

# Zero-inflated models: Poisson, Binomial, negative Binomial and BetaBinomial

## Parametrisation

There is support two types of zero-inflated models, which we name type 0 and type 1. These are defined for both the Binomial, the Poisson, the censored Poisson, the negative Binomial and BetaBinomial likelihood. For simplicity we will describe only the Poisson as the other cases are similar.

### Type 0

The (type 0) likelihood is defined as

$$\text{Prob}(y \mid \dots) = p \times 1_{[y=0]} + (1 - p) \times \text{Poisson}(y \mid y > 0)$$

where  $p$  is a hyperparameter where

$$p = \frac{\exp(\theta)}{1 + \exp(\theta)}$$

and  $\theta$  is the internal representation of  $p$ ; meaning that the initial value and prior is given for  $\theta$ . This is model is called `zeroinflatedpoisson0` (and `zeroinflatedbinomial0`).

### Type 1

The (type 1) likelihood is defined as

$$\text{Prob}(y \mid \dots) = p \times 1_{[y=0]} + (1 - p) \times \text{Poisson}(y)$$

where  $p$  is a hyperparameter where

$$p = \frac{\exp(\theta)}{1 + \exp(\theta)}$$

and  $\theta$  is the internal representation of  $p$ ; meaning that the initial value and prior is given for  $\theta$ . This is model is called `zeroinflatedpoisson1` (and `zeroinflatedbinomial1`).

## Link-function

As for the Poisson, the Binomial the negative Binomial and the BetaBinomial.

## Hyperparameters

For Poisson and the Binomial, there is one hyperparameter; where

$$p = \frac{\exp(\theta)}{1 + \exp(\theta)}$$

and the prior and initial value is is given for  $\theta$ .

For the negative Binomial and BetaBinomial, there are two hyperparameters. The overdispersion parameter  $n$  for the negative Binomial is represented as

$$\theta_1 = \log(n)$$

and the prior is defined on  $\theta_1$ . The zero-inflation parameter  $p$ , is represented as

$$p = \frac{\exp(\theta_2)}{1 + \exp(\theta_2)}$$

and the prior and initial value is is given for  $\theta_2$ . For the BetaBinomial it is similar.

## Specification

- `family="zeroinflatedbinomial0"`
- `family="zeroinflatedbinomial1"`
- `family="zeroinflatednbinomial0"`
- `family="zeroinflatednbinomial1"`
- `family="zeroinflatedpoisson0"`
- `family="zeroinflatedpoisson1"`
- `family="zeroinflatedcenpoisson0"`
- `family="zeroinflatedcenpoisson1"`
- `family="zeroinflatedbetabinomial0"`
- `family="zeroinflatedbetabinomial1"`
- Required arguments: As for the Binomial, the negative Binomial, BetaBinomial and Poisson likelihood.

## Hyperparameter specification and default values

### Zeroinflated Binomial Type 0

**doc** Zero-inflated Binomial, type 0

**hyper**

**theta**

**hyperid** 90001

**name** logit probability

**short.name** prob

**initial** -1

**fixed** FALSE

**prior** gaussian

**param** -1 0.2

**to.theta** `function(x) log(x / (1 - x))`

**from.theta** `function(x) exp(x) / (1 + exp(x))`

**survival** FALSE

**discrete** FALSE

**link** default logit loga cauchit probit cloglog ccloglog loglog robit sn

**pdf** zeroinflated

## **Zeroinflated Binomial Type 1**

**doc** Zero-inflated Binomial, type 1

**hyper**

**theta**

**hyperid** 91001

**name** logit probability

**short.name** prob

**initial** -1

**fixed** FALSE

**prior** gaussian

**param** -1 0.2

**to.theta** function(x) log(x / (1 - x))

**from.theta** function(x) exp(x) / (1 + exp(x))

**survival** FALSE

**discrete** FALSE

**link** default logit loga cauchit probit cloglog ccloglog loglog robit sn

**pdf** zeroinflated

## **Zeroinflated NegBinomial Type 0**

**doc** Zero inflated negBinomial, type 0

**hyper**

**theta1**

**hyperid** 95001

**name** log size

**short.name** size

**initial** 2.30258509299405

**fixed** FALSE

**prior** pc.mgamma

**param** 7

**to.theta** function(x) log(x)

**from.theta** function(x) exp(x)

**theta2**

**hyperid** 95002

**name** logit probability

**short.name** prob

**initial** -1

**fixed** FALSE

**prior** gaussian

**param** -1 0.2

**to.theta** function(x) log(x / (1 - x))

```

    from.theta function(x) exp(x) / (1 + exp(x))
survival FALSE
discrete FALSE
link default log
pdf zeroinflated

