Econ/Demog C175 Lab 1: World Population Growth

Overview

This is the first lab of Economic Demography (Econ/Demog C175). Our goals in this first lab are:

1. To get everyone started programming and doing their assignments with R, RStudio, and bCourses.
2. To use the exponential model to learn about world population history

   This document is written in the "R markdown" format and should be read and edited within RStudio. The notebook interface allows you to execute and display R-code within a single window. You can edit this notebook directly and save it. We recommend you save it with a different name (e.g., "world_lab_1_newname.Rmd") to avoid overwriting your edits.

   Viewing note: the labs are formatted using hard line-endings. Try resizing viewing window if lines are overflowing.

Writing and executing R commands

(Note: In addition to this introduction, make sure to read "The Rstudio 175 cloud server for Demog/Econ C175" by Carl Mason et al. available at [https://courses.demog.berkeley.edu/C175/Instructions/rstudio175.pdf], which provides additional information.)

In the RStudio Notebook, we mix executable R commands in with regular written text by creating a "code chunk." To open a code chunk, we type ““`{r}" to start. To close the code chunk we type "`”” to end. Here are some examples:

To print a string of text:

```r
print("Hello, world")
```

```
## [1] "Hello, world"
```

You can hit the green "play" icon to execute the chunk of code. Try modifying the chunk so it prints: "Hello, Berkeley". (Note the [1] just means that it is the first element of the displayed object. You can ignore this.)

To add 2 + 2:

```r
2+2
```

```
## [1] 4
```

To assign the value 4 to a variable named "x":

```r
x <- 4
print(x)
```

```
## [1] 4
```

The output of a chunk is only shown when you tell it to be. For example,

```r
x <- 3
print(x)
```

```
## [1] 3
```

```r
y <- 4
print(y)
```

```
## [1] 4
```

```r
## note: we don't tell R to show us the value of "y"
z <- 5
print(z)
```

```
## [1] 5
```

Try to modify the above code chunk so it also prints the value the variable “y”

Using R to calculate exponential population growth rates

```r
## comments (within code chunks) begin with hashtags. They are ignored
## by R.

## We start by inputting world population sizes by hand, assigning
## them to variables named "N.1900" and "N.2000" using the assignment
## operator: "<-"

N.1900 <- 1650 # estimated world population in 1900 (in millions)
N.2000 <- 6127 # same for 2000

## we can display the value of the variable called N.1900 (hit the
## "play" button)
print(N.2000)
```

```
## [1] 6127
```

```r
## We now calculate growth rate from 1900 to 2000, using our formula
## for the slope of the logarithm of population.
R.twentieth.century <- ( log(N.2000) - log(N.1900) ) / (2000 - 1900)
R.twentieth.century
```

```
## [1] 0.0131193
```

You should get “[1] 0.0131193”, or about 1.3 percent.

We can check this answer

```r
N.2000.check <- N.1900 * exp(100 * 0.0131193)
N.2000.check
```

```
## [1] 6127
```

Which is “6127”, the correct value for the world population in 2000.

Now let’s calculate the exponential growth rate for the fifty years from 1850 to 1900. You need to alter the code below to get the right answer.

```r
N.1850 <- 1262 # these are millions
## Note: We don't need to re-enter N.1900, since variables are saved
## across chunks.
```

```r
## Now modify the code below to give the right answer. (Hint: you need
## to rename the variables N.2000 and N.1900 and change the dates
## "2000" and "1900".)
R.1850.to.1900 <- ( log(N.1900) - log(N.1850) ) / (1900 - 1850)
print( R.1850.to.1900 )
```

```
## [1] 0.00536155
```

You should get 0.00536155, about 0.5 percent. (Hint: If you're still getting 0.0131193, it means you haven't modified the code and have assigned the new variable R.1850.to.1900 with the answer for 1900 to 2000.)

(Note: class demo ends about here.)

