Mathematical Statistics II

STA2212H S LEC9101

Week 4

January 28 2025

According to one survey, only 31 per cent of Canadians trust AI. This is a problem

OPINION CLIFTON VAN DER LINDEN

Associate professor and director of the Digital Society Lab at McMaster University. He is also the founder and chief executive officer of Vox Pop Labs.

Many Canadians are worried about artificial intelligence. While the sentiment is well-warranted in several ways, the technology is poised to be a cornerstone of the innovation economy in the coming years. In order for Canada to capitalize on the economic opportunities ahead, it will be essential to make AI worthy of public trust.

According to the Edelman Trust Barometer 2024 annual survey, only 31 per cent of Canadians trust AI – 19 points below the global average. (The sample includes 1,500 respondents from Canada. The margin of error for the Canadian data is plus or minus 3.3 to plus or minus 3.9 percentage points, 99 times out of 100.)

Among the concerns Canadians have about AI are fears of job displacement, mishandling of personal data and the reinforcement of unfair biases in areas such as hiring and policing. There is also apprehension about the technology being used to spread misinformation and undermine privacy.

The federal government has taken steps to promote the development

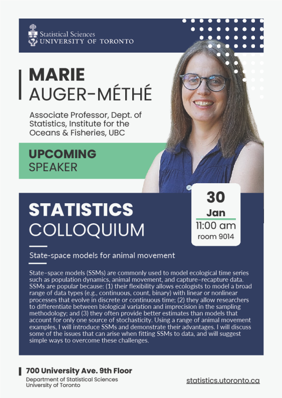
A woman takes a picture in Davos last week. According to the Edelman Trust Barometer 2024 survey, only 31 per cent of Canadians trust AI, 19 points below the global average.

Today

1. Recap Jan 21 significance functions, misspecified models
2. Bayesian inference and estimation MS Ch.5.8
3. Optimality in estimation MS §6.2 and 6.4
4. HW3, Statistics in the News

Upcoming seminar

Department Seminar Thursday January 30 11.00 – 12.00
Hydro Building, Room 9014
"State-space models for animal movement"
Marie Auger-Méthé, UBC