```

### **Zeroinflated NegBinomial Type 1**

**doc** Zero inflated negBinomial, type 1

**hyper**

**theta1**

```

    hyperid 96001
    name log size
    short.name size
    initial 2.30258509299405
    fixed FALSE
    prior pc.mgamma
    param 7
    to.theta function(x) log(x)
    from.theta function(x) exp(x)

```

**theta2**

```

    hyperid 96002
    name logit probability
    short.name prob
    initial -1
    fixed FALSE
    prior gaussian
    param -1 0.2
    to.theta function(x) log(x / (1 - x))
    from.theta function(x) exp(x) / (1 + exp(x))

```

**survival** FALSE

**discrete** FALSE

**link** default log

**pdf** zeroinflated

### **Zeroinflated BetaBinomial Type 0**

**doc** Zero-inflated Beta-Binomial, type 0

**hyper**

**theta1**

```

    hyperid 88001
    name overdispersion
    short.name rho
    initial 0
    fixed FALSE
    prior gaussian
    param 0 0.4
    to.theta function(x) log(x / (1 - x))
    from.theta function(x) exp(x) / (1 + exp(x))
  theta2
    hyperid 88002
    name logit probability
    short.name prob
    initial -1
    fixed FALSE
    prior gaussian
    param -1 0.2
    to.theta function(x) log(x / (1 - x))
    from.theta function(x) exp(x) / (1 + exp(x))

survival FALSE

discrete TRUE

link default logit loga cauchit probit cloglog ccloglog loglog robit sn

pdf zeroinflated

```

### **Zeroinflated BetaBinomial Type 1**

**doc** Zero-inflated Beta-Binomial, type 1

**hyper**

```

  theta1
    hyperid 89001
    name overdispersion
    short.name rho
    initial 0
    fixed FALSE
    prior gaussian
    param 0 0.4
    to.theta function(x) log(x / (1 - x))
    from.theta function(x) exp(x) / (1 + exp(x))
  theta2
    hyperid 89002
    name logit probability
    short.name prob

```

```

initial -1
fixed FALSE
prior gaussian
param -1 0.2
to.theta function(x) log(x / (1 - x))
from.theta function(x) exp(x) / (1 + exp(x))

```

**survival** FALSE

**discrete** TRUE

**link** default logit loga cauchit probit cloglog ccloglog loglog robit sn

**pdf** zeroinflated

### **Zeroinflated Poisson Type 0**

**doc** Zero-inflated Poisson, type 0

**hyper**

**theta**

```

hyperid 85001
name logit probability
short.name prob
initial -1
fixed FALSE
prior gaussian
param -1 0.2
to.theta function(x) log(x / (1 - x))
from.theta function(x) exp(x) / (1 + exp(x))

```

**survival** FALSE

**discrete** FALSE

**link** default log

**pdf** zeroinflated

### **Zeroinflated Poisson Type 1**

**doc** Zero-inflated Poisson, type 1

**hyper**

**theta**

```

hyperid 86001
name logit probability
short.name prob
initial -1
fixed FALSE
prior gaussian

```

```
param -1 0.2
to.theta function(x) log(x / (1 - x))
from.theta function(x) exp(x) / (1 + exp(x))
```

**survival** FALSE

**discrete** FALSE

**link** default log

**pdf** zeroinflated

### **Zeroinflated Censored Poisson Type 0**

**doc** Zero-inflated censored Poisson, type 0

**hyper**

**theta**

```
hyperid 87101
name logit probability
short.name prob
initial -1
fixed FALSE
prior gaussian
param -1 0.2
to.theta function(x) log(x / (1 - x))
from.theta function(x) exp(x) / (1 + exp(x))
```

**status** experimental

**survival** FALSE

**discrete** FALSE

**link** default log

**pdf** zeroinflated

### **Zeroinflated Censored Poisson Type 1**

**doc** Zero-inflated censored Poisson, type 1

**hyper**

**theta**

```
hyperid 87201
name logit probability
short.name prob
initial -1
fixed FALSE
prior gaussian
param -1 0.2
```

```

to.theta function(x) log(x / (1 - x))
from.theta function(x) exp(x) / (1 + exp(x))

status experimental

survival FALSE

discrete FALSE

link default log

pdf zeroinflated

```

## Example

In the following example we estimate the parameters in a simulated example for both type 0 and type 1.