The *complete* history of world population

First we're going to read in data from a file that we've placed on the course lab website.

```r
dat <- read.table("/data175/world_population_data.txt", header = T)
dat
```

```
##     year  pop
## 1  -8000    5
## 2      1  200
## 3   1000  400
## 4   1500  458
## 5   1600  580
## 6   1700  682
## 7   1750  791
## 8   1800 1000
## 9   1850 1262
## 10  1900 1650
## 11  1950 2525
## 12  1955 2758
## 13  1960 3018
## 14  1965 3322
## 15  1970 3682
## 16  1975 4061
## 17  1980 4440
## 18  1985 4853
## 19  1990 5310
## 20  1995 5735
## 21  2000 6127
## 22  2005 6520
## 23  2010 6930
## 24  2015 7349
```

Look at the data set, which has the form of a table with two labeled columns "pop" and "year". We're going to extract the contents into our two vectors year.vec and N.vec. (You don't need to understand this yet. We'll be learning about why this works in later labs.)

```r
million <- 1000000
N.vec <- dat$pop / 1000 ## converts millions to billions
year.vec <- dat$year
names(N.vec) <- year.vec
```

Let's look at both of these

```
year.vec
```

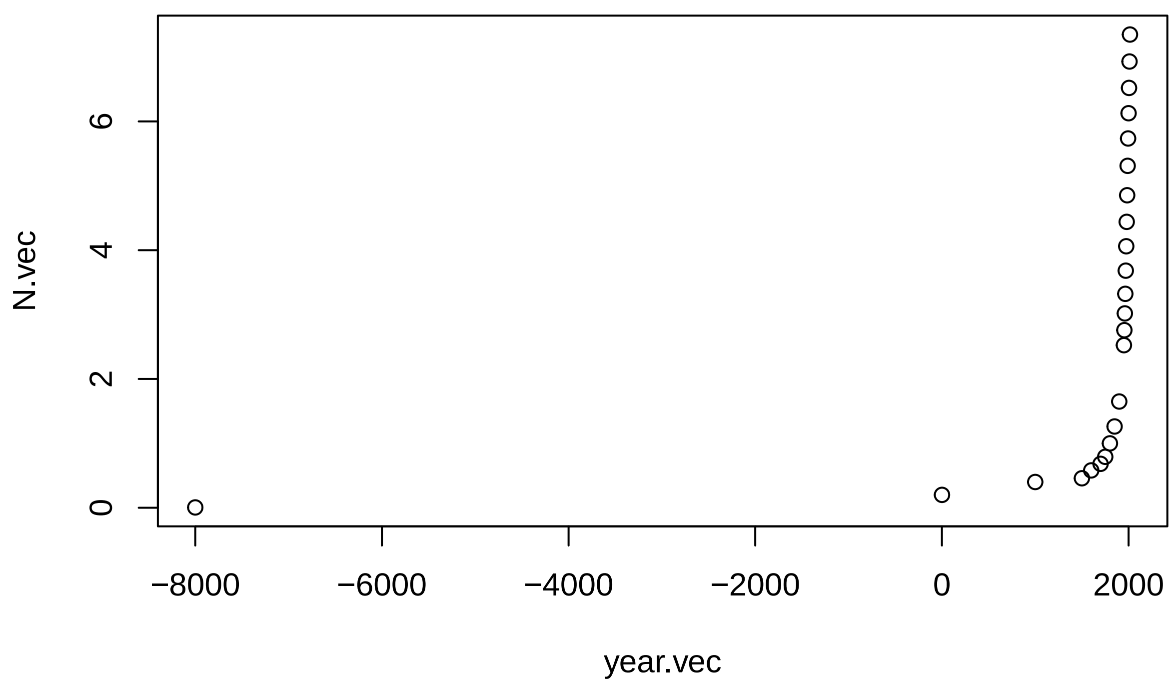
```
##  [1] -8000     1  1000  1500  1600  1700  1750  1800  1850  1900  1950  1955
## [13]  1960  1965  1970  1975  1980  1985  1990  1995  2000  2005  2010  2015
```

```
N.vec
```

```
## -8000     1  1000  1500  1600  1700  1750  1800  1850  1900  1950  1955  1960
## 0.005 0.200 0.400 0.458 0.580 0.682 0.791 1.000 1.262 1.650 2.525 2.758 3.018
##  1965  1970  1975  1980  1985  1990  1995  2000  2005  2010  2015
## 3.322 3.682 4.061 4.440 4.853 5.310 5.735 6.127 6.520 6.930 7.349
```

