Hypothesis Testing With Python

True Difference or Noise?

169.61

169.88

Which is better?

Noise?

That's a question.

Mosky

- Python Charmer at Pinkoi.
- Has spoken at: PyCons in TW, MY, KR, JP, SG, HK, COSCUPs, and TEDx, etc.
- Countless hours on teaching Python.
- Own the Python packages: ZIPCodeTW, MoSQL, Clime, etc.
- http://mosky.tw/

Outline

1. Tests with datasets
2. How tests work
3. Common tests
4. Complete a test

The Packages

- `$ pip3 install jupyter numpy scipy sympy matplotlib ipython pandas seaborn statsmodels scikit-learn`
- Or:
- `> conda install jupyter numpy scipy sympy matplotlib ipython pandas seaborn statsmodels scikit-learn`
- Or:
- `$ curl -fLo Pipfile.lock https://raw.githubusercontent.com/moskytw/data-science-with-python/master/Pipfile.lock`
- `$ pipenv sync`

Tests with datasets

To buy, or not to buy

- Going to buy a bulb on an online store.
- If see *10/100* bad reviews? Hmm ...
- If see *5/100* bad reviews? Good to buy.
- If see *1/100* bad reviews? Good to buy.

To buy, or not to buy (cont.)

- Going to buy a notebook computer on an online store.
- If see *10/100* bad reviews? Hmm ...
- If see *5/100* bad reviews? Hmm ...
- If see *1/100* bad reviews? Maybe good enough.

Build our "bad reviews" in statistics

- Build a statistical model.
  - "The means of two populations are equal."
- Put the data into the model, get a probability, *p-value*.
  - "How compatible the data and the model are."
    - If see *p-value* = *0.10*?
    - If see *p-value* = *0.05*?
    - If see *p-value* = *0.01*?
    - Depends on your research question.
- It is just the "Hypothesis Testing".

Null, alternative, and p-value

- **Null hypothesis**: can build a model directly:
  - "The means of two populations are equal."
  - ≡ "The expected value of difference is zero."
  - E.g., GMV didn't change.
- **Alternative hypothesis**: can build a model by negating it.
  - "The means of two populations are different."
  - ≡ Not "The expected value of difference is zero."
  - E.g., GMV changed.
- **P-value**: how compatible data and **a null hypothesis** are.

Misunderstandings of p-values

- "Buy or not" is a decision based on the study context.
  - In other words, "accept" or "reject" a hypothesis.
  - Not "prove a hypothesis is true or false."
- Misunderstandings of p-values – Wikipedia

Suggested formatting

p-value & α	Wording	Summary
p-value < 0.001	Very significant	***
p-value < 0.01	Very significant	**
p-value < 0.05	Significant	*
p-value ≥ 0.05	Not significant	ns

- Many researchers also suggest to report **without** formatting.
  - Since the largely misunderstandings, e.g.,
    - *p-value* < 0.05 ≡ the hypothesis is false **(wrong)**
- Scientists rise up against statistical significance – Natural
  - "We are not calling for a ban on P values. Nor are we saying they cannot be used as a decision criterion in certain specialized applications."
  - "We are calling for a stop to the use of P values in the conventional, dichotomous way — to decide whether a result refutes or supports a scientific hypothesis."

Go with the notebooks

- The notebooks are available on https://github.com/moskytw/hypothesis-testing-with-python.
- *01_tests_with_simulated_datasets.ipynb* [skip]
- *02_tests_with_actual_datasets.ipynb*

How tests work

Seeing is believing

- *p-value* $= 0.0027$ (< 0.01)
  - 👏👏👏
- *p-value* $= 0.0271$ $(0.01–0.05)$
  - 👏❓👏❓❓❓
- *p-value* $= 0.2718$ (≥ 0.05)
  - ❓❓❓❓❓❓
- *03_how_tests_work.ipynb*

Common tests

The cheat sheet

- If testing homogeneity:
  - If total sample size < 1000, or
    more than 20% of cells have expected frequencies < 5, Fisher's exact test.
  - Else, **chi-squared test**, or **two-proportion z-test** ($\equiv 2\times2$ chi-squared test).
- If testing equality:
  - If median is better, don't want to trim outliers,
    variable is ordinal, or any group size ≤ 20:
    - If groups are paired, Wilcoxon signed-rank test.
    - If groups are independent, **Mann–Whitney U test**.
  - Else:
    - If groups are paired, Paired Student's t-test.
    - If groups are independent, **Welch's t-test**, not Student's.