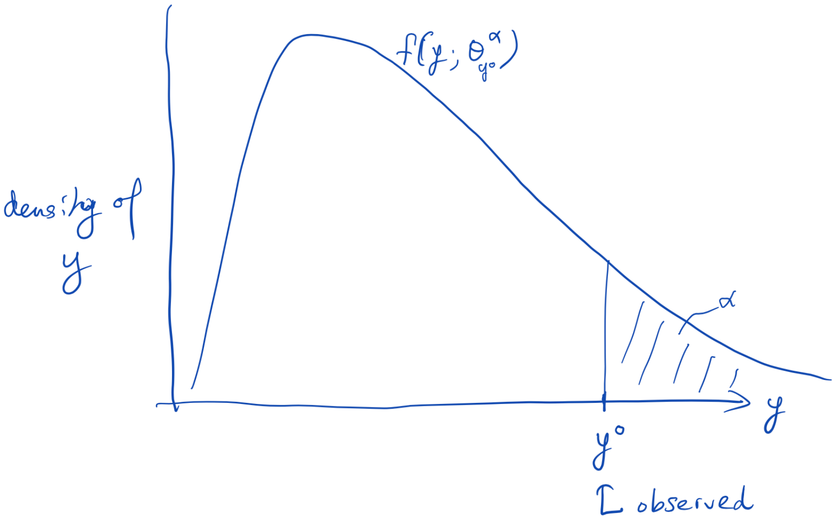


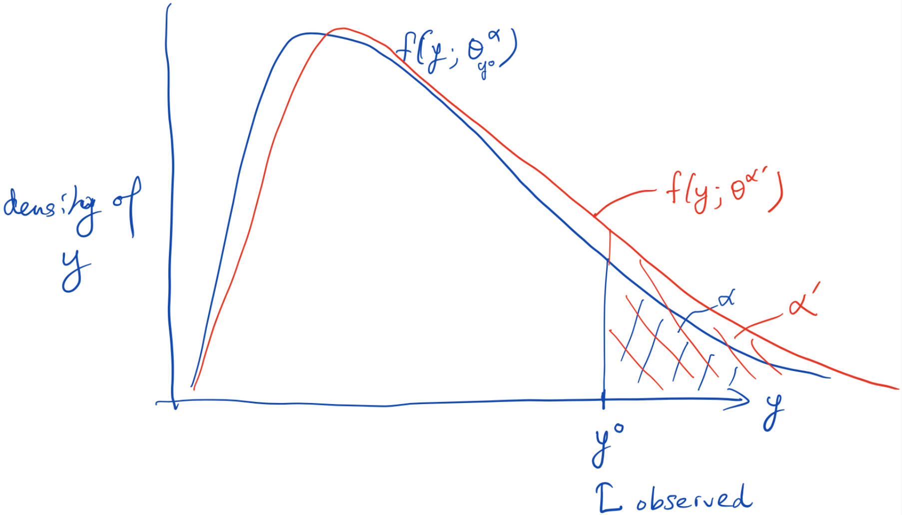
Recap significance functions

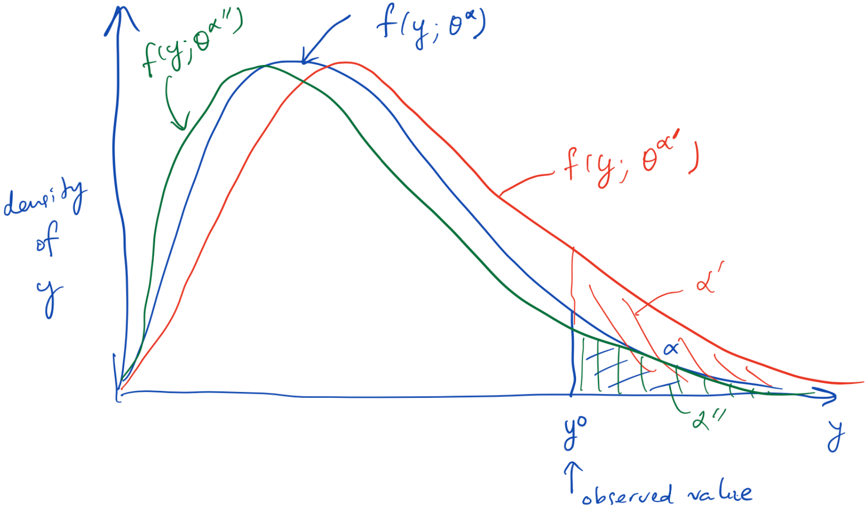
- approximate pivotal quantities q, r, s

- significance function $\Phi\{\quad\}, \Phi\{\quad\}, \Phi\{\quad\},$
- meaning?

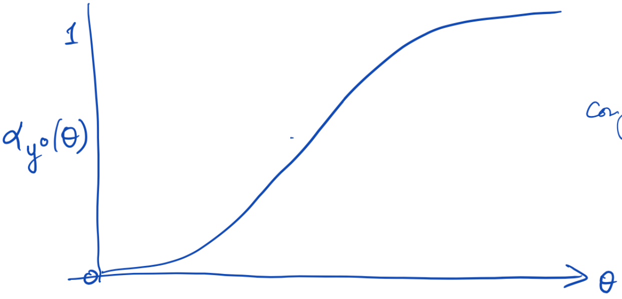
- exact pivotal quantity $n\bar{X}\theta \sim \Gamma(n, 1)$


$f(y;\theta^{\alpha}_{y^o})$
density of y
α
y
y^o
observed


density of y
$f(y; \theta^{\alpha}_{y^o})$
$f(y; \theta^{\alpha'})$
α
α'
y
y^o
observed



f(y; θ^α'')
f(y; θ^α)
f(y; θ^α')
density of y
α'
α
α''
y^o
y
observed value



confidence dist^n

$$\frac{d\alpha_{y^\circ}(\theta)}{d\theta}$$ confidence density

Example: the ANDROMEDA Trial

Hernandez et al., 2019

Research

JAMA | Original Investigation | CARING FOR THE CRITICALLY ILL PATIENT

Effect of a Resuscitation Strategy Targeting Peripheral Perfusion Status vs Serum Lactate Levels on 28-Day Mortality Among Patients With Septic Shock

