Software Overview



bayesTFR: Modeling Total Fertility Rate (TFR)

bayesTFR: Modeling Total Fertility Rate (TFR)

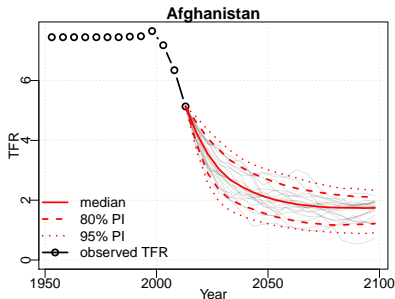
- ▶ Using Bayesian Hierarchical Model (Alkema et al. 2011)

bayesTFR: Modeling Total Fertility Rate (TFR)

- ▶ Using Bayesian Hierarchical Model (Alkema et al. 2011)
- ▶ Results in set of future TFR trajectories for each country.

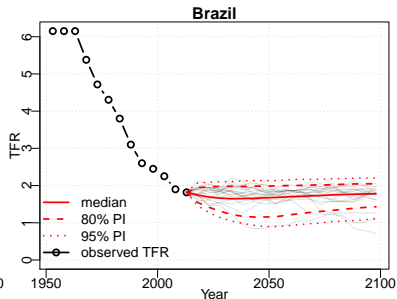
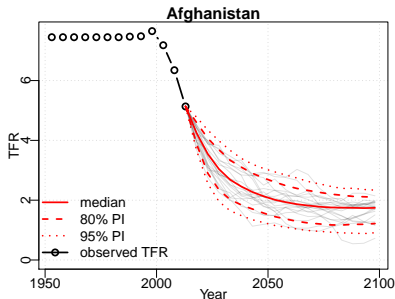
bayesTFR: Modeling Total Fertility Rate (TFR)

- ▶ Using Bayesian Hierarchical Model (Alkema et al. 2011)
- ▶ Results in set of future TFR trajectories for each country.



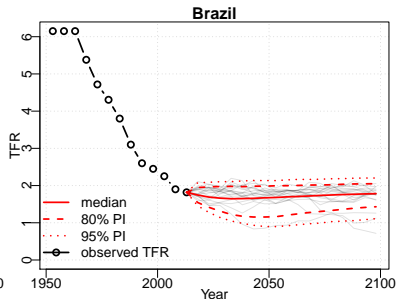
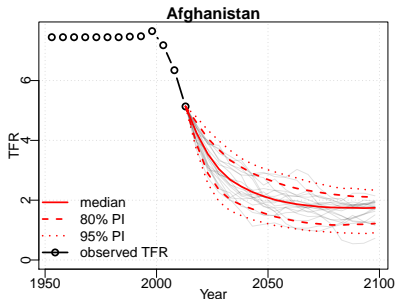
bayesTFR: Modeling Total Fertility Rate (TFR)

- ▶ Using Bayesian Hierarchical Model (Alkema et al. 2011)
- ▶ Results in set of future TFR trajectories for each country.



bayesTFR: Modeling Total Fertility Rate (TFR)

- ▶ Using Bayesian Hierarchical Model (Alkema et al. 2011)
- ▶ Results in set of future TFR trajectories for each country.



bayesLife: Modeling Life Expectancy at Birth (e_0)

bayesLife: Modeling Life Expectancy at Birth (e_0)

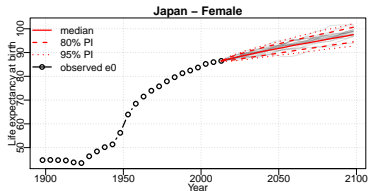
- ▶ Female life expectancy:

bayesLife: Modeling Life Expectancy at Birth (e_0)

- ▶ Female life expectancy:
 - ▶ Using Bayesian Hierarchical Model (Raftery et al. 2013)

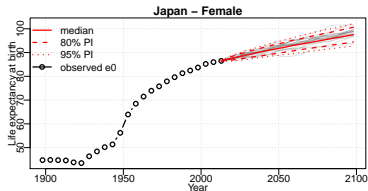
bayesLife: Modeling Life Expectancy at Birth (e_0)

