

# Bayesian Beta Regression with Bayesianbetareg R-package

Edilberto Cepeda-Cuervo, Daniel Jaime, Margarita Marín Jaramillo, Javier Rojas

Universidad Nacional de Colombia, Departamento de Estadística

## Introduction

Cepeda-Cuervo (2001) propose the beta regression model and a Bayesian method to fit the proposed model, where samples of the posterior distribution are obtained from the posterior conditional distributions of the regression parameters, assuming normal prior distributions for them (Cepeda and Gutierrez, 2002).

The conditional posterior distributions are analytically intractable. Then, two normal transition kernel are built in order to apply a Metropolis-Hastings algorithm to obtain posterior samples.

We develop the Bayesianbetareg R-package for the estimation of the beta regression model when mean and precision are modeled (Cepeda-Cuervo et al., 2015), and the extension to mean and variance (in progress).

## Beta Regression

The probability density function for a beta variable is

$$f(x|\mu, \sigma) = \frac{\Gamma(\mu + \sigma)}{\Gamma(\mu)\Gamma(\sigma)} x^{\mu-1} (1-x)^{\sigma-1} \mathbb{I}_{(0,1)}(x), \quad (1)$$

With the re-parameterization of the beta distribution as a function of the mean,  $\mu = E(Y) = \frac{p}{p+q}$  and the precision  $\sigma = p+q$  parameters, (Jorgensen, 1987; Cepeda-Cuervo, 1991), the beta density function can be written as

$$f(x|\mu, \sigma) = \frac{\Gamma(\sigma)}{\Gamma(\mu)\Gamma(\sigma-\mu)} x^{\mu-1} (1-x)^{\sigma-\mu-1} \mathbb{I}_{(0,1)}(x), \quad (2)$$

where  $p = \mu\sigma$ ,  $q = \sigma(1 - \mu)$  and

$$\sigma^2 = \frac{\mu(1-\mu)}{p+1}. \quad (3)$$

The Equation 3 can also be re-parameterized as a function of the mean and variance (Cepeda-Cuervo, 2002)

$$p = \frac{\mu^2(1-\mu) - \mu\sigma^2}{\sigma^2}. \quad (4)$$

$$q = \frac{(1-\mu)(\mu - \sigma^2 - \sigma^2)}{\sigma^2}. \quad (5)$$

A random sample  $\mathbf{Y} = (Y_1, \dots, Y_n)$  is assumed, where the mean and precision (variance) parameters are modeled as

$$g(\mu_i) = \mathbf{X}_i^T \boldsymbol{\beta} \quad (6)$$

$$h(\sigma_i) = \mathbf{X}_i^T \boldsymbol{\gamma} \quad (7)$$

$$k(\sigma_i) = \mathbf{X}_i^T \boldsymbol{\eta} \quad (8)$$

where we assume that  $g$  is the logit function and  $h$  is the exponential function (Cepeda-Cuervo, 2001).

## Bayesian method to fit beta regression models

With  $L(\boldsymbol{\theta})$  data, the likelihood function, and  $p(\boldsymbol{\theta})$ , the joint prior distribution  $\boldsymbol{\theta} = (\boldsymbol{\beta}, \boldsymbol{\gamma})$ , the posterior distribution is  $\pi(\boldsymbol{\theta}|\text{data}) \propto L(\boldsymbol{\theta})p(\boldsymbol{\theta})$  (analytically intractable).

Cepeda-Cuervo (2001) proposed to get samples of  $\boldsymbol{\theta}$  by sampling  $\boldsymbol{\beta}$  and  $\boldsymbol{\gamma}$  from the posterior conditional distributions  $\pi(\boldsymbol{\beta}|\boldsymbol{\gamma}, \text{data})$  and  $\pi(\boldsymbol{\gamma}|\boldsymbol{\beta}, \text{data})$  from the normal transition kernels.

The kernel transition function  $q_1$  is given by

$$q_1(\boldsymbol{\beta}|\boldsymbol{\beta}^{(t)}, \boldsymbol{\gamma}^{(t)}) = N(\boldsymbol{\beta} | \mathbf{B}^t), \quad (9)$$

where

$$\mathbf{B}^t = \mathbf{B}^0(\mathbf{B}^0 - \mathbf{b} + \mathbf{X}^T \boldsymbol{\Sigma}^{-1} \mathbf{y})$$

$$\mathbf{D}^t = (\mathbf{B}^0)^{-1} + \mathbf{X}^T \boldsymbol{\Sigma}^{-1} \mathbf{X}$$

and where  $\boldsymbol{\Sigma}$  is a diagonal matrix with diagonal entries  $\sigma_i^2$ ,  $i = 1, 2, \dots, n$ , and (Cepeda-Cuervo, 2001; Cepeda and Gutierrez, 2002)

$$\hat{\sigma}_i = \hat{\sigma}_i^{(t)} + \frac{\sum_{j=1}^n \sigma_j^{(t)2}}{(\hat{\sigma}_i^{(t)} - \hat{\sigma}_i^{(t)})}, \quad i = 1, 2, \dots, n. \quad (10)$$

And the normal transition kernel  $q_2$  is given by

$$q_2(\boldsymbol{\gamma}|\boldsymbol{\gamma}^{(t)}, \boldsymbol{\beta}^{(t)}) = N(\boldsymbol{\gamma} | \mathbf{G}^t), \quad (11)$$

where

$$\mathbf{G}^t = \mathbf{G}^0(\mathbf{G}^0 - \mathbf{g} + \mathbf{Z}^T \boldsymbol{\Psi}^{-1} \mathbf{y}),$$

$$\mathbf{G}^t = (\mathbf{G}^0)^{-1} + \mathbf{Z}^T \boldsymbol{\Psi}^{-1} \mathbf{Z}$$

$\boldsymbol{\Psi}$  is a diagonal matrix with entries  $\sigma_i^2$  for  $i = 1, 2, \dots, n$  and for  $\sigma$

$$\hat{\sigma}_i = \hat{\sigma}_i^{(t)} + \frac{\sum_{j=1}^n \sigma_j^{(t)2}}{\hat{\sigma}_i^{(t)}}, \quad i = 1, 2, \dots, n. \quad (12)$$

For  $q_2^t$

$$\hat{\sigma}_i = \hat{\sigma}_i^{(t)} + \frac{\sum_{j=1}^n \sigma_j^{(t)2}}{\hat{\sigma}_i^{(t)}}, \quad i = 1, 2, \dots, n. \quad (13)$$

## An application of the Bayesianbetareg

We carry out an example of the Bayesianbetareg package using the dyshmia data set presented in Smithson and Verbeulen (2006), in which the response variable represents the mean obtained by 41 children in a reading accuracy test. The explanatory variables correspond to the dyshmia (D) or lack of status (I) (the standardized non-verbal IQ) and their interaction. This database is available in the betareg package (R Core Team, 2014).

Table 1. Estimate Results

	Estimate	StdErr	LCredInt	UCredInt
beta.X0	1.00	0.21	0.21	1.74
beta.X1	-1.11	0.21	-0.69	-0.61
beta.X2	1.79	0.21	1.27	1.99
beta.X3	-1.00	0.21	-0.58	-1.02
gamma.D0	1.06	0.23	0.99	1.14
gamma.D1	0.21	0.24	0.00	0.79
gamma.D2	0.20	0.27	0.00	0.44



Figure 1. Plot - Chain of beta parameter



Figure 2. Plot - Chain of gamma parameter

## Conclusions

- the Bayesianbetareg R package can be used to fit beta regression with mean and precision
- The program for fit beta regression with mean and variance is in progress

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