European Doctoral School of Demography 2021-22

Population Projections

Lecture 1
Introduction to population projections

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Presentations

- A little bit about myself ...
- ... and a little bit about you

Miscellaneous

- Course materials available at https://github.com/ubasellini/EDSD2022-population-projections
- Please ask questions during the class or email me at any time
- Slides inspired by Chapter 6 of Preston et al. (2001) & Guy Abel's EDSD course in 2015-16
- Lectures consist of theoretical slides and small exercises in `R` to make the class more entertaining
- On top of population projections, we will learn how to use animations to make nice dynamic visualizations, and how to use `shiny` apps

Assignment

- Group assignment, with three students for each group
- Five exercises (out of nine), which will be given after each class
- The exercises follow up on what we have touched during the class
- Please email me a single `.pdf` file containing your answers, as well as the `R` codes and data to generate the results. Ideally you can send an `R Markdown` document
- Deadline: Sunday 3$^{\mathrm{rd}}$ July

Brief course summary

Lecture 1:

- introduction to population projections
- first model of population projections

Lecture 2: cohort component method

Lecture 3: matrix projections & dynamic visualizations

Lecture 4: extensions of matrix projections

Motivations for population projections I

"*Population projection is probably the demographic technique that is most frequently requested by demography's clients*" (Preston et al. 2001)

- Governments: to anticipate demands for schools, roads, medical personnel, ...
- Private businesses: potential size of their future market
- Public and private sector: future pension expenditures

$\Rightarrow$ more generally, they are the base for many other projections that are essential for social and economic planning, e.g. labour, education, health, housing, social security, energy, climate, transport, ...

Motivations for population projections II

Demographers use population projections for a variety of needs:

- to analyse the implications of a certain set of demographic parameters on population size, composition and growth
- to help understand the determinants of population change and inform policy discussions
- to illustrate the implications of certain demographic characteristics (the model's *inputs*) on population parameters over time (the model's *outputs*)
- typical inputs: fertility, mortality and migration - although methodology can be extended to different demographic processes (marriage patterns, contraceptive use regimes, ...)
- to identify realistic goals and targets for future development trends

Projections vs forecasts I

"*Population projections are calculations which show the future development of a population when certain assumptions are made about the future course of fertility, mortality and migration. They are in general purely formal calculations, developing the implications of the assumptions that are made.*" (United Nations 1958)

- quality of projections is determined by their *internal* validity: do projections obey fundamental demographic accounting relations?
- can be used to answer "*what if*" questions, i.e. purely hypothetical scenarios corresponding to different assumptions. For example, what would happen to the population:
  - *if* mortality had not changed in the last ten years
  - *if* fertility had been 10% lower
  - *if* ...

Projections vs forecasts II

"*A population forecast is a projection in which the assumptions are considered to yield a realistic picture of the probable future development of a population*" (United Nations 1958)

- quality of forecasts is determined by their *external* validity: are the predictions of subsequent events accurate?
- important feature of forecasts is its **uncertainty**
- stochastic forecasts are characterized by probabilistic distributions from which one can compute:
  - central (point) forecast
  - uncertainty via prediction interval

Projections vs forecasts III

In Nathan Keyfitz (1972) words: "*Population projections are correct beyond any testing against the subsequent population performance; in fact they can be incorrect only in the trivial sense that the author made an arithmetic error that prevents his final numbers from being consistent with his initial assumptions.*"

"*Yet in fact projections and forecasts are not easily distinguished. ... A demographer makes a projection, and his reader uses it as a forecast*"

- this course: population projections **only**
- interested in mortality forecasting? Check https://github.com/ubasellini/IDEM117-AdvancesMortalityForecasting

Population projection methodology

A desirable methodology should:

- obey the demographic accounting relationships, i.e. balancing equation of population growth
- be implementable with the available inputs
- provide the desired level of detail in the output
  - only total population
  - disaggregated by sex
  - by age
  - by age and sex
  - 1y or 5y intervals
  - including additional information (education, ethnicity, urban/rural, ...)

Global projections - who does them?