- ▶ Female life expectancy:
 - ▶ Using Bayesian Hierarchical Model (Raftery et al. 2013)



bayesLife: Modeling Life Expectancy at Birth (e_0)

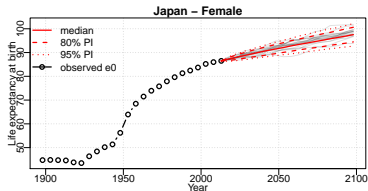
- ▶ Female life expectancy:
 - ▶ Using Bayesian Hierarchical Model (Raftery et al. 2013)



- ▶ Male life expectancy:

bayesLife: Modeling Life Expectancy at Birth (e_0)

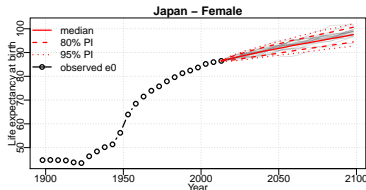
- ▶ Female life expectancy:
 - ▶ Using Bayesian Hierarchical Model (Raftery et al. 2013)



- ▶ Male life expectancy:
 - ▶ Regression model of the gap between female & male e_0

bayesLife: Modeling Life Expectancy at Birth (e_0)

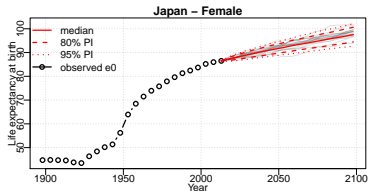
- ▶ Female life expectancy:
 - ▶ Using Bayesian Hierarchical Model (Raftery et al. 2013)



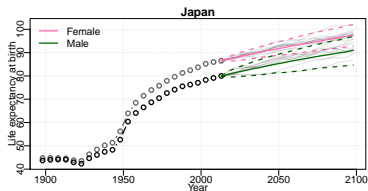
- ▶ Male life expectancy:
 - ▶ Regression model of the gap between female & male e_0
 - ▶ Using female projections and [gap projections](#), project male e_0 .

bayesLife: Modeling Life Expectancy at Birth (e_0)

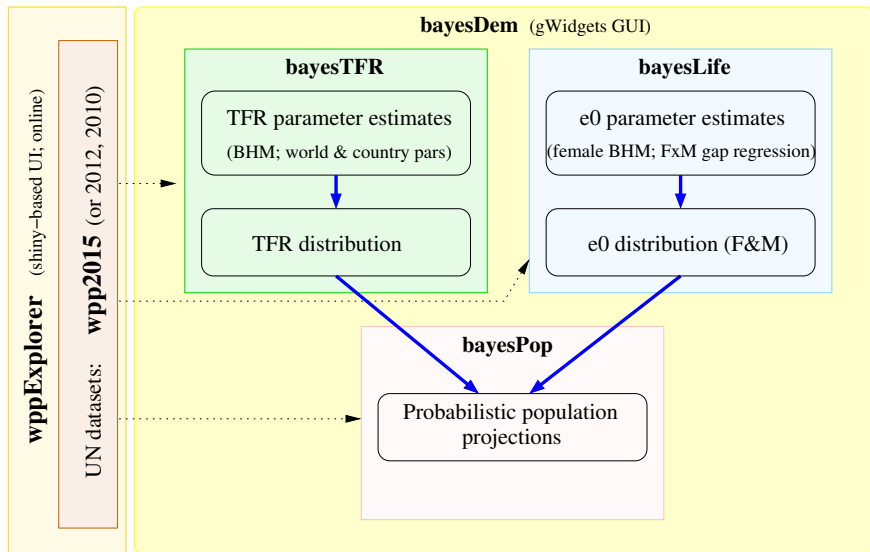
- ▶ Female life expectancy:
 - ▶ Using Bayesian Hierarchical Model (Raftery et al. 2013)



- ▶ Male life expectancy:
 - ▶ Regression model of the gap between female & male e_0
 - ▶ Using female projections and [gap projections](#), project male e_0 .