- More cheat sheets:
  - Common statistical tests are linear models – Lindeloev
  - Selecting Commonly Used Statistical Tests – Bates College
  - Which statistical test should I use? – University of Sheffield
  - Choosing a statistical test – HBS
- References:
  - Fisher's exact test of independence – HBS
  - Statistical notes for clinical researchers – Restor Dent Endod
  - Chi-squared test of proportions is identical to z-test squared – Rinterested
  - Nonparametric Test and Parametric Test – Minitab
  - Advantages and limitations – Welch's t-test – Wikipedia
  - Dependent t-test for paired samples – Student's t-test – Wikipedia

Complete a test

The elements of a complete test

1. The null hypothesis, data, p-value, α.
2. The raw effect size, β, sample size.
3. The false negative rate, inverse α, inverse β.

➤ Will introduce them by the confusion matrix.

Confusion matrix, where $A = OO_2 = C[0, 0]$

	predicted negative AC	predicted positive BD
actual negative **AB**	true negative A	false positive B
actual positive **CD**	false negative C	true positive D

False positive rate = P(BD|AB) = B/AB = 4/(96+4) = 4/100

	predicted negative AC	predicted positive BD
actual negative AB	96 A	4 B
actual positive CD	9 C	41 D

How similar! Let's try to rename:

null hypothesis is ture	actual negative
alternative hypothesis is true	actual positive
accept null hypothesis	predict negative
accept alternative hypothesis	predict positive

$\alpha = P(\text{accept alt}|\text{null}) = P(\text{predicted positive}|\text{actual negative})$

	predicted negative AC	predicted positive BD
actual negative **AB**	true negative A	false positive B
actual positive **CD**	false negative C	true positive D

Predefined acceptable confusion matrix

	predicted negative AC	predicted positive BD
actual negative AB	true negative A	false positive B
actual positive CD	false negative C	true positive D

False positive, p-value, and α

false positive rate	Calculated with the actual answer.
p-value	Calculated false positive rate by a null hypothesis.
α	Predefined acceptable false positive rate.

Raw effect size, and β

- DSM5: The case for double standards – James Coplan, M.D.
  - The figures explain *raw effect size*, *a*, and *β* and perfectly, but due to the copyright, only put the link here.
  - "FP": *a*
  - "The distance between the means": *raw effect size*
  - "FN": *β*

$\beta = P(AC|CD) = C/CD$

	predicted negative AC	predicted positive BD
actual negative AB	true negative A	false positive B
actual positive CD	false negative C	true positive D

- Given α, β, raw effect size, get the sample size.
- Given α, raw effect size, sample size, get the β.
- Increase sample size to decrease α, β, or raw effect size.

Given α, raw effect size, sample size, get the β

- "The conversion rates are the same."
- $a = 0.05$
- *raw effect size* $= 4\% - 3\% = 1\%$
- With two-proportion z-test, given:
  - *sample size* $= 1{,}000$, get $\beta = 0.86$
  - *sample size* $= 10{,}000$, get $\beta = 0.22$
  - *sample size* $= 17{,}550$, get $\beta = 0.05$

Inverse α = P(AB|BD) = B/BD

	predicted negative AC	predicted positive BD
actual negative AB	true negative A	false positive B
actual positive CD	false negative C	true positive D

Inverse β = P(CD|AC) = C/AC

	predicted negative AC	predicted positive BD
actual negative AB	true negative A	false positive B
actual positive CD	false negative C	true positive D