- **United Nations**: World Population Prospects (WPP, available here)
  - since 1946, published every two/three years
  - recent switch to a probabilistic projection model
  - very good track record of accurate projections
- **IIASA**: (see executive summary of latest release here)
  - since 1970s, published less frequently
  - first global projections by age, sex and **educational attainment**
  - based on over 550 expert opinions
- **IHME**: (paper here, nice visualization tool here)
  - more recent
  - based on an epidemiological approach to answer policy-oriented "what-if" questions
  - received some criticism from demographic community (see here)
- **US Census Bureau**: available here

The constant exponential growth model

Given the total population at time 0, $N(0)$, and the mean annualized growth rate between 0 and T, $\bar{r}[0, T]$, what is the total population at time T, $N(T)$?

$$N(T) = N(0)e^{\int_0^T r(t)dt} = N(0)e^{\bar{r}[0,T]T} \tag{1}$$

Let's simplify things: assume that population growth rate is constant over time, i.e. $\bar{r}[0, T] = r$ for all T. Then, using the first two terms of the exponential Taylor series:

$$N(T) = N(0)e^{rT} \approx N(0)(1 + r)^T \tag{2}$$

Note: the approximation is accurate for small values of r

The constant exponential growth model - exercise

Open your R session.

Exercise

Take two populations with $N_a(0) = 50$, $N_b(0) = 35$, $r_a = 5\%$ and $r_b = 15\%$, and let us focus on the first 10 years ($T = 0, \dots, 10$). After how many years will population b surpass a? Plot your results.

Reminder:

$$N(T) = N(0)(1 + r)^T$$

For greater accuracy, define a "continuous" time vector (use a sequence with tiny increments)

The constant exponential growth model - one possible solution

Example

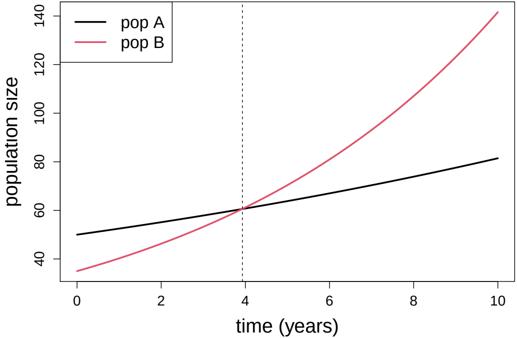
```
rm(list=ls(all=TRUE))
N0_a <- 50
N0_b <- 35
t <- seq(0,10,0.01)
r_a <- 0.05
r_b <- 0.15
PopProj <- function(N0,r,t){
NT <- N0 * (1+r)^t
return(NT)
}
Na <- PopProj(N0_a,r_a,t)
Nb <- PopProj(N0_b,r_b,t)
t_hat <- t[which(Nb > Na)[1]]
```

$$\Rightarrow \hat{t} = 3.93 \text{ years}$$

One possible solution (contd)

Example

```
plot(t,Na,t="l",lwd=2,ylim=range(Na,Nb),
xlab="time (years)",ylab="population size")
lines(t,Nb,col=2,lwd=2)
abline(v=t_hat,lty=2)
legend("topleft",c("pop A","pop B"),col=1:2,lwd=2)
```



Adding demographic components

Let $B[0,T], D[0,T]$ and $M[0,T]$ denote then number of births, deaths and net migrations between 0 and T. From the balancing equation of population growth:

$$N(T) = N(0) + B[0,T] - D[0,T] + M[0,T], \tag{3}$$

and dividing by the number of person-years lived, $PY[0,T]$, we get:

$$\begin{array}{ccccccccc} \dfrac{N(T) - N(0)}{PY[0,T]} & = & \dfrac{B[0,T]}{PY[0,T]} & - & \dfrac{D[0,T]}{PY[0,T]} & + & \dfrac{M[0,T]}{PY[0,T]} \\ r & = & b & - & d & + & m \end{array} \tag{4}$$

i.e. we can decompose the crude growth rate r in terms of the three demographic components, i.e. birth (b), death (d) and net migration (m) crude rates.