### Poisson

```

## type 0
n=100
a = 1
b = 1
z = rnorm(n)
eta = a + b*z
p = 0.2
E = sample(c(1,5,10,15), size=n, replace=TRUE)
lambda = E*exp(eta)

## first sample y|y>0
y = rpois(n, lambda = lambda)
is.zero = (y == 0)
while(sum(is.zero) > 0)
{
  y[is.zero] = rpois(sum(is.zero), lambda[is.zero])
  is.zero = (y == 0)
}
## then set some of these to zero
y[ rbinom(n, size=1, prob=p) == 1 ] = 0

data = list(y=y,z=z)
formula = y ~ 1+z
result0 = inla(formula, family = "zeroinflatedpoisson0", data = data, E=E)
summary(result0)

## type 1
y = rpois(n, lambda = lambda)
y[ rbinom(n, size=1, prob=p) == 1 ] = 0
data = list(y=y,z=z)
formula = y ~ 1+z
result1 = inla(formula, family = "zeroinflatedpoisson1", data = data, E=E)
summary(result1)

```



## Binomial

```
## type 0
n=100
a = 1
b = 1
z = rnorm(n)
eta = a + b*z
p = 0.2
Ntrials = sample(c(1,5,10,15), size=n, replace=TRUE)
prob = exp(eta)/(1 + exp(eta))

y = rbinom(n, size = Ntrials, prob = prob)
is.zero = (y == 0)
while(sum(is.zero) > 0)
{
  y[is.zero] = rbinom(sum(is.zero), size = Ntrials[is.zero], prob = prob[is.zero])
  is.zero = (y == 0)
}
y[ rbinom(n, size=1, prob=p) == 1 ] = 0
data = list(y=y,z=z)
formula = y ~ 1+z
result0 = inla(formula, family = "zeroinflatedbinomial0", data = data, Ntrials = Ntrials)
summary(result0)

## type 1
y = rbinom(n, size = Ntrials, prob = prob)
y[ rbinom(n, size=1, prob=p) == 1 ] = 0
data = list(y=y,z=z)
formula = y ~ 1+z
result1 = inla(formula, family = "zeroinflatedbinomial1", data = data, Ntrials=Ntrials)
summary(result1)
```

## Advanced example

In the following example we estimate the parameters in a simulated example for a type0 likelihood, where one linear predictor enters the zero-probability and one other linear predictor enters the non-zero Poisson for example. The same trick can be used for other models of type0. The trick is that the likelihood

$$p^* 1_{[y=0]} + (1 - p^*) P(y|y > 0)$$

can be reformulated as a Bernoulli likelihood for the “class”-variable

$$z = \begin{cases} 1, & \text{if } y = 0 \\ 0, & \text{if } y > 0. \end{cases}$$

where  $p^*$  is the probability for success, and zero-inflated type0 likelihood (with fixed  $p = 0$ ) for those  $y > 0$ . Since  $p^*$  and the linear predictor in  $P$  is separated into two likelihoods, we can apply one linear predictor to each one, hence extend the basic model to cases where  $p^*$  also depends on a linear predictor. Here is a small simulated example doing this.

```
require(INLA)

n = 100
a = 0.5
b = 1.5
x1 = rnorm(n, sd = 0.5)

eta.z = -a - b*x1
z = rbinom(n, 1, inla.link.logit(eta.z, inverse=TRUE))
n.y = sum(z)

x2 = rnorm(n.y, sd = 0.5)
eta.y = a + b*x2
lambda = exp(eta.y)
y = rpois(n.y, lambda)

is.zero = (y == 0)
while(sum(is.zero) > 0)
{
  y[is.zero] = rpois(sum(is.zero), lambda[is.zero])
  is.zero = (y == 0)
}

Y = matrix(NA, n + n.y, 2)
Y[1:n, 1] = z
Y[n + 1:n.y, 2] = y

form = Y ~ 0 + mu.z + mu.y + cov.z + cov.y
ldat = list(
  Y=Y,
  mu.z=rep(1:0, c(n, n.y)),
  mu.y=rep(0:1, c(n, n.y)),
  cov.z=c(x1, rep(NA,n.y)),
  cov.y=c(rep(NA, n), x2))
```

```

res <- inla(form, data=ldat,
            family=c('binomial', 'zeroinflatedpoisson0'),
            control.family=list(
                list(),
                list(hyper = list(
                    prob = list(
                        initial = -20,
                        fixed = TRUE))))))
round(res$summary.fix, 4)

```

## Notes

None.

## Extentions

There are some extentions available which currently is only implemented for the cases where its needed/requested.

**Type 2** Is like Type 1 but where (for the Poisson)

$$p = 1 - \left( \frac{E \exp(x)}{1 + E \exp(x)} \right)^\alpha$$

where  $\alpha > 0$  is the hyperparameter instead of  $p$  (and  $E \exp(x)$  is the mean). Available for Poisson as **zeroinflatedpoisson2**, for binomial as **zeroinflatedbinomial2** and for the negative binomial as **zeroinflatednbinomial2**.

The internal representation is  $\theta = \log(\alpha)$  and prior is defined on  $\log(\alpha)$ .