The ANDROMEDA-SHOCK Randomized Clinical Trial

Glenn Hernández, MD, PhD; Gustavo A. Ospina-Tascón, MD, PhD; Lucas Petri Damiani, MSc; Elisa Estenssoro, MD; Arnaldo Dubin, MD, PhD; Javier Hurtado, MD; Gilberto Friedman, MD, PhD; Ricardo Castro, MD, MPH; Leyla Alegría, RN, MSc; Jean-Louis Teboul, MD, PhD; Maurizio Cecconi, MD, FFICM; Giorgio Ferri, MD; Manuel Jibaja, MD; Ronald Pairumani, MD; Paula Fernández, MD; Diego Barahona, MD; Vladimir Granda-Luna, MD, PhD; Alexandre Biasi Cavalcanti, MD, PhD; Jan Bakker, MD, PhD; for the ANDROMEDA-SHOCK Investigators and the Latin America Intensive Care Network (LIVEN)

Visual Abstract

Editorial page 647

Supplemental content

IMPORTANCE Abnormal peripheral perfusion after septic shock resuscitation has been associated with organ dysfunction and mortality. The potential role of the clinical assessment of peripheral perfusion as a target during resuscitation in early septic shock has not been established.

OBJECTIVE To determine if a peripheral perfusion–targeted resuscitation during early

Example: the ANDROMEDA Trial

Hernandez et al., 2019

	Died	Lived	
New	74	138	212
Old	92	120	212
Total	166	258	424

2-sided p-value = 0.07

likelihood ratio test

no adjustment for covariates

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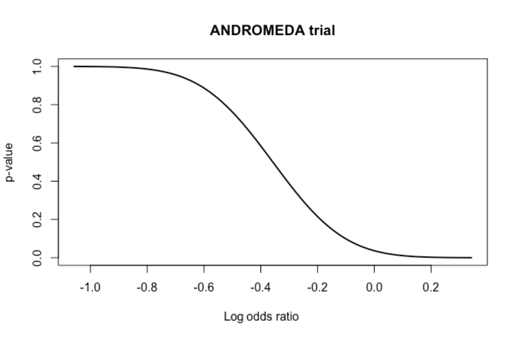

A p-value function

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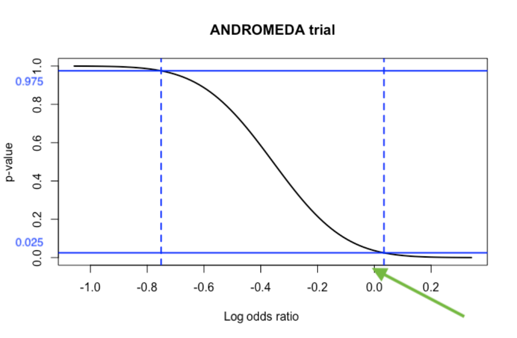

90% confidence interval: [−0.688, −0.030]
95% confidence interval: [−0.751, 0.034]
99% confidence interval: [−0.825, 0.107]

- model assumption $X_1, \dots, X_n$ i.i.d. $f(x;\theta), \theta \in \Theta$
- true distribution $X_1, \dots, X_n$ i.i.d. $F(x)$ notation
- maximum likelihood estimator based on model: $\ell(\theta; x_i) = \log f(x_i;\theta)$ (1 obs)

$$\ell'(\theta; \boldsymbol{X}) = \sum_{i=1}^{n} \ell'(\hat{\theta}_n; X_i) = 0$$

- define the parameter $\theta(F)$ by $\int_{-\infty}^{\infty} \ell'\{\theta(F); x\} dF(x) = 0$

$$\sqrt{n}\{\hat{\boldsymbol{\theta}}_n - \boldsymbol{\theta}(F)\} \xrightarrow{d} N_p\{\mathbf{0}, G^{-1}(F)\}$$

- sandwich variance estimate estimate of G^{-1}/n

$$\text{a. var}\,(\hat{\theta}_n) \doteq \{\hat{J}(\hat{\boldsymbol{\theta}}_n)\}^{-1} \hat{I}(\hat{\boldsymbol{\theta}}_n) \{\hat{J}(\hat{\boldsymbol{\theta}}_n)\}^{-1}$$