Adding demographic components - exercise

Exercise

Assume again two populations with $N_a(0) = 50$, $N_b(0) = 35$, $b_a = 3\%$, $d_a = 5\%$ and $m_a = 1\%$, and $b_b = 7\%$, $d_b = 4\%$ and $m_b = 3\%$. After how many years will population b surpass a?

Hint: substitute $r = b - d + m$ into

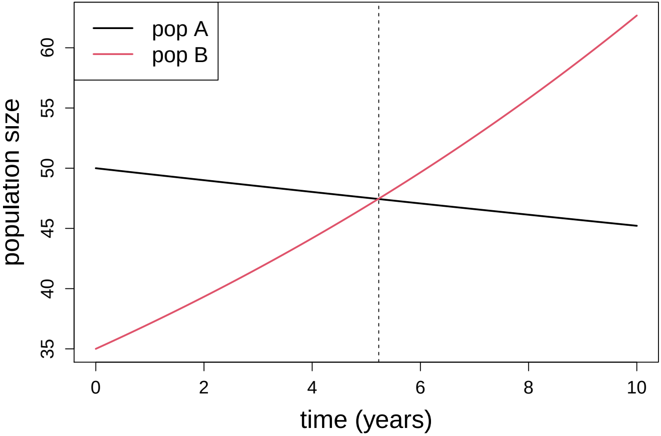
$$N(T) = N(0)(1 + r)^T$$

Adding demographic components - one possible solution

Example

```
N0_a <- 50
N0_b <- 35
t <- seq(0,10,0.01)
b_a <- m_b <- 0.03
d_a <- 0.05
m_a <- 0.01
b_b <- 0.07
d_b <- 0.04
PopProj <- function(N0,b,d,m,t){
r <- b - d + m
NT <- N0 * (1+r)^t
return(NT)
}
Na <- PopProj(N0_a,b_a,d_a,m_a,t)
Nb <- PopProj(N0_b,b_b,d_b,m_b,t)
t_hat <- t[which(Nb > Na)[1]]
```

Adding demographic components - one possible solution



$\Rightarrow \hat{t} =$ 5.23 years

From net migration rates to counts

Rogers, A. (1990). *Requiem for the net migrant*. Geographical Analysis, 22(4), 283-300:

- the net migrant is "a nonexistent category of individuals"
- net migration rate is a flawed measure: it is the difference between a true rate (out-migration) and a prevalence (in-migration). Denominators are different!
- they obscure regularities in age profiles of migration

Use net migration counts instead:

$$N(t+1) = N(t)(1+b-d) + M \tag{5}$$

or immigration counts (I) and emigration rates (e):

$$N(t+1) = N(t)(1+b-d-e) + I \tag{6}$$

From net migration rates to counts - exercise

Exercise

Take a population with $N(0) = 50$, $b = 5\%$, $d = 4\%$, $e = 1\%$ and $I = 1.5$. What is the projected population after 20 years?

Hint: write a `for` loop in your `PopProj` function for the formula

$$N(t+1) = N(t)(1 + b - d - e) + I$$

where each step of the loop corresponds to one-year increments (i.e. use a discrete time vector $t = 1, \ldots, 21$)

From net migration rates to counts - one possible solution

Example

```
N0 <- 50
t <- 1:21   ## one more than projection period
b <- 0.05
d <- 0.04
e <- 0.01
I <- 1.5
PopProj <- function(N0,b,d,e,I,t){
r <- b - d - e
NT <- rep(NA,t)
NT[1] <- N0
for (i in 2:t){
NT[i] <- NT[i-1] * (1+r) + I
}
return(NT)
}
NT <- PopProj(N0,b,d,e,I,max(t))
NT[max(t)]
```

Incorporating future assumptions

We can extend formula

$$N(t+1) = N(t)(1 + b - d - e) + I \tag{7}$$

to incorporate future assumptions on demographic components

$$N(t+1) = N(t)(1 + b_{t,t+1} - d_{t,t+1} - e_{t,t+1}) + I_{t,t+1} \tag{8}$$

This allows us to experiment different assumptions in order to answer "*what if*" questions (the aim of projections).