## Zeroinflated Poisson Type 2

**doc** Zero-inflated Poisson, type 2

**hyper**

**theta**

```

hyperid 87001
name log alpha
short.name a
initial 0.693147180559945
fixed FALSE
prior gaussian
param 0.693147180559945 1
to.theta function(x) log(x)
from.theta function(x) exp(x)

```

**survival** FALSE

**discrete** FALSE

**link** default log

**pdf** zeroinflated

## **Zeroinflated Binomial Type 2**

**doc** Zero-inflated Binomial, type 2

**hyper**

**theta**

**hyperid** 92001  
**name** alpha  
**short.name** alpha  
**initial** -1  
**fixed** FALSE  
**prior** gaussian  
**param** -1 0.2  
**to.theta** function(x) log(x)  
**from.theta** function(x) exp(x)

**survival** FALSE

**discrete** FALSE

**link** default logit loga cauchit probit cloglog ccloglog loglog robit sn

**pdf** zeroinflated

## **Zeroinflated Negative Binomial Type 2**

**doc** Zero inflated negBinomial, type 2

**hyper**

**theta1**

**hyperid** 99001  
**name** log size  
**short.name** size  
**initial** 2.30258509299405  
**fixed** FALSE  
**prior** pc.mgamma  
**param** 7  
**to.theta** function(x) log(x)  
**from.theta** function(x) exp(x)

**theta2**

**hyperid** 99002  
**name** log alpha  
**short.name** a  
**initial** 0.693147180559945  
**fixed** FALSE  
**prior** gaussian  
**param** 2 1  
**to.theta** function(x) log(x)

```

    from.theta function(x) exp(x)
survival FALSE
discrete FALSE
link default log
pdf zeroinflated

```

## **Zeroinflated Negative Binomial Type 1 Strata 2**

**doc** Zero inflated negBinomial, type 1, strata 2

**hyper**

**theta1**

```

    hyperid 97001
    name log size
    short.name size
    initial 2.30258509299405
    fixed FALSE
    prior pc.mgamma
    param 7
    to.theta function(x) log(x)
    from.theta function(x) exp(x)

```

**theta2**

```

    hyperid 97002
    name logit probability 1
    short.name prob1
    initial -1
    fixed FALSE
    prior gaussian
    param -1 0.2
    to.theta function(x) log(x / (1 - x))
    from.theta function(x) exp(x) / (1 + exp(x))

```

**theta3**

```

    hyperid 97003
    name logit probability 2
    short.name prob2
    initial -1
    fixed FALSE
    prior gaussian
    param -1 0.2
    to.theta function(x) log(x / (1 - x))
    from.theta function(x) exp(x) / (1 + exp(x))

```

**theta4**

```

    hyperid 97004

```

```

name logit probability 3
short.name prob3
initial -1
fixed TRUE
prior gaussian
param -1 0.2
to.theta function(x) log(x / (1 - x))
from.theta function(x) exp(x) / (1 + exp(x))
theta5
hyperid 97005
name logit probability 4
short.name prob4
initial -1
fixed TRUE
prior gaussian
param -1 0.2
to.theta function(x) log(x / (1 - x))
from.theta function(x) exp(x) / (1 + exp(x))
theta6
hyperid 97006
name logit probability 5
short.name prob5
initial -1
fixed TRUE
prior gaussian
param -1 0.2
to.theta function(x) log(x / (1 - x))
from.theta function(x) exp(x) / (1 + exp(x))
theta7
hyperid 97007
name logit probability 6
short.name prob6
initial -1
fixed TRUE
prior gaussian
param -1 0.2
to.theta function(x) log(x / (1 - x))
from.theta function(x) exp(x) / (1 + exp(x))
theta8
hyperid 97008
name logit probability 7
short.name prob7
initial -1
fixed TRUE

```

```

    prior gaussian
    param -1 0.2
    to.theta function(x) log(x / (1 - x))
    from.theta function(x) exp(x) / (1 + exp(x))
theta9
    hyperid 97009
    name logit probability 8
    short.name prob8
    initial -1
    fixed TRUE
    prior gaussian
    param -1 0.2
    to.theta function(x) log(x / (1 - x))
    from.theta function(x) exp(x) / (1 + exp(x))
theta10
    hyperid 97010
    name logit probability 9
    short.name prob9
    initial -1
    fixed TRUE
    prior gaussian
    param -1 0.2
    to.theta function(x) log(x / (1 - x))
    from.theta function(x) exp(x) / (1 + exp(x))
theta11
    hyperid 97011
    name logit probability 10
    short.name prob10
    initial -1
    fixed TRUE
    prior gaussian
    param -1 0.2
    to.theta function(x) log(x / (1 - x))
    from.theta function(x) exp(x) / (1 + exp(x))

status experimental

survival FALSE

discrete FALSE

link default log

pdf zeroinflated

```

### **Zeroinflated Negative Binomial Type 1 Strata 3**

**doc** Zero inflated negBinomial, type 1, strata 3

**