- Godambe information one observation

$$G(F) = J(F) I^{-1}(F) J(F),$$

- MS defines I, J for one observation; see Thm 5.5, and last para. before §5.6

Bayesian estimation

model $\quad f(x;\theta), \quad \theta \in \Theta; x \in \mathcal{X}$

prior $\quad \pi(\theta)$ density $\pi : \Theta \longrightarrow (0, \infty)$

posterior $\quad \pi(\theta \mid x) \propto f(x;\theta)\pi(\theta)$

sample $\quad x_1, \ldots, x_n$

$$\pi(\theta \mid \boldsymbol{x}) \propto f(\boldsymbol{x};\theta)\pi(\theta) = L(\theta;\boldsymbol{x})\pi(\theta)$$

Frequentist and Bayesian contrast

Frequentist:

- There is a fixed parameter (unknown) we are trying to learn
- Our methods are evaluated using probabilities based on $f(\boldsymbol{x}; \theta)$

Bayesian:

- The parameter can be treated as a random variable
- We model its distribution $\pi(\theta)$
- Combine this with a model $f(\boldsymbol{x} \mid \theta)$
- Update prior belief on the basis of the data

Example: censored exponential

$X_1, \ldots, X_n$ i.i.d. Exponential (λ) $\qquad$ $\pi(\lambda) \sim \text{Exp}(\alpha)$

censored at r smallest x; let $Y_i = X_{(i)}, i = 1, \ldots, r$

$$f(\boldsymbol{y} \mid \lambda) = \prod_{i=1}^{r} \lambda^r \exp(-\lambda y_i) \prod_{i=r+1}^{n} \exp(-\lambda y_r) = \lambda^r \exp[-\lambda\{\Sigma_{i=1}^r y_i + (n-r)y_r\}]$$

$$f(\boldsymbol{y} \mid \lambda) = \prod_{i=1}^{r} \lambda^{r} \exp(-\lambda y_i) \prod_{i=r+1}^{n} \exp(-\lambda y_r) = \lambda^{r} \exp[-\lambda\{\Sigma_{i=1}^{r} y_i + (n-r) y_r\}], \quad \pi(\lambda) = \alpha \exp(-\alpha\lambda)$$

$$\pi(\lambda \mid \boldsymbol{y})$$

posterior mean and and mode

$$f(x;\theta) = \exp\{c(\theta)S(x) - d(\theta) + h(x)\}; \qquad \pi(\theta;\alpha,\beta) = K(\alpha,\beta)\exp\{\alpha c(\theta) - \beta d(\theta)\}$$

Exponential families and conjugate priors

$$f(x;\theta) = \exp\{c(\theta)S(x) - d(\theta) + h(x)\}; \qquad \pi(\theta;\alpha,\beta) = K(\alpha,\beta)\exp\{\alpha c(\theta) - \beta d(\theta)\}$$

Choosing priors

MS p.287 ff

- conjugate priors
- non-informative priors — flat, “ignorance”
- convenience priors
- minimally/weakly informative priors
- hierarchical priors

Flat priors

- if parameter space is closed (interval), e.g. $\Theta = [a, b]$, then $\pi(\theta) \sim U(a, b)$ represents 'indifference'

- example: Beta (1,1) prior for Bernoulli probability

- example 5.34: $X \sim N(\mu, 1), \pi(\mu) \propto 1$

Flat priors

- if parameter space is closed (interval), e.g. $\Theta = [a, b]$, then $\pi(\theta) \sim U(a, b)$ represents 'indifference'
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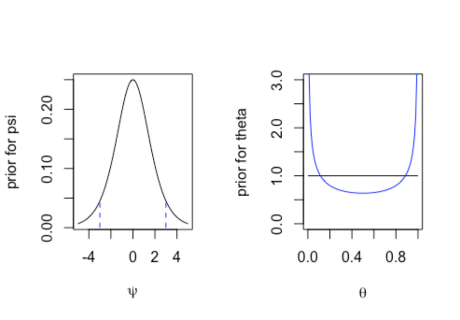
- example 5.34: $X \sim N(\mu, 1), \pi(\mu) \propto 1$
- improper priors can lead to proper posteriors ntbc
- priors flat in one parameterization are not flat in another

