Statistical Methods for Replicability Assessment

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March 31, 2022

Roles of Reproducibility in Scientific Research

- A necessary characteristic of correctness and rigor for scientific discoveries
- Irreproducible findings can erode public trust in science and cause damages to society
- Growing awareness in public since 2010s (”Replication crisis” Wikipedia)

Challenges

- Confusions in different modes of reproducibility
- Lack of consensus on specifying "replication successes"
- Lack of rigorous statistical method for replicability assessment

Different modes of reproducibility

By emphasizing the interplays between data and methods:

- Methods Reproducibility: consistency between results generated from same data, same method
- Inferential Reproducibility: consistency under same data, different methods
- **Results Reproducibility** or **Replicability**: consistency under different data, same method

Inference Principles

- Concern **variation of underlying true effects** in different experiments:
  - Define an acceptable extent of variability
- Role of experimental random noise:
  - **Non-informative principle**: extremely noisy observations contain little information for assessment

Existing Approach

- Defining replication success based on repeated statistically significant findings
  - Utilize the compound quantity: signal-to-noise ratio (i.e., p-values)
  - Violates non-informative principle

Define Replication Success

DC Criterion

With a high probability, the underlying effects of replicable signals are expected to have the same (positive or negative) sign.

- Emphasize on true underlying effect
- Range of acceptable heterogeneity
- Establishing a baseline for assessing extent of heterogeneity

Application Scenarios

- Two-group scenario:
  - Original study and replication follows a chronological order
  - E.g., Reproducibility Project Psychology (RPP), a systematic replication attempt for findings in psychology
- Exchangeable group scenario:
  - A group of multiple experiments is gathered
  - E.g., systematic review

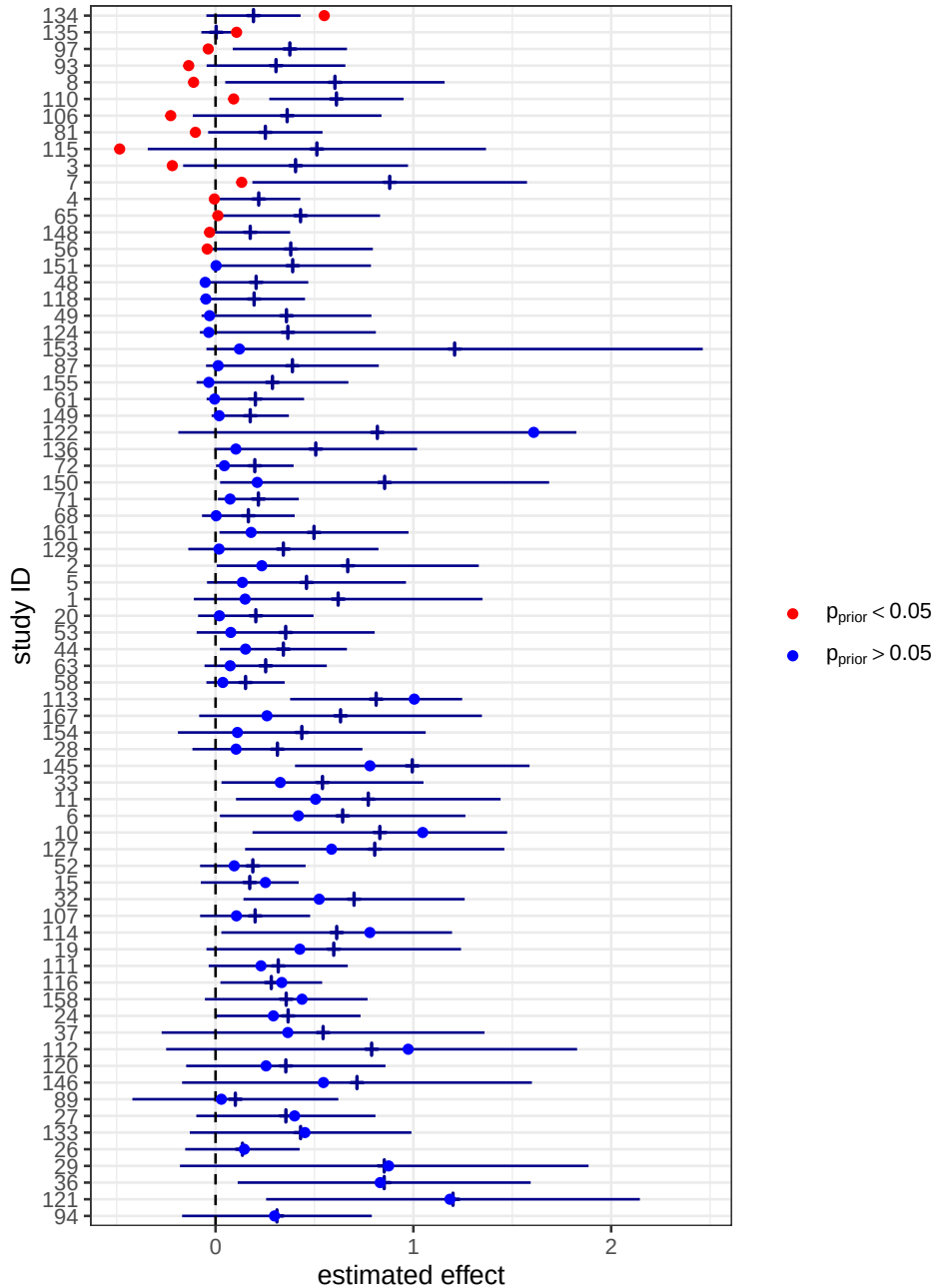
Model Criticism Strategy

- Define a family of reference models for characteristics of replicable results (i.e. high DC probability)
- Fit the replicable model with the observed data
- Evaluate the goodness-of-fit via Bayesian predictive checking procedures
  - Prior/Posterior-predictive replication p-value
  - $(1-\alpha)\%$ predictive interval
- Poor-fitting indicates rejection of "the observed data are likely replicable"

