Lecture 1 Basic Concepts of Probability and Inference

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E6930 Applied Bayesian Statistics

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What Is the Course About?

- Introduce Bayesian inferential methods & develop hands-on skills for Python data science
- Why Bayesian paradigm? Handle sophisticated models & uncertainty in decision making
- Main references
  - required: Greenberg (2008), "*Introduction to Bayesian Econometrics*"
  - optional: Geweke (2005), "*Contemporary Bayesian Econometrics and Statistics*"
  - optional: Herbst & Schorfheide (2015), "*Bayesian Estimation of DSGE Models*"
- Homework production
  - LaTeX typesetting: www.overleaf.com
  - Python programming: www.anaconda.com

The Road Ahead...

- Frequentist v.s. Bayesian views of probability
- Prior, likelihood, and posterior
- Coin-tossing example

Frequentist v.s. Bayesian

Probability axioms

1. $0 \leq \mathbb{P}(A) \leq 1$ for any event A
2. $\mathbb{P}(A) = 1$ if event A represents logical truth
3. $\mathbb{P}(A \cup B) = \mathbb{P}(A) + \mathbb{P}(B)$ for disjoint events A and B
4. $\mathbb{P}(A|B) = \mathbb{P}(A \cap B)/\mathbb{P}(B)$ (conditional probability)

- Satisfied by any assignment of probabilities
  - frequentists assign probabilities to events describing outcome of *repeated* experiment
  - Bayesians assign 'subjective' probabilities to uncertain events [de Finetti's (1990) coherency principle]
- How likely it rains tomorrow?

Prior, Likelihood, and Posterior

Bayes theorem

$$\pi(\theta|y) = \frac{f(y|\theta)\pi(\theta)}{m(y)} \propto f(y|\theta)\pi(\theta)$$

- Learning of random vector $Y = [Y_1, \ldots, Y_n]'$
  - call their realizations $y = [y_1, \ldots, y_n]'$ *data*
  - parametric distribution $\mathbb{P}_\theta$ for Y
  - learning of unknown parameter θ
- Bayesian approach treats θ as being random
  - start with *prior* density $\pi(\theta)$
  - update by *likelihood* function $f(y|\theta)$
  - *posterior* density $\pi(\theta|y)$ proportional to prior $\times$ likelihood
  - *marginal likelihood* $m(y) = \int f(y|\theta)\pi(\theta)d\theta$

Coin-Tossing Example

- Likelihood function
  - one toss (Bernoulli): $\mathbb{P}_\theta(Y_i = 1) = \theta = 1 - \mathbb{P}_\theta(Y_i = 0)$

    $$f(y_i|\theta) = \theta^{y_i}(1-\theta)^{1-y_i}$$

  - n independent tosses

    $$f(y_1, \ldots, y_n|\theta) = \theta^{\sum y_i}(1-\theta)^{n-\sum y_i}$$

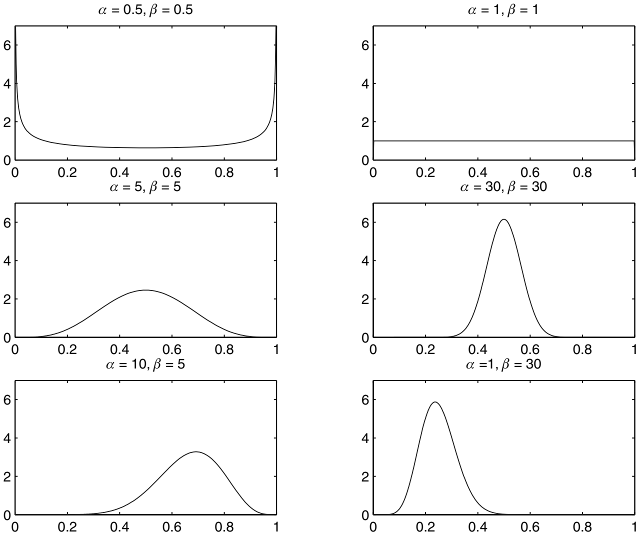
- (Conjugate) beta prior: $\theta \sim \mathbb{B}(\alpha, \beta)$

  $$\pi(\theta) = \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)}\theta^{\alpha-1}(1-\theta)^{\beta-1}, \quad 0 \leq \theta \leq 1, \quad \alpha, \beta > 0$$

- Beta posterior: $\theta|y \sim \mathbb{B}(\alpha + \sum y_i, \beta + n - \sum y_i)$

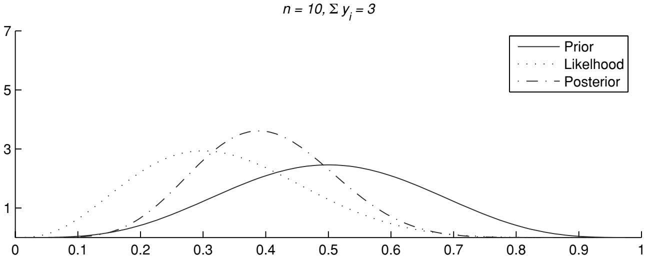
  $$\pi(\theta|y) \propto \theta^{\alpha+\sum y_i - 1}(1-\theta)^{\beta+n-\sum y_i - 1}$$

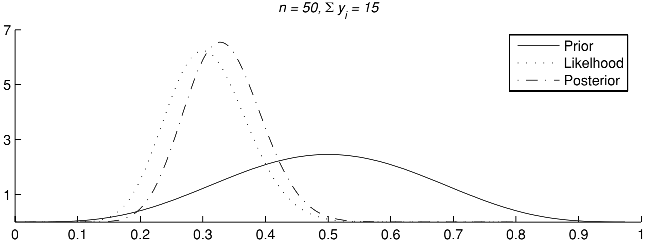
Hyperparameters



- Shape of beta: $\mathbb{E}(\theta) = \frac{\alpha}{\alpha+\beta}$, $\mathbb{V}(\theta) = \frac{\alpha\beta}{(\alpha+\beta)^2(\alpha+\beta+1)}$

Sample Size





- $\mathbb{E}(\theta|y) = \frac{\alpha+\beta}{\alpha+\beta+n}\mathbb{E}(\theta) + \frac{n}{\alpha+\beta+n}\bar{y} \rightarrow_{n\rightarrow\infty} \bar{y}$ (MLE)

References

- de Finetti (1990), “Theory of Probability,” John Wiley & Sons