Actaul Negative Rate \ α, β = 0.20	0.10	0.09	0.08	0.07	0.06	0.05	0.04	0.03	0.02	0.01
1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
0.95	0.70	0.68	0.66	0.62	0.59	0.54	0.49	0.42	0.32	0.19
0.90	0.53	0.50	0.47	0.44	0.40	0.36	0.31	0.25	0.18	0.10
0.85	0.41	0.39	0.36	0.33	0.30	0.26	0.22	0.18	0.12	0.07
0.80	0.33	0.31	0.29	0.26	0.23	0.20	0.17	0.13	0.09	0.05
0.75	0.27	0.25	0.23	0.21	0.18	0.16	0.13	0.10	0.07	0.04
0.70	0.23	0.21	0.19	0.17	0.15	0.13	0.10	0.08	0.06	0.03
0.65	0.19	0.17	0.16	0.14	0.12	0.10	0.08	0.07	0.04	0.02
0.60	0.16	0.14	0.13	0.12	0.10	0.09	0.07	0.05	0.04	0.02
0.55	0.13	0.12	0.11	0.10	0.08	0.07	0.06	0.04	0.03	0.02
0.50	0.11	0.10	0.09	0.08	0.07	0.06	0.05	0.04	0.02	0.01

Actaul Negative Rate \ $\alpha = 0.05, \beta$	0.20	0.18	0.16	0.14	0.12	0.10	0.08	0.06	0.04	0.02
0.50	0.17	0.16	0.14	0.13	0.11	0.10	0.08	0.06	0.04	0.02
0.45	0.20	0.19	0.17	0.15	0.13	0.11	0.09	0.07	0.05	0.03
0.40	0.24	0.22	0.20	0.18	0.16	0.14	0.11	0.09	0.06	0.03
0.35	0.28	0.26	0.24	0.21	0.19	0.16	0.14	0.10	0.07	0.04
0.30	0.33	0.31	0.28	0.26	0.23	0.20	0.16	0.13	0.09	0.05
0.25	0.39	0.36	0.34	0.31	0.27	0.24	0.20	0.16	0.11	0.06
0.20	0.46	0.43	0.40	0.37	0.34	0.30	0.25	0.20	0.14	0.08
0.15	0.54	0.52	0.49	0.46	0.42	0.37	0.32	0.26	0.19	0.11
0.10	0.65	0.63	0.60	0.57	0.53	0.49	0.43	0.36	0.27	0.16
0.05	0.80	0.78	0.76	0.74	0.71	0.67	0.62	0.55	0.44	0.29
0.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Inverse β

1.0
0.8
0.6
0.4
0.2
0.0

Rates in predefined acceptable confusion matrix

	=	=	= predefined
α	B/AB	significance level type I error rate	false positive rate
β	C/CD	type II error rate	false negative rate
inverse α	B/BD		false discovery rate
inverse β	C/AC		false omission rate
confidence level	A/AB	1-α	specificity
power	D/CD	1-β	sensitivity recall