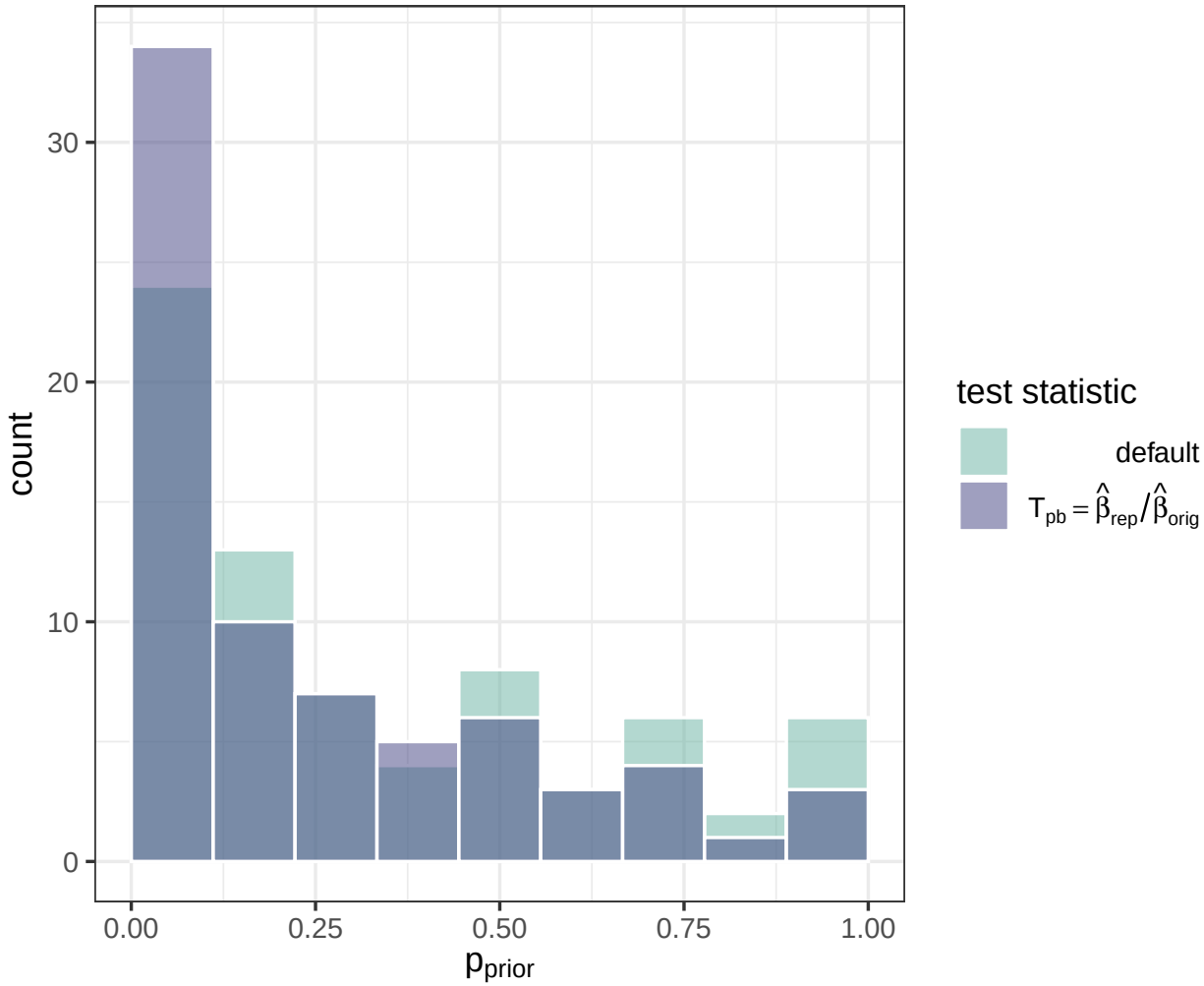
Application: Re-analysis of RPP

- Reproducibility Project: Psychology
- Goal: attempt to replicate 100 psychology studies published in three top psychology journals during 2008
- Findings reported: more than half of the scientific results are not reproducible because $pval_{orig} < 0.05$ and $pval_{rep} > 0.05$.

Re-analysis of RPP



RE-ANALYSIS OF RPP



- Manuscript: Zhao, Y. and Wen, X. Statistical Assessment of Replicability via Bayesian Model Criticism. arXiv:2105.03993

- R CRAN package is available: https://CRAN.R-project.org/package=PRP