{capn} and groundwater exercise for Yale FES Nature as Capital

The results from Fenichel et al. 2016 PNAS can be reproduced using capn. The necessary data files are in my_gw_data.RData, which holds the data set used in the paper, gw.data and two additional data sets csp.raw and csp.means. You will also need groundwater_capn.R, which holds the code for the system model and test of the capn installation. The default settings in groundwater_capn.R reproduce the main result in Fenichel et al. 2016.

A note: code the can be copy and pasted into an R script is in dark green.

The elements of gw.data are

1. The parameters from the multinomial logit for crop shares, to know which is which see the labels on the additional csp.means data using the `View(csp.means)` command.
2. The average amount planted in each field type defined by a wellhead
3. A water withdraw constant, α
4. A water withdraw coefficient, β
5. Water withdraw crop coefficients, γ (includes main and squared terms)
6. Water withdraw crop coefficients main terms only, $\gamma 1$
7. Water withdraw crop coefficients squared terms only, $\gamma 2$
8. Per acre prices (gross revenues) used in the profit function
9. Costs used in the profit function

Also included are the raw coefficients for the crop shares models (csp.raw) and their mean values csp.means.

Getting ready (not graded)

1. Install R and RStudio, instructions are here https://www.rstudio.com/products/rstudio/download/, if you have not done so already.
2. On the left-hand side of RStudio go to File -> Open File and navigate to open groundwater_capn.R.
3. Press Ctrl+Shift+Enter run the whole script or step through using Ctrl+Enter.
4. Verify all is installed correctly by running groundwater_capn.R. You should see a price curve and intertemporal welfare curve in the lower right Plots window and the console should show that at 21.5 acre feet of water the shadow price is $16.82 or about $17.

Some Exercises

First, let's explore the model (20% equally weighted). The simulation model is built on two statistical models: one for water withdraw (a two-stage regression linear regression model that controls for selection bias) and one for crop mix (a multinomial logit model). Recharge is considered constant, so the physical model is just recharge minus water withdraw. However, capn can certainly use more complicated biophysical models. Line 15 in groundwater_capn.R, starting source_data…, gets the estimated parameters from my github page, so you have them. We will not focus on their estimation, but rather how to use them once they are estimated.

1. Plot water withdraws as a function of water depth on the representative acre. The water withdraw function is Wwd(water, parameters).
    a. Create new script
    b. Try Wwd function at 21.5 feet of water. The arguments are Wwd(21.5, gw.data).
    c. Simulate the model using a for loop.
        i. Make a matrix to hold the output (called pre-allocation), by typing `data.ww <- matrix(0, nrow = 100, ncol = 2)`. This says make a matrix of zeros that is 100 rows long and two columns wide.
        ii. Name these columns by adding a line `colnames(data.ww) <- c("water", "water.withdrawl")`
        iii. Now run the simulation with the following block of code:

```
for(j in 1:100){
        data.ww[j,1] <- j
        data.ww[j,2] <-Wwd(j,gw.data)
}
```

    Can you explain what this does?

        iv. Check your result by adding a line `View(data.ww)`
        v. Change your data.ww to a dataframe, by typing `data.ww <- as.data.frame(data.ww)`
    d. Let's plot the data using the ggplot2 package.
        i. First make sure the package is installed, try adding code that says `library(ggplot2)`
            1. If it runs, then great.
            2. If it does not run, add `install.packages("ggplot2")` and try again.
        ii. Copy the following

```
ggplot() +
  geom_line(data = data.ww, aes(x = water, y = water.withdrawl),
            color = 'blue') +
  labs(
    x= "Stored groundwater",
    y = "Intertemporial Welfare")  +
  theme(  #http://ggplot2.tidyverse.org/reference/theme.html
    axis.line = element_line(color = "black"),
    panel.background = element_rect(fill = "transparent",color = NA),
    plot.background = element_rect(fill = "transparent",color = NA)
  )
```

The first line sets up a place for the plot. The second line draws the plot. The third line changes the line color to blue. The four – sixth lines label the axes. The last four lines control the color of the axis lines and the background of the plot.