Software Overview



Population Projection

$$P_t = P_{t-1} + B_t - D_t + M_t \quad \longrightarrow \text{solved using Cohort Component Method}$$

Population Projection

$P_t = P_{t-1} + B_t - D_t + M_t \longrightarrow$ solved using Cohort Component Method

Inputs for probabilistic projections:

- ▶ Projection trajectories of total fertility rate [bayesTFR]
- ▶ Projection trajectories of sex-specific life expectancy [bayesLife]

Population Projection

$P_t = P_{t-1} + B_t - D_t + M_t \longrightarrow$ solved using Cohort Component Method

Inputs for probabilistic projections:

- ▶ Projection trajectories of total fertility rate [bayesTFR]
- ▶ Projection trajectories of sex-specific life expectancy [bayesLife]
- ▶ Projections of sex- and age-specific migration (can be probabilistic)

Population Projection

$P_t = P_{t-1} + B_t - D_t + M_t \longrightarrow$ solved using Cohort Component Method

Inputs for probabilistic projections:

- ▶ Projection trajectories of total fertility rate [bayesTFR]
- ▶ Projection trajectories of sex-specific life expectancy [bayesLife]
- ▶ Projections of sex- and age-specific migration (can be probabilistic)
- ▶ Historical data on various demographic quantities

Population Projection

$P_t = P_{t-1} + B_t - D_t + M_t \longrightarrow$ solved using Cohort Component Method

Inputs for probabilistic projections:

- ▶ Projection trajectories of total fertility rate [bayesTFR]
- ▶ Projection trajectories of sex-specific life expectancy [bayesLife]
- ▶ Projections of sex- and age-specific migration (can be probabilistic)
- ▶ Historical data on various demographic quantities

Method:

1. Convert each future trajectory of TFR and e_0 to age-specific rates

Population Projection

$P_t = P_{t-1} + B_t - D_t + M_t \longrightarrow$ solved using Cohort Component Method

Inputs for probabilistic projections:

- ▶ Projection trajectories of total fertility rate [bayesTFR]
- ▶ Projection trajectories of sex-specific life expectancy [bayesLife]
- ▶ Projections of sex- and age-specific migration (can be probabilistic)
- ▶ Historical data on various demographic quantities

Method:

1. Convert each future trajectory of TFR and e_0 to age-specific rates
2. Apply CCM to each trajct. of age-spec. fertility and mortality rates.

Population Projection

$$P_t = P_{t-1} + B_t - D_t + M_t \quad \longrightarrow \text{solved using Cohort Component Method}$$

Inputs for probabilistic projections:

- ▶ Projection trajectories of total fertility rate [bayesTFR]
- ▶ Projection trajectories of sex-specific life expectancy [bayesLife]
- ▶ Projections of sex- and age-specific migration (can be probabilistic)
- ▶ Historical data on various demographic quantities

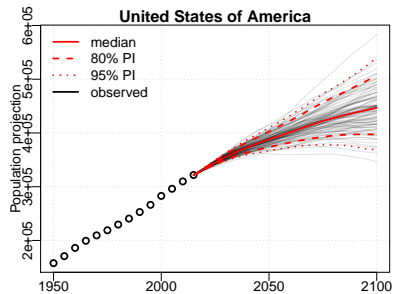
Method:

1. Convert each future trajectory of TFR and e_0 to age-specific rates
2. Apply CCM to each traject. of age-spec. fertility and mortality rates.

