1 Murder rates

Punishment for crime has many philosophical justifications. An important one is that fear of punishment may deter people from committing crimes. In the United States, some jurisdictions execute some people who are convicted of particularly serious crimes, like murder. This punishment is called the death penalty or capital punishment. The death penalty is controversial, and deterrence has been one focal point of the debate. There are other reasons to support or oppose the death penalty, but in this project we'll focus on deterrence.

The key question about deterrence is: Does instituting a death penalty for murder actually reduce the number of murders?

You might have a strong intuition in one direction, but the evidence turns out to be surprisingly complex. Different sides have variously argued that the death penalty has no deterrent effect and that each execution prevents 8 murders, all using statistical arguments! We'll try to come to our own conclusion.

Here is a road map for this project:

1. In the rest of this section, we'll investigate the main dataset we'll be using.

2. In section 2, we'll see how to test null hypotheses like this: "For this set of U.S. states, the murder rate was equally likely to go up or down each year."

3. In section 3, we'll apply a similar test to see whether U.S. states that suddenly ended or reinstituted the death penalty were more likely to see murder rates increase than decrease.

4. In section 4, we will run some more tests to further claims we had been developing in previous sections.

5. In section 5, we'll try to answer our question about deterrence using a visualization rather than a formal hypothesis test.

1.1 The Data

The main data source for this project comes from a paper by three researchers, Dezhbakhsh, Rubin, and Shepherd. The dataset contains rates of various violent crimes for every year 1960-2003 (44 years) in every US state. The researchers compiled their data from the FBI's Uniform Crime Reports. Since crimes are committed by people, not states, we need to account for the number of people in each state when we're looking at state-level data. Murder rates are calculated as follows:

murder rate for state X in year Y = 100000 * (number of murders in state X in year Y / population in state X in year Y)

(Murder is rare, so we multiply by 100,000 just to avoid dealing with tiny numbers.)

So far, this looks like a dataset that lends itself to an observational study. In fact, these data aren't even enough to demonstrate an association between the existence of the death penalty in a state in a year and the murder rate in that state and year!

Question 1.1. What additional information will we need before we can check for that association?

Murder rates vary over time, and different states exhibit different trends. The rates in some states change dramatically from year to year, while others are quite stable. Let's plot a couple, just to see the variety.

Question 1.2. Draw a line plot with years on the horizontal axis and murder rates on the vertical axis. Include two lines: one for Alaska murder rates and one for Minnesota murder rates. Create this plot using a single call: ak mn.plot('Year').

Question 1.3. Implement the function most murderous, which takes a year (an integer) as its argument. It does two things:

1. It draws a horizontal bar chart of the 5 states that had the highest murder rate in that year.

2. It returns an array of the names of these states in order of increasing murder rate.

Question 1.4. How many more people were murdered in California in 1988 than in 1975? Assign ca change to the answer.

2 Changes in Murder Rates

Murder rates vary widely across states and years, presumably due to the vast array of differences among states and across US history. Rather than attempting to analyze rates themselves, here we will restrict our analysis to whether or not murder rates increased or decreased over certain time spans. We will not concern ourselves with how much rates increased or decreased; only the direction of the change - whether they increased or decreased.

Question 2.1. Implement the function two year changes that takes an array of murder rates for a state, ordered by increasing year. For all two-year periods (e.g., from 1960 to 1962), it computes and returns the number of increases minus the number of decreases.

We can use two year changes to summarize whether rates are mostly increasing or decreasing over time for some state or group of states. Let's see how it varies across the 50 US states.

Question 2.2. Assign changes by state to a table with one row per state that has two columns: the State name and the Murder Rate two year changes statistic computed across all years in our data set for that state.

Question 2.3. Assign total changes to the total increases minus the total decreases for all two-year periods and all states in our data set.

Question 2.4. Set num changes to the number of different two-year periods in the entire data set that could result in a change of a state's murder rate. Include both those periods where a change occurred and the periods where a state's rate happened to stay the same.