... Flat priors

- Example: $X \sim Bin(n, \theta), 0 < \theta < 1; \theta \sim U(0, 1)$
- log-odds ratio $\psi = \psi(\theta) = \log\{\theta/(1-\theta)\}$
- $\pi(\psi) = \dfrac{e^{\psi}}{(1+e^{\psi})^2}, -\infty < \psi < \infty$
- prior probability $-3 < \psi < 3 \approx 0.9$
- an invariant prior: $\pi(\theta) \propto I^{1/2}(\theta)$



Jeffreys' prior

- $\pi(\theta) \propto I^{1/2}(\theta)$
- Example: $X \sim Bin(n, \theta)$ $\quad I(\theta) = n/\{\theta(1-\theta)\}, \quad 0 < \theta < 1$
- Example 5.35: $X \sim Poisson(\lambda)$, $\quad I(\lambda) = 1/\lambda, \quad \lambda > 0$ posterior proper?
- Jeffreys' prior for multiparameter $\boldsymbol{\theta}$: $\pi(\boldsymbol{\theta}) \propto |I(\boldsymbol{\theta})|^{1/2}$ not recommended even by Jeffreys
- Example: $X_1, \dots, X_n$ i.i.d. $N(\mu, \sigma^2)$ $\quad I(\mu, \sigma^2) =$

ANDROMEDA, revisited

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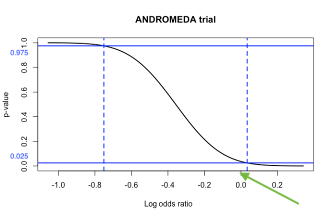

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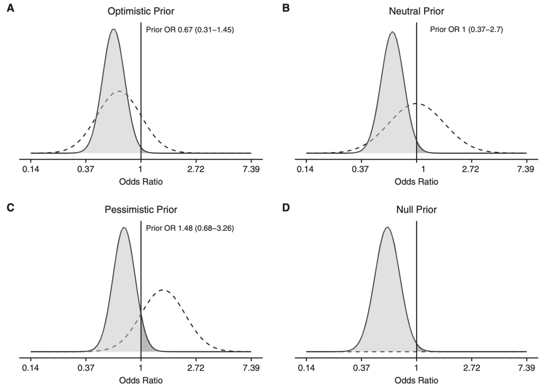
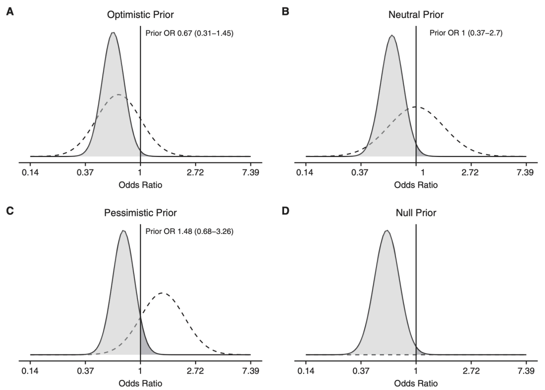


Figure 1. *(A–D)* Prior distributions for the odds ratio (OR) of the intervention (dashed lines). Posterior distributions of the ORs are shown by the solid lin The light gray areas indicate the areas associated with benefit for peripheral perfusion–targeted resuscitation (i.e., OR < 1) and the dark gray areas areas associated with harm (i.e., OR > 1). The text inside each frame reports the median and lower and upper 95% credible limits for the priors of the eff of the intervention for 28-day mortality.

a range of normal priors for the log-odds ratio

- the posterior probability that the odds-ratio is less than 1 — treatment is beneficial
- ranges from 0.94 to 0.99 — most pessimistic to most optimistic prior



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Zampieri et al 2020

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- 28-day mortality, Cox proportional hazards model
- adjustment for 5 baseline covariates
- estimated hazard ratio 0.75 (0.55, 1.02)

- Bayesian re-analysis based on logistic regression
- focus on posterior probability $\beta < 0$

log odds ratio

- equivalently P(hazard ratio $< 1 \mid$ data)

- added random effect for center, used default priors for covariates, change to logistic regression

ANDROMEDA, revisited

Zampieri et al 2020

Table 1. Odds Ratio, 95% Credible Interval, Probability That the Odds Ratio Is below Given Thresholds, and Absolute Difference between Groups

