Topic 2-1: Likelihood Construction & Estimation

Univariate Models

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Statistical Models

- A statistical model is a general functional relation between the unknown parameter(s) and the observed data.
- After a statistical model for the observed data has been formulated, the likelihood function of the data is the natural starting point for the inference in many statistical problems.
- The likelihood function typically leads to essentially automatic methods of inference, including point estimation, interval estimation, and hypothesis testing.
- In this topic, we will focus on constructing the likelihood functions from various types of data, including discrete, continuous, mixture of discrete and continuous, and censored data.

Statistical Models

- The likelihood is the joint density of the observed data to be analyzed.

Statistical Models

- The likelihood is the joint density of the observed data to be analyzed.
- Let the random variables $Y_1, \cdots, Y_n$ have a joint density function $f(\mathbf{Y} = (Y_1, \cdots, Y_n)^T; \boldsymbol{\theta})$ with unknown b density parameters $\boldsymbol{\theta} = (\theta_1, \cdots, \theta_b)$. Then, given observed data $\mathbf{Y} = \mathbf{y}$, where $\mathbf{y} \equiv (y_1, \cdots, y_n)^T$, the function of $\boldsymbol{\theta}$

$$L(\boldsymbol{\theta}; \mathbf{y}) = f(\mathbf{Y} = \mathbf{y}; \boldsymbol{\theta})$$

is the likelihood function.

Likeliihod for iid data

- If the random variables $Y_1, \cdots, Y_n$ are indenpendent, then the likelihood function becomes

$$L(\boldsymbol{\theta}; \mathbf{y}) = \prod_{i=1}^{n} f_i(Y_i = y_i; \boldsymbol{\theta}),$$

where $f_i(Y_i; \boldsymbol{\theta})$ is the density of Y_i.

- If the random variables $Y_1, \cdots, Y_n$ are indenpendent and indentically distributed (denoted by iid), then the likelihood function becomes

$$L(\boldsymbol{\theta}; \mathbf{y}) = \prod_{i=1}^{n} f(Y_i = y_i; \boldsymbol{\theta}),$$

where f is the distribution that all $Y_1, \cdots, Y_n$ follow.

Solving the Likelihood

- The value of $\boldsymbol{\theta}$ that maximizes the likelihood function $L(\boldsymbol{\theta}; \mathbf{y})$ is called the maximum likelihood estimator (MLE) denoted by $\hat{\boldsymbol{\theta}}_{MLE}$.
- In practice, $\hat{\boldsymbol{\theta}}_{MLE}$ is usually calculated by optimizing the log likelihood function $\log(L(\boldsymbol{\theta}; \mathbf{y}))$
- Note: $\hat{\boldsymbol{\theta}}_{MLE}$ is "optimal" under some regularity conditions (to be discussed in a future topic).

Solving the Likelihood-differentiable likelihoods

- Denote the log likelihood function $\log(L(\boldsymbol{\theta}; \mathbf{y}))$ by $\ell(\boldsymbol{\theta})$, and assume $\ell(\boldsymbol{\theta})$ is differentiable with respect to $\boldsymbol{\theta}$.
- The procedure for obtaining the MLE from $\ell(\boldsymbol{\theta})$ is
  1. Differentiate $\ell(\boldsymbol{\theta})$ with respect to $\boldsymbol{\theta}$ to obtain the likelihood score function $S(\boldsymbol{\theta}) = (\frac{\partial \ell(\boldsymbol{\theta})}{\partial \theta_1}, \cdots, \frac{\partial \ell(\boldsymbol{\theta})}{\partial \theta_b})^T$.
  2. Find possible MLE cadidates by solving the likelihood equations $S(\boldsymbol{\theta}) = \mathbf{0}_{b\times 1}$.
  3. Check if the solution from the last step is the global maximizer of $\ell(\boldsymbol{\theta})$. If it is, then the solution is the MLE of $\ell(\boldsymbol{\theta})$.

An R Example

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Remark

- A non-differentiable likelihood example can be found in Example 7.2.9 of Casella and Berger (2002).
- An example for checking if the solution of the score function equation with two unknown parameters is a global maximizer can be found in Example 7.2.12 of Casella and Berger (2002).

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Discrete IID Random Variables

Continuous IID Variables

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- References: More examples for constructing the product likelihood likelihood associated with iid data can be found in Section 7.2.2 of Casella and Berger (2002).

Multinomial

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- References: Examples for

Multivariate Normal

Mixture of discrete and continuous

Multinomial

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- References: Examples for

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Proportional Likelihood

Empirical Likelihood

Likelihood With Censored data

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A general working defintion of the likelihood

Empirical Likelihood

Likelihood With Censored data