Our first plot

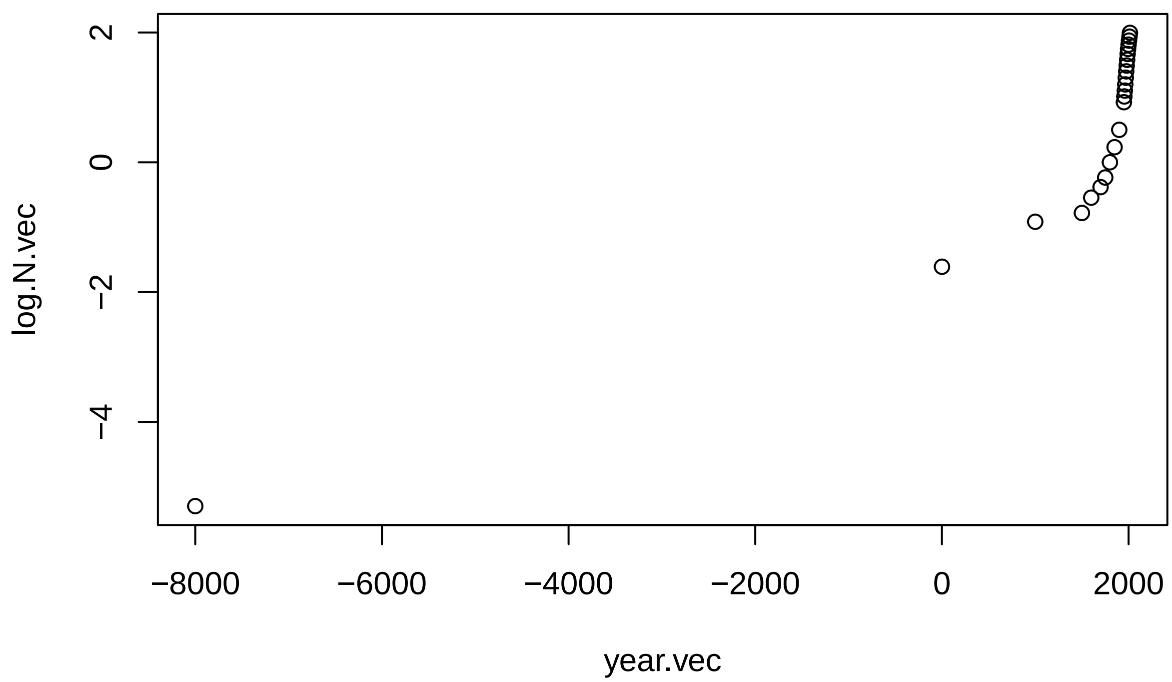
```
plot(x = year.vec,
     y = N.vec)
```



Wow, looks like world population is exploding.

Let's see what is happening in terms of proportional changes (by taking logs)

```
log.N.vec <- log(N.vec)
plot(x = year.vec, y = log.N.vec)
```



Wow, it looks like even proportional rate of growth has increased.

You can now guess-timate the exponential population growth rate by eye-ing the "slope" of the log rate of population growth is equal to the calculated growth rate. For example, the 8000 year period from -8000 to 0 saw an increase of about 4 in log-population size. The slope is thus about 4/8000 = 0.0005. We can check this with our calculations below.

Calculating growth rates through history

Calculate a vector of exponential growth rate.

Here we will use the `diff()` function in R, which tells us the differences between elements in a vector.