Rates in confusion matrix

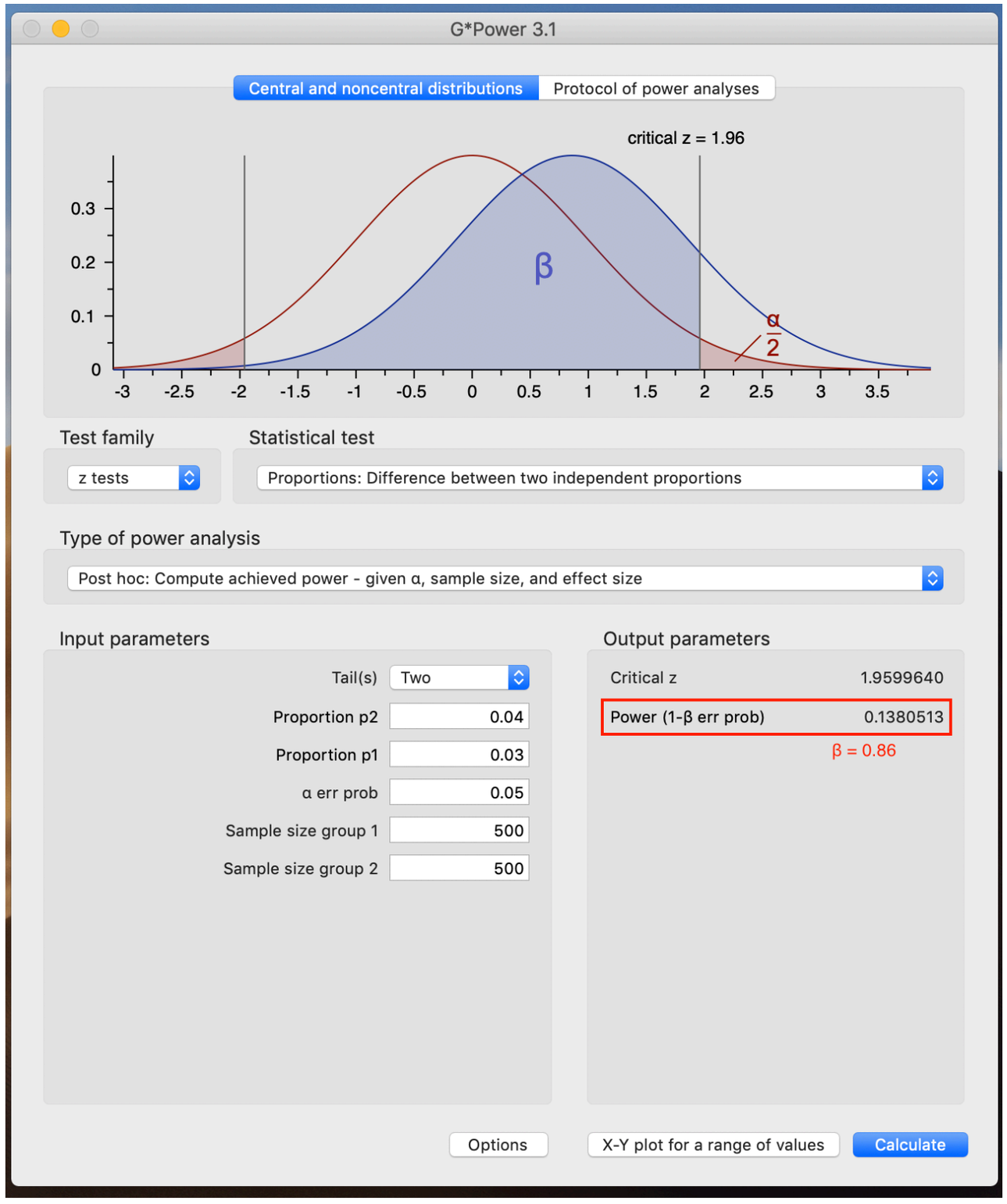
	=	=	= observed
false positive rate	B/AB		α
false negative rate	C/CD		β
false discovery rate	B/BD		inverse α
false omission rate	C/AC		inverse β
actual negative rate	AB/ABCD		
sensitivity	D/CD	recall	power
specificity	A/AB		confidence level
precision	D/BD		inverse power
recall	D/CD	sensitivity	power

Most formal steps

1. The hypothesis → what test.
2. The *actual negative rate* → how much a, β are required.
3. The a, β, *raw effect size* → how large *sample size* is required.
4. Still collect a sample as large as possible.
5. Understand and preprocess the sample.
   - ➤ Plotting, missing data, outliers, transform, etc.
6. Test.
7. Report fully.
   - ➤ The *mean*, *confidence interval*, *p-value*, study context, etc.

Calculate by yourself

- G*Power is awesome.
  - http://www.gpower.hhu.de/



Keep learning

1. Seeing Theory
2. Statistics – SciPy Tutorial
3. StatsModels
4. Biological Statistics
5. Research method
    - ➤ Study design, experimental design, survey design etc.

Recap

1. *p-value*:
    - ➤ How compatible data and a null hypothesis are.
    - ➤ The false positive rate by a null hypothesis.
2. β does matter.
3. *actual negative rate* does matter.
4. The study context does matter.
5. Visualization and simulation do help.
    - ➤ More: 04, 05, and a1 notebooks in handouts.
6. Let's accept or reject a hypothesis efficiently!