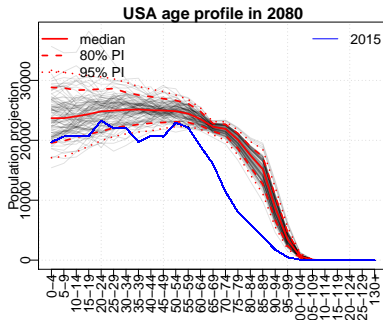
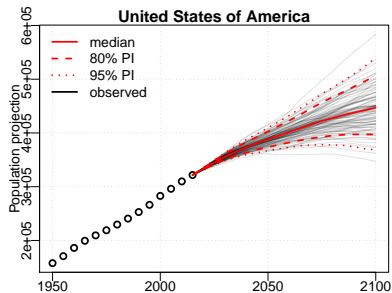
Result:

- ▶ Future trajectories of age- and sex-specific population quantities.

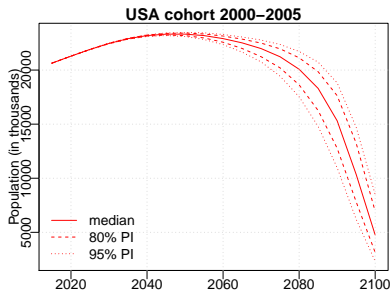
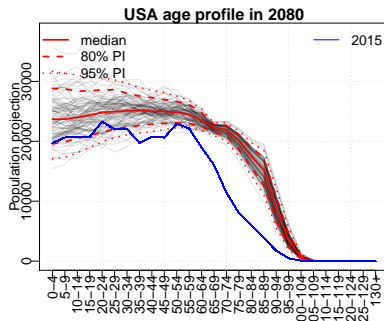
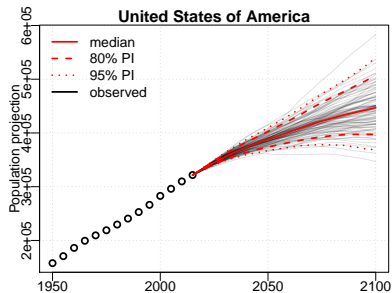
bayesPop: Probabilistic Population Projection



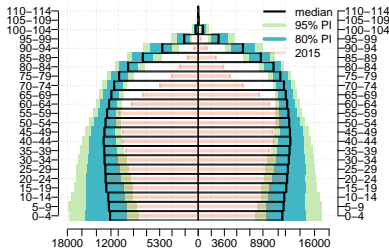
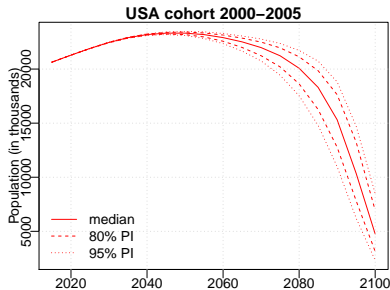
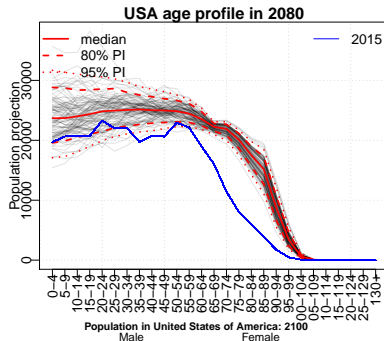
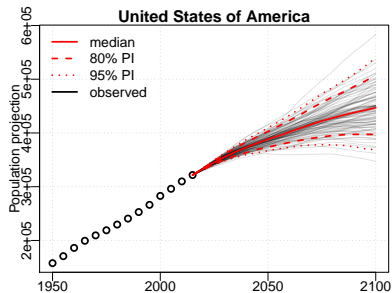
bayesPop: Probabilistic Population Projection



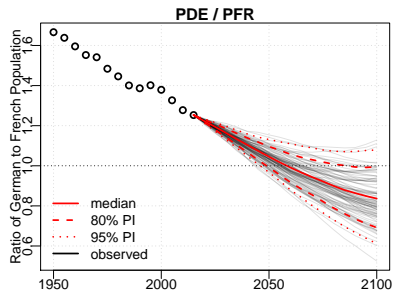
bayesPop: Probabilistic Population Projection