For example,

```
x = c(4, 5, 7) ## this is a vector with three elements.
diff(x) # gives us the differences between elements
```

```
## [1] 1 2
```

We'll formulate this as the slope of the graph of log population sizes

```
rise.vec <- diff(log.N.vec) # these are the "rise", the vertical distances between points
run.vec <- diff(year.vec) # these are "run", the horizontal distances between points
slope.vec <- rise.vec / run.vec
R.vec <- slope.vec
R.vec
```

```
##              1         1000         1500         1600         1700         1750
```

```
## 0.0004610523 0.0006938410 0.0002708093 0.0023615892 0.0016200155 0.0029653662
##         1800         1850         1900         1950         1955         1960
## 0.0046891462 0.0046539553 0.0053615505 0.0085093155 0.0176529433 0.0180177162
##         1965         1970         1975         1980         1985         1990
## 0.0191945302 0.0205778143 0.0195946332 0.0178450255 0.0177885388 0.0179989530
##         1995         2000         2005         2010         2015
## 0.0153991831 0.0132234966 0.0124338284 0.0121970875 0.0117408873
```

Let's make a bit more readable by expressing in percentage points, and rounding

```r
R.vec.in.percent <- 100 * round(R.vec, 4)
R.vec.in.percent
```

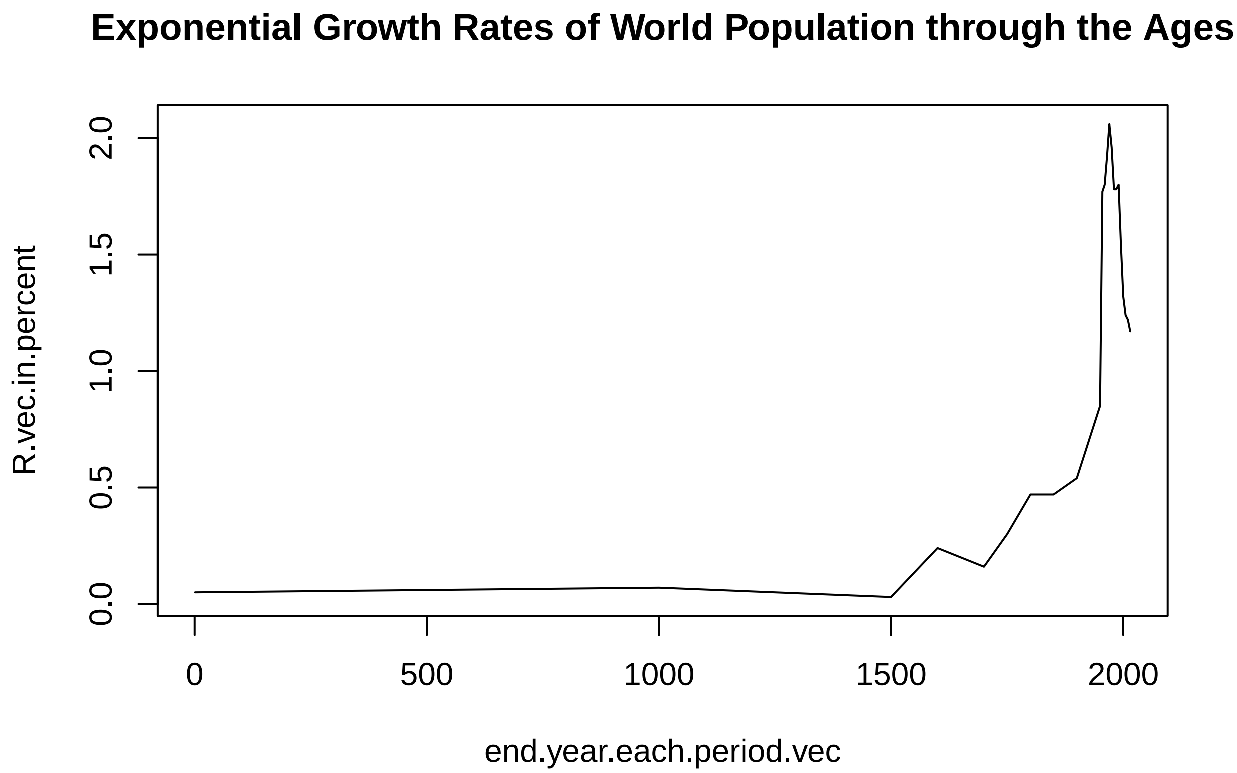
```
##    1 1000 1500 1600 1700 1750 1800 1850 1900 1950 1955 1960 1965 1970 1975 1980
## 0.05 0.07 0.03 0.24 0.16 0.30 0.47 0.47 0.54 0.85 1.77 1.80 1.92 2.06 1.96 1.78
## 1985 1990 1995 2000 2005 2010 2015
## 1.78 1.80 1.54 1.32 1.24 1.22 1.17
```

We see that growth rates increased for nearly 10,000 years, but have recently begun to decrease a bit.