We now have enough information to perform a hypothesis test.

Null Hypothesis: State murder rates increase and decrease over two-year periods as if "increase" or "decrease" were sampled at random from a uniform distribution, like a fair coin flip.

Since it's possible that murder rates are more likely to go up or more likely to go down, our alternative hypothesis should contemplate either case:

Alternative Hypothesis: State murder rates are either more likely or less likely to increase than decrease over two-year periods.

Technical note: These changes in murder rates are not random samples from any population. They describe all murders in all states over all recent years. However, we can imagine that history could have been different, and that the observed changes are the values observed in only one possible world: the one that happened to occur. In this sense, we can evaluate whether the observed "total increases minus total decreases" is consistent with a hypothesis that increases and decreases are drawn at random from a uniform distribution.

Question 2.5. Given these null and alternative hypotheses, define a good test statistic.

Important requirements for your test statistic: Choose a test statistic for which large positive values are evidence in favor of the alternative hypothesis, and other values are evidence in favor of the null hypothesis. Your test statistic should depend only on whether murder rates increased or decreased, not on the size of any change.

Question 2.6. Complete the simulation below, which samples num changes increases/decreases at random many times and forms an empirical distribution of your test statistic under the null hypothesis. Your job is to

• fill in the function simulate under null, which simulates a single sample under the null hypothesis, and
• fill in its argument when it's called below.

```
def simulate_under_null(num_chances_to_change):
    """Simulates some number changing several times, with an equal
    chance to increase or decrease.  Returns the value of your
    test statistic for these simulated changes.

    num_chances_to_change is the number of times the number changes.
    """
    ...

uniform_samples = make_array()
for i in np.arange(5000):
    uniform_samples = np.append(uniform_samples, simulate_under_null(...))

# Feel free to change the bins if they don't make sense for your test statistic.
Table().with_column('Test statistic under null', uniform_samples).hist(0, bins=np.arange(-100, 40
0+25, 25))
```

Question 2.7. Looking at this histogram, draw a conclusion about whether murder rates basically increase as often as they decrease.

3 The death penalty

Some US states have the death penalty, and others don't, and laws have changed over time. In addition to changes in murder rates, we will also consider whether the death penalty was in force in each state and each year. Using this information, we would like to investigate how the death penalty affects the murder rate of a state.

Question 3.1. Describe this investigation in terms of an experiment. What population are we studying? What is the control group? What is the treatment group? What outcome are we measuring?

Question 3.2. We want to know whether the death penalty causes a change in the murder rate. Why is it not sufficient to compare murder rates in places and times when the death penalty was in force with places and times when it wasn't?

3.1 A Natural Experiment

In order to attempt to investigate the causal relationship between the death penalty and murder rates, we're going to take advantage of a natural experiment. A natural experiment happens when something other than experimental design applies a treatment to one group and not to another (control) group, and we can reasonably expect that the treatment and control groups don't have any other systematic differences.

Our natural experiment is this: in 1972, a Supreme Court decision called Furman v. Georgia banned the death penalty throughout the US. Suddenly, many states went from having the death penalty to not having the death penalty.

As a first step, let's see how murder rates changed before and after the court decision. We'll define the test as follows:

• **Population:** All the states that had the death penalty before the 1972 abolition. (There is no control group for the states that already lacked the death penalty in 1972, so we must omit them.) This includes all US states except Alaska, Hawaii, Maine, Michigan, Wisconsin, and Minnesota.

• **Treatment group:** The states in that population, in the year after 1972.

• **Control group:** The states in that population, in the year before 1972.

• **Null hypothesis:** Each state's murder rate was equally likely to be higher or lower in the treatment period than in the control period. (Whether the murder rate increased or decreased in each state was like the flip of a fair coin.)

• **Alternative hypothesis:** The murder rate was more likely to increase or more likely to decrease.