2. Try the cropFwater(water, parameters) function. This function determines how much land is planted with the representative well as a function of water depth. It returns a horizontal vector of acres planted [alfalfa, corn, sorghum, soy, wheat, unirrigated or fallow]. Continue working in your script.
    a. Use a similar approach as before to simulate acres planted and their shares. You might want to create a new variable, e.g., data.cs. Also, your storage matrix will need to be 7 columns wide, one for water level, then one for each of the six crops (including fallow).
    b. You can sum across the crops columns by using the command rowSums(data.cs[,2:7]). This will give you the total area planted for irrigated crops. Use this result to plot the irrigated acres as a function of water.
    c. Create some pie charts at various water depths, e.g., 2, 5, 15, 20, 50, 90 to see you the share of crops changes. Use the following code

```
my.pie<- data.frame(
  crops = c("alfalfa", "corn", "sorghum", "soy", "wheat","fallow"),
  fracs = cropFwater(20 ,gw.data)
)

ggplot(my.pie, aes(x = factor(1), y=fracs, fill=factor(crops)) )+
  geom_bar(width = 1,stat="identity")+coord_polar(theta = "y") +
  labs(
    x= "",
    y = "") +
  theme(axis.ticks = element_blank(),
        panel.grid  = element_blank(),
        axis.text = element_blank(),
        panel.background = element_rect(fill = "transparent",color = NA),
        plot.background = element_rect(fill = "transparent",color = NA)
        )+
  guides(fill=guide_legend(title="crop fractions"))
```

20 is what needs to be changed to try different levels.

Now we are ready to explore capN (80% equally weighted). Go back to the groundwater_capn.R script. You may want to review the capn documentation (https://cran.r-project.org/web/packages/capn/capn.pdf). In this exercise we will focus on the “p” family of functions. Read through the code and see if you can understand what is happening. The two functions to pay close attention to are the paprox and psim functions. The top two sections let you control additional simulation parameters (discount rate, dr, and recharge rate per year, recharge).

3. Explore the effects of the discount rate by changing it to 5% and then to 7%. How does the shadow price at 21.5 feet change relative to the default 3%? How about at 18 feet? Hint: you can use

```
output<-psim(pcoeff = pC,
        stock = 21.5)
```

to simulate a specific water depth. Then `output$shadowp` will give you the shadow price.

4. Now set the discount rate back to 3% and try changing the recharge rate. What if the recharge rate were half the assumed rate, how about double, or five times? Does it matter if you make comparisons at 21.5, 18, or 30 feet?
5. capn also reports inclusive wealth, using output above, the IW is output$iw. Show that this is the same as quantity of water times shadow price.
6. What really matters is change in IW.
    a. Draw figure by hand that helps you figure out the change in IW. Remember it is meant as a linear approximation of the change in area under the price curve (really in a multi-dimensional space, but we are only working with one stock).
    b. Is it possible to subtract two different capn IW values to get the change, why or why not?
    c. How could you more accurately compute the change in inclusive wealth? Demonstrate this approach to measuring the change in inclusive wealth going from 21.5 to 20.5 feet and then from 21.5 to 18.5 feet for the representative acre.
    d. capn also approximates the intertemporal welfare, but this is only meaningful for changes. This is called output$vfun. However, if you try this you will get an error. Re-run with some extra information

```
output<-psim(pcoeff = pC,
        stock = 21.5,
        wval = profit(21.5, gw.data),
        sdot = sdot(21.5, recharge, gw.data)
```

    e. Now revisit part c and compare difference between the vfun value and the iw values and compare.
    f. Draw a picture (not using R) that explains why the difference between vfun and iw are different.

Let's consider a policy shift. What if crop subsidizes were used for water conservation. Corn is the most commonly grown crop in the system and is relatively water intensive. Wheat is also grown and is the least water intensive crop. Let's first consider a water motivated tax on corn and then a water motivated subsidy on wheat.

7. First, copy the data. This will let you go back to the original data set without downloading it again.
    a. gw.data.alt<-gw.data
    b. csp.means.alt<-csp.means

The relevant prices of corn and wheat are in csp.means. The prices vector is not important, because we would want to add back the tax or subtract of the subsidy from profits farmers earn. csp.means[[14]] is the corn price and csp.means[[17]] is the wheat price. Let's first consider a 10% tax on corn revenue.

8. We will do this by modifying gw.data.alt with the following code (in a new script)

```
csp.means.alt[[14]]<-0.9*csp.means[[14]]
#we leave of the first element off because it is the water withdrawl element and is
#actually a different vector in the parameter set. It is also unaffected by this change.
#The operation below is matrix multiplication, the t is a transpose
gw.data.alt[[1]]$crop.share.a<-t(csp.means.alt[-1]%*%csp.raw[-1,])
```

9. How does the tax change affect the amount of water withdrawn if there is 21.5 acre feet of water?
10. How does the tax change to the total acreage planted for the representative well at 21.5 acre feet?
11. How does the tax change the share of crops planted and irrigated at 21.5 acre feet?

12. How does the tax change farm profit for the representative acre [use the function profit(water, parameters)]. Don’t worry about adding back in the tax, focus on the private farm profit.
13. How does the tax affect the shadow price of water?
14. Does the tax increase the wealth stored in water? What about sustainability?