Plotting the growth rates

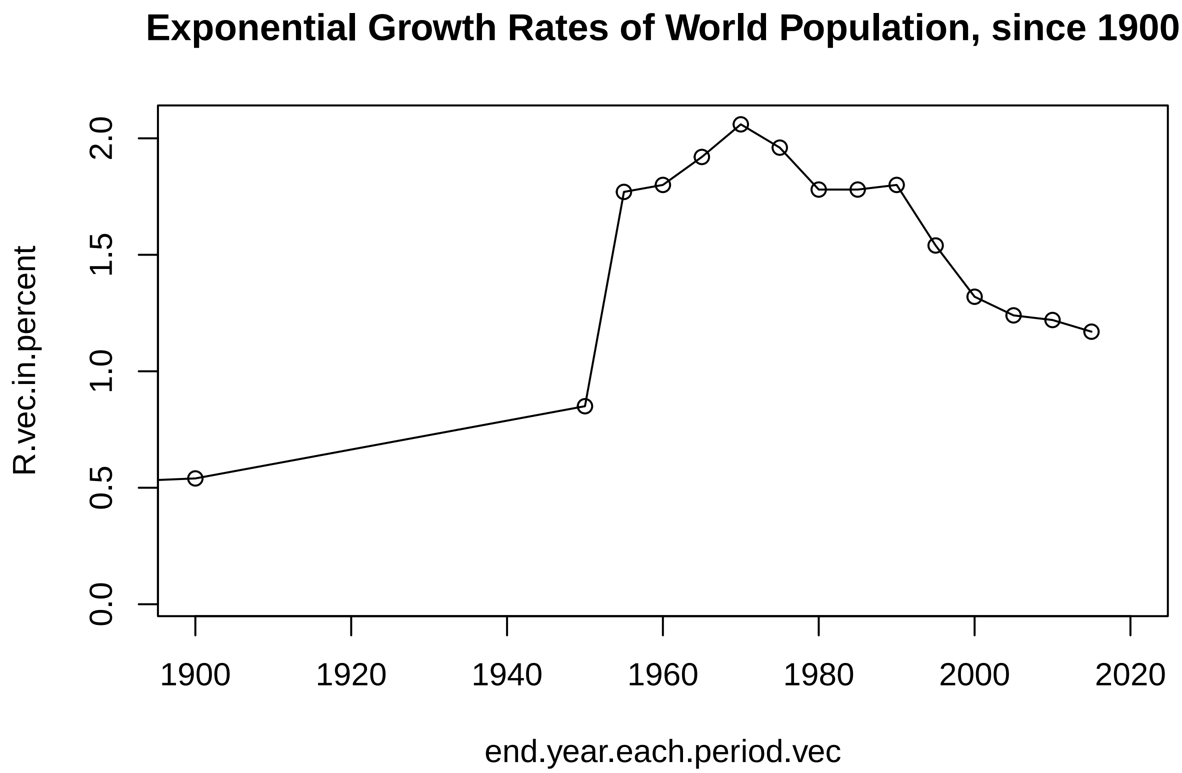
Let's try a plot:

```r
end.year.each.period.vec <- names(R.vec.in.percent)
plot(x = end.year.each.period.vec,
     y = R.vec.in.percent,
     main = "Exponential Growth Rates of World Population through the Ages",
     type = "l")
```



It looks like population growth rates have begun to decline. To see a bit better, we can graph only the more recent years

```
plot(x = end.year.each.period.vec,
     y = R.vec.in.percent,
     xlim = c(1900, 2020),               # limit the x-axis to 1900 to 2020
     main = "Exponential Growth Rates of World Population, since 1900",
     type = "o")
```



Congratulations

You've finished all of the computing for the first lab!

Graded Questions

(See the syllabus for instructions on submitting your answers at https://courses.demog.berkeley.edu/goldstein175/)

1. [Multiple choice] Which of the following descriptions is best for the history of human population growth?