Incorporating future assumptions - exercise

Exercise

Take the previous population ($N(0) = 50$, $b = 5\%$, $d = 4\%$, $e = 1\%$ and $I = 1.5$) and project again for 20 years ahead. However, make two assumptions about migration. After ten projected years: (i) the emigration rate e doubles, and (ii) the immigration counts I start to decrease and linearly converge to zero at the last projected year. Compare this scenario with the previous projection.

Hint: within your `for` loop, feed vectors rather than constant numbers

Incorporating future assumptions - one possible solution

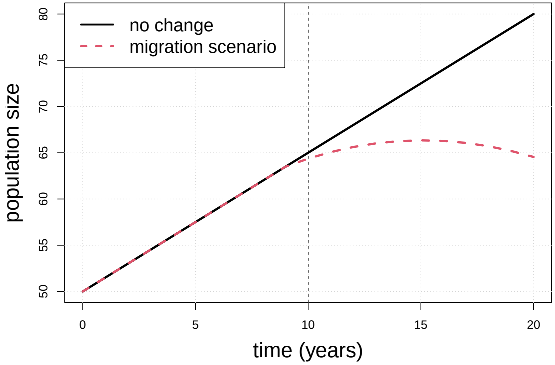
Example

```
y <- t-1   ## x-axis (start from 0)
e <- c(rep(0.01,10),rep(0.02,11))
I <- c(rep(1.5,10),seq(1.5,0,length.out = 11))
par(mfrow=c(1,2))
plot(y,e,main="emigration rate",xlab="time (years)");abline(v=10,lty=2)
plot(y,I,main="immigration counts",xlab="time (years)");abline(v=10,lty=2)
par(mfrow=c(1,1))
PopProj <- function(N0,b,d,e,I,t){
NT <- rep(NA,t)
NT[1] <- N0
for (i in 2:t){
r <- b - d - e[i]
NT[i] <- NT[i-1] * (1+r) + I[i]
}
return(NT)
}
NT_scenario <- PopProj(N0,b,d,e,I,max(t))
```

Incorporating future assumptions - one possible solution

Example

```
plot(y,NT,t="n",xlab="time (years)",ylab="population size")
grid()
lines(y,NT,lwd=2)
lines(y,NT_scenario,col=2,lwd=2,lty=2)
abline(v=10,lty=2)
legend("topleft",c("no change","migration scenario"),col=1:2,lwd=2,lty=c(1,2))
```



Some final remarks

- Reminder: crude rates are very sensitive to age-compositional effects
- The constant exponential growth model shown today is sensible when we can assume:
  - demographic components do not vary much over projection period, *and*
  - the age distribution remains constant
- However, the age distribution itself is determined by population change. An improved projection methodology should take into account age effects by modeling the age distribution as by-product of fertility, mortality and migration conditions

$\Rightarrow$ cohort component method (tomorrow's lecture)

Assignment

Exercise #1

Go back to the first exercise that we saw today (constant exponential growth model), and compute $\hat{t}$ (time when population b surpasses a) without using the approximation formula, i.e. use $N(T) = N(0)e^{rT}$ instead of $N(T) = N(0)(1+r)^T$. Is $\hat{t}$ higher or lower? When does the approximation formula works better?

Assignment

Exercise #2

Take the population time-series for any country (data from HMD or UN), and answer to the following questions:

1. Estimate the population growth rate using two different time intervals (e.g. the last 10 and the last 15 years).
2. Project the population 30-year ahead using the constant exponential model and the two different growth rates
3. Make an assumption about one of the demographic components, and compare this projection with the baseline one
4. Assume that your observed data ends 15 years before the last available data point. Project the population 15-year ahead with the two growth rates estimated in point 1. Which of the two projections is more accurate?

References

- Keyfitz, N. (1972). On Future Population. *Journal of the American Statistical Association*, **67**(338), 347–363
- Preston, S. H., Heuveline, P., and Guillot, M. (2001). *Demography. Measuring and Modeling Population Processes*. Blackwell.
- Rogers, A. (1990). Requiem for the Net Migrant. *Geographical Analysis*, **22**(4), 283–300.
- United Nations (1958). *Multilingual Demographic Dictionary*. United Nations Population Studies, No. 29