	28-d Outcome			**90-d Outcome**			
Prior	**OR (95% Credible Interval)**	**Probability OR < 1 (Probability OR < 0.8)**	**Absolute Difference (95% Credible Interval)***	**OR (95% Credible Interval)**	**Probability OR < 1 (Probability OR < 0.8)**	**Absolute Difference (95% Credible Interval)***	**Reason for Prior Use**
Optimistic	0.61 (0.41 to 0.90)	99% (92%)	−9% (−17% to −1%)	0.69 (0.47 to 1.01)	97% (79%)	−7% (−16% to 2%)	Considers an OR of 0.67 for the intervention (slightly more conservative than the effect size ANDROMEDA-SHOCK was powered to detect), while considering that there is still a 15% probability that the intervention was harmful
Neutral	0.65 (0.43 to 0.96)	98% (85%)	−7% (−16% to 1%)	0.74 (0.50 to 1.08)	94% (66%)	−5% (−14% to 4%)	Has a mean OR of 1 (i.e., absence of effect) and 50% probability of benefit and 50% of harm from the intervention
Pessimistic	0.74 (0.50 to 1.09)	94% (66%)	−5% (−13% to 3%)	0.83 (0.57 to 1.21)	83% (42%)	−3% (−11% to 6%)	Opposite values of the optimistic prior; considers a very pessimistic scenario in which the intervention is harmful but still acknowledges a 15% chance that the intervention might be beneficial
Null	0.59 (0.38 to 0.92)	98% (91%)	−8% (−17% to 1%)	0.69 (0.45 to 1.07)	95% (74%)	−6% (−15% to 4%)	No prior information is considered

Definition of abbreviation: OR = odds ratio.
*Refers to a simple model adjusted only for study arm and not for all predictors.

Marginalization

- Bayes posterior carries all the information about θ, given $\boldsymbol{x}$ by definition
- probabilities for any set A computed using the posterior distribution
- $\mathrm{pr}(\boldsymbol{\Theta} \in A \mid \boldsymbol{x}) =$
- if $\boldsymbol{\theta} = (\psi, \boldsymbol{\lambda})$, ...
- or, if $\psi = \psi(\boldsymbol{\theta})$
- in this context, 'flat' priors can have a large influence on the marginal posterior

Example: many normal means

Stein, 1959

- recall, in regular models,

$I(\theta)$ definition

$$\sqrt{n}(\hat{\theta} - \theta) \xrightarrow{d} N\{0, I^{-1}(\theta)\}$$

- smaller variance means more precise estimation
- Is $I^{-1}(\theta)$ small?

Optimality of estimators

- recall, in regular models,

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- smaller variance means more precise estimation
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- Yes, there's a sense in which it is "as small as possible"

- Step 1: suppose $\boldsymbol{X} = X_1, \ldots, X_n$ is an i.i.d. sample from a density $f(x;\theta)$
- Let $U = U(\boldsymbol{X}) = \ell'(\theta; \boldsymbol{X})$ score function
- Let $S = S(\boldsymbol{X})$ be an unbiased estimator of $g(\theta)$ $\mathrm{E}_\theta\{S(\boldsymbol{X})\} = g(\theta)$
- then $\mathrm{var}_\theta(S) \geq \{\mathrm{Cov}_\theta(S, U)\}^2/\mathrm{Var}_\theta(U)$ proof: Cauchy-Schwarz

- Cauchy-Schwartz inequality: for random variables Z_1, Z_2, with $\mathrm{E}(Z_1^2) < \infty, \mathrm{E}(Z_2^2) < \infty$,

$$\{\mathrm{Cov}(Z_1, Z_2)\}^2 \leq \mathrm{var}(Z_1)\mathrm{var}(Z_2)$$

- take $Z_1 = S(\boldsymbol{X})$, an unbiased estimator of $g(\theta)$
- take $Z_2 = U(\boldsymbol{X}) = \Sigma\ell'(\theta; X_i)$ score function
- then

$$\{\mathrm{Cov}_\theta(S, U)\}^2 \leq \mathrm{var}_\theta(S)\mathrm{var}_\theta(U)$$