A. Constant exponential growth at a rate slightly larger than zero.

B. Thousands of years of near zero growth, followed by centuries of accelerating growth, with a recent slowing of growth.

C. Thousands of years of essentially zero growth, followed by a one time increase in growth rates.

D. Alternating lengthy periods of positive and negative growth.

ANSWER: **B**

2. [A numerical answer] How large would the world population be today if annual growth rates had always been .0005 larger for the last 10,000 years?

Hint 1: The rules of exponents tell us

$$exp((R+d)*t) = exp(R*t)*exp(d*t)$$

Hint 2: To calculate exp(10000 * .0005), you can use a calculator or any other tool. You don't have to use R.

Hint 3: You should get a population roughly 150 time as large as today.

Note: Imagine we increased the reproduction rate of each generation by a tiny bit – so, for example, instead of each woman having on average 1 surviving daughter, imagine she had 1.015 surviving daughters. If generations were 30 years in length, then this would mean an increase in the growth rate by about log(1.015/1.00)/30 = .0005. So, the calculation we just did tells us what would have happened to the human population if fertility rates had always been just slightly, only 1.5 percent, higher.

ANSWER: $N(t) = N(0) \cdot e^{Rt} \cdot e^{dt}$ $N(t) = N(0) \cdot e^{(R+d)t}$ $N(t) = N(0) \cdot e^{10000 \cdot 0.0005}$ $N(t) = 7300000000 \cdot e^{10000 \cdot 0.0005}$

```
print(exp(10000 * 0.0005))
```

```
## [1] 148.4132
```

```
print(exp(10000 * 0.0005) * 7300000000)
```

```
## [1] 1.083416e+12
```

Population is 148.4132X times larger, or roughly 1.083416e+12 people.

3. [A numerical answer] How large would the world population in 2115 be if current exponential growth rates continue? Use 7.3 billion as the population size in 2015 and assume $R = 0.01. You can do this calculation however you choose (with R, by hand with a calculator, or any other way.)

ANSWER: $N(t) = N(0) \cdot e^{Rt} \cdot e^{dt}$ $N(t) = N(0) \cdot e^{(R+d)t}$ $N(t) = N(0) \cdot e^{100 \cdot 0.01}$ $N(t) = 7300000000 \cdot e^{100 \cdot 0.01}$

```
print(exp(100 * 0.01) * 7300000000)
```

```
## [1] 19843457348
```

19843457348 people.

5. [A short answer.] Do you think this estimate of the world population in 2115 is likely to be too high or too low? Explain your reasoning in a sentence.

The estimate is probably too high, because world population growth rate has slowed down. The new population is 2.71 times larger and doesn't rationally match up. Plus slower growth rates generally means lower exponential growth rates as well. The reference taken is not appropriate in the calcuations.

6. [Optimum Population Exercise] Imagine there's an island that can only sustain a few people. The marginal product starts at 5 units for the first person and declines by 1 unit for each additional person until the MP of the 6th person is zero. Each person needs to consume 2 units per year to subsist.

   (Hint: if you are having trouble here with the definitions of the optimum populations, consult the lecture slides.)

   (a) Fill in the Average Product row of the table below. (We recommend you do this by hand to enhance understanding.)

   (Hint: The average can be obtained by summing up the marginal product to produce the total product and then dividing by the number of people.)

Population Size	1	2	3	4	5	6	7	8	9	10
Marginal Product	5	4	3	2	1	0	0	0	0	0
Average Product	5	4.5	4	3.5	3	2.5	2.14	1.875	1.67	1.5

(b) What size population gives Sauvy's economic optimum? 1, since Sauvy's optimum is when marginal product is at its peak.

(c) What size population gives Sauvy's power optimum? 4, subsistence level is 2 according to the problem, so the population size is 4 when that is reached in the marginal product.

(d) What size population is the "maximum" sustainable population? 7, since it is when the average product is equal to subsistence level 2, which 2.14 is the closest.

7. [non-graded] About how much time (in hours and minutes) did it take you to complete this lab?

1 hour

Congratulations! You have completed Lab 1.