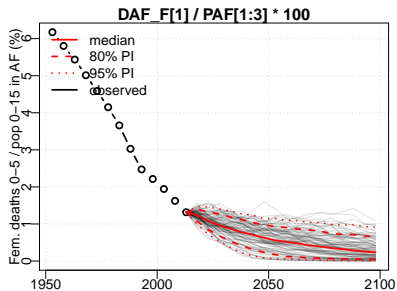
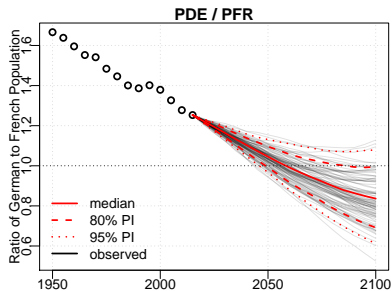
bayesPop: Probabilistic Population Projection



bayesPop: Expression language

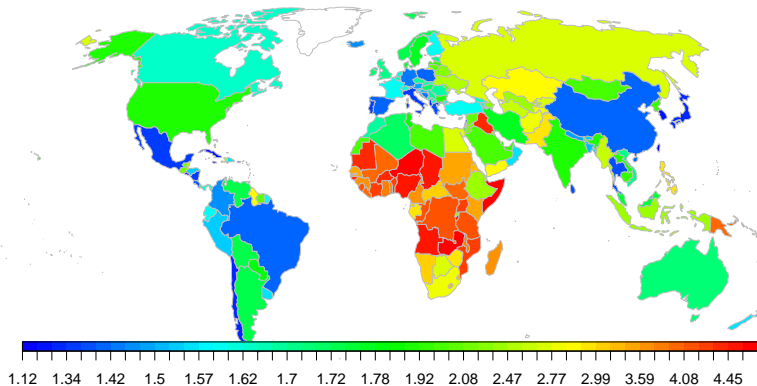


bayesPop: Expression language



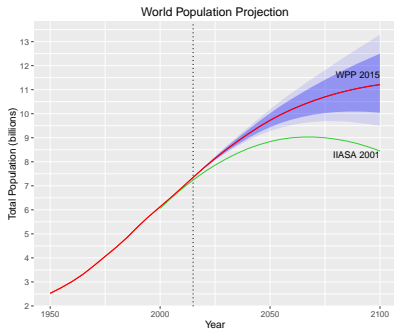
bayesPop: Expression language

PXXX[5:13] / PXXX[14:27] (median in 2100)

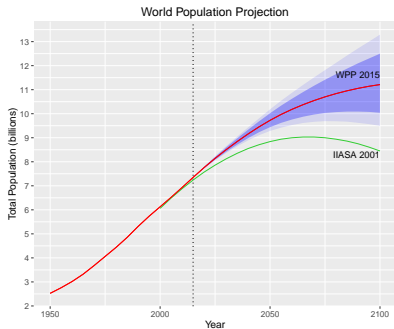


Potential support ratio for all countries

Highlights from UN Projections 2015

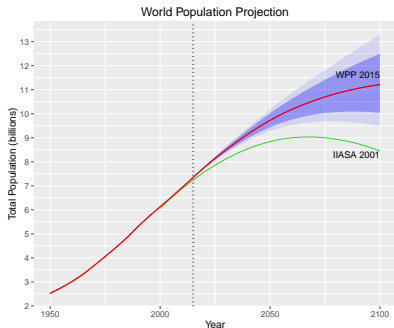


Highlights from UN Projections 2015



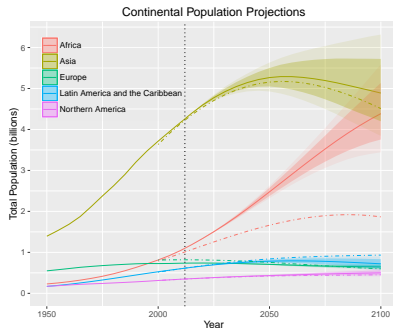
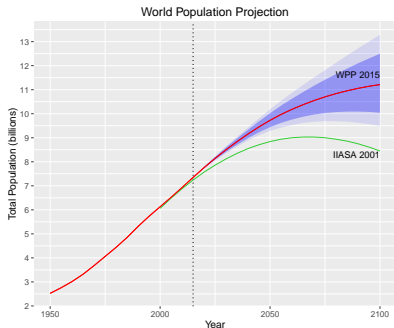
- ▶ World population projected between 9.5 and 13 billions by 2100.