- $$\mathrm{var}_\theta(S) \geq \frac{\mathrm{Cov}_\theta^2(S, U)}{I_n(\theta)}$$

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- when would we get equality?
- special case, $g(\theta) = \theta$

Example: Poisson

Unbiased estimator of λ^2: $S_1(\boldsymbol{X}) = (1/n)\Sigma X_i(X_i - 1)$ ntbc

Maximum likelihood estimator of λ^2: $S_2(\boldsymbol{X}) = \{(1/n)\Sigma X_i\}^2$

$$\begin{aligned} \mathrm{var}(S_1) &= \frac{4\lambda^3}{n} + \frac{2\lambda^2}{n} \\ \mathrm{var}(S_2) &= \frac{4\lambda^3}{n} + \frac{5\lambda^2}{n^2} + \frac{\lambda}{n^3} \end{aligned}$$

Cramer-Rao lower bound: $\{g'(\lambda)\}^2/nI(\lambda) = (2\lambda)^2/(n/\lambda) = 4\lambda^3/n$

Note: CRLB cannot be attained even by an unbiased estimator

What about maximum likelihood estimator?

- Suppose $\tilde{\theta}_n$ is a sequence of estimators with

$$\sqrt{n}(\tilde{\theta}_n - \theta) \xrightarrow{d} N\{0, \sigma^2(\theta)\}$$

- Is $\sigma^2(\theta) \geq 1/I(\theta)$?
- Yes, if $\tilde{\theta}_n$ is "regular", and $\sigma^2(\theta)$ continuous in θ

see MS §6.4, and Thm. 6.6

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- there are other regular estimators that are also asymptotically fully efficient
- and might be better in finite samples

- comparison of two consistent estimators — via limiting distributions
- $\sqrt{n}(T_{1n} - \theta) \xrightarrow{d} N\{0, \sigma_1^2(\theta)\}, \quad \sqrt{n}(T_{2n} - \theta) \xrightarrow{d} N\{0, \sigma_2^2(\theta)\}$
- asymptotic relative efficiency of T_1, relative to T_2 is $\dfrac{\sigma_2^2(\theta)}{\sigma_1^2(\theta)}$

- comparison of two consistent estimators — via limiting distributions

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- asymptotic relative efficiency of T_1, relative to T_2 is $\dfrac{\sigma_2^2(\theta)}{\sigma_1^2(\theta)}$

- if T_{2n} is the MLE $\hat{\theta}_n$, then $\sigma_2^2(\theta) = I^{-1}(\theta)$ — as small as possible

- the MLE is fully efficient

- the asymptotic efficiency of T_1 is $1/\sigma_1^2(\theta)I(\theta)$ — relative to the MLE implicit

CBC funding plan on ice with halt of Parliament

+4 more MARIE WOOLF

Observers say chances of a new mandate being approved before the next election are slim

Ottawa's plans to sustain funding for the CBC, and update its mandate, have been derailed by the prorogation of Parliament, with the future of the public broadcaster unlikely to be resolved until after the coming election.

The federal Conservatives have pledged to strip CBC of public funding, while preserving French services, if they form the next government.

Legislation on the CBC had yet to be presented to Parliament when it was suddenly prorogued earlier this month after Justin Trudeau announced he was resigning as Prime Minister.

Heritage Minister Pascale StOnge has argued that the public broadcaster is crucial to preserve, including as an antidote to misinformation and disinformation online.

But observers say the chances of Parliament approving a new mandate before the next election are slim, even if the government presents it to MPs on the day they return in March.

Opposition parties have threatened a non-confidence vote in the government soon after Parliament returns, which could lead to the dissolution of Parliament shortly

thereafter.

Ms. St-Onge, in a CBC interview earlier this month, called on the

A survey conducted last year found 78 per cent of Canadians said they would like to see CBC/Radio-Canada continue if it addresses its major criticisms.

- "… a survey of 2,055 adults from Aug.28, to Sept. 6, 2024, using a commercial survey panel provider. Seventy-eight per cent of Canadians said they would like to see the CBC/Radio-Canada continue if it addresses major criticisms"
- "the margin of error for a comparable probability-based sample of the same size is plus or minus 2.16 percentage points, 19 times out of 20"

Statistics in the News

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