Technical Note: It's not clear that the murder rates were a "sample" from any larger population. Again, it's useful to imagine that our data could have come out differently and to test the null hypothesis that the murder rates were equally likely to move up or down.

Question 3.3. Assign death penalty murder rates to a table with the same columns and data as murder rates, but that has only the rows for states that had the death penalty in 1971.

The null hypothesis doesn't specify how the murder rate changes; it only talks about increasing or decreasing. So, we will use the same test statistic you defined in section 2.

Question 3.4. Assign changes 72 to the value of the test statistic for the years 1971 to 1973 and the states in death penalty murder rates.

Question 3.5. Draw an empirical histogram of the statistic under the null hypothesis by simulating the test statistic 5,000 times.

3.2 Conclusion

Question 3.6. Complete the analysis as follows:

1. Compute a P-value.

2. Draw a conclusion about the null and alternative hypotheses.

3. Describe your findings using simple, non-technical language. Be careful not to claim that the statistical analysis has established more than it really has.

4 Further evidence

So far, we have discovered evidence that when executions were outlawed, the murder rate increased in many more states than we would expect from random chance. We have also seen that across all states and all recent years, the murder rate goes up about as much as it goes down over two-year periods. These discoveries seem to support the claim that eliminating the death penalty increases the murder rate. Should we be convinced? Let's conduct some more tests to strengthen our claim.

Conducting a test for this data set required the following steps:

1. Select a table containing murder rates for certain states and all years,

2. Choose two years and compute the observed value of the test statistic,

3. Simulate the test statistic under the null hypothesis that increases and decreases are drawn uniformly at random, then

4. Compare the observed difference to the empirical distribution to compute a P-value.

This entire process can be expressed in a single function, called run test.

Question 4.1. Implement run test, which takes the following arguments:

• A table of murder rates for certain states, sorted by state and year like murder rates, and

• the year when the analysis starts. (The comparison group is two years later.)

It prints out the observed test statistic and returns the P-value for this statistic under the null hypothesis.

4.1 The death penalty reinstated

In 1976, the Supreme Court repealed its ban on the death penalty in its rulings on a series of cases including Gregg v. Georgia, so the death penalty was reinstated where it was previously banned. This generated a second natural experiment. To the extent that the death penalty deters murder, reinstating it should decrease murder rates, just as banning it should increase them.

Question 4.3. Now we've analyzed states where the death penalty went away and came back, as well as states where the death penalty was outlawed all along. What do you conclude from the results of the tests we have conducted so far? Does all the evidence consistently point toward one conclusion, or is there a contradiction?

5 Visualization

While our analysis appears to support the conclusion that the death penalty deters murder, a 2006 Stanford Law Review paper argues the opposite: that historical murder rates do not provide evidence that the death penalty deters murderers. To understand their argument, we will draw a picture. In fact, we've gone at this whole analysis rather backward; typically we should draw a picture first and ask precise statistical questions later! What plot should we draw?

We know that we want to compare murder rates of states with and without the death penalty. We know we should focus on the period around the two natural experiments of 1972 and 1976, and we want to understand the evolution of murder rates over time for those groups of states. It might be useful to look at other time periods, so let's plot them all for good measure.

Question 5.1. Create a table called average murder rates with 1 row for each year in murder rates. It should have 3 columns:

• Year, the year,

• Death penalty states, the average murder rate of the states that had the death penalty in 1971, and

• No death penalty states, the average murder rate of the other states. average murder rates should be sorted in increasing order by year.

Question 5.2. Describe in one short sentence a high-level takeaway from the line plot below. Are the murder rates in these two groups of states related? average murder rates.plot('Year').

Question 5.3. Complete their argument in 2-3 sentences; what features of these plots indicate that the death penalty is not an important factor in determining the murder rate? (If you're stuck, read the paper.)

Question 5.5. What assumption(s) did we make in Parts 1 through 4 of the project that led us to believe that the death penalty deterred murder, when in fact the line plots tell a different story?