Highlights from UN Projections 2015



- ▶ World population projected between 9.5 and 13 billions by 2100.
- ▶ No growth stabilization before 2100.

Highlights from UN Projections 2015



- ▶ World population projected between 9.5 and 13 billions by 2100.
- ▶ No growth stabilization before 2100.
- ▶ Africa projected to grow from 1 to 4.5 billion.

Summary

- ▶ We developed R packages for probabilistic population projection.

Summary

- ▶ We developed R packages for probabilistic population projection.
- ▶ It includes:
 - ▶ **bayesTFR**: projection of total fertility rate

Summary

- ▶ We developed R packages for probabilistic population projection.
- ▶ It includes:
 - ▶ **bayesTFR**: projection of total fertility rate
 - ▶ **bayesLife**: projection of life expectancy at birth

Summary

- ▶ We developed R packages for [probabilistic population projection](#).
- ▶ It includes:
 - ▶ **bayesTFR**: projection of total fertility rate
 - ▶ **bayesLife**: projection of life expectancy at birth
 - ▶ **bayesPop**: population projection

Summary

- ▶ We developed R packages for [probabilistic population projection](#).
- ▶ It includes:
 - ▶ **bayesTFR**: projection of total fertility rate
 - ▶ **bayesLife**: projection of life expectancy at birth
 - ▶ **bayesPop**: population projection
 - ▶ **bayesDem**: graphical user interface

Summary

- ▶ We developed R packages for probabilistic population projection.
- ▶ It includes:
 - ▶ **bayesTFR**: projection of total fertility rate
 - ▶ **bayesLife**: projection of life expectancy at birth
 - ▶ **bayesPop**: population projection
 - ▶ **bayesDem**: graphical user interface
- ▶ Supporting packages include **wppExplorer** and **wpp2015**.

Summary

- ▶ We developed R packages for [probabilistic population projection](#).
- ▶ It includes:
 - ▶ [bayesTFR](#): projection of total fertility rate
 - ▶ [bayesLife](#): projection of life expectancy at birth
 - ▶ [bayesPop](#): population projection
 - ▶ [bayesDem](#): graphical user interface
- ▶ Supporting packages include [wppExplorer](#) and [wpp2015](#).
- ▶ The United Nations Population Division adopted the methodology and software for their [World Population Prospects](#).

Summary

- ▶ We developed R packages for [probabilistic population projection](#).
- ▶ It includes:
 - ▶ [bayesTFR](#): projection of total fertility rate
 - ▶ [bayesLife](#): projection of life expectancy at birth
 - ▶ [bayesPop](#): population projection
 - ▶ [bayesDem](#): graphical user interface
- ▶ Supporting packages include [wppExplorer](#) and [wpp2015](#).
- ▶ The United Nations Population Division adopted the methodology and software for their [World Population Prospects](#).
- ▶ It made the UN work more transparent and reproducible.

Summary

- ▶ We developed R packages for [probabilistic population projection](#).
- ▶ It includes:
 - ▶ [bayesTFR](#): projection of total fertility rate
 - ▶ [bayesLife](#): projection of life expectancy at birth
 - ▶ [bayesPop](#): population projection
 - ▶ [bayesDem](#): graphical user interface
- ▶ Supporting packages include [wppExplorer](#) and [wpp2015](#).
- ▶ The United Nations Population Division adopted the methodology and software for their [World Population Prospects](#).
- ▶ It made the UN work more transparent and reproducible.

bayespop.csss.washington.edu
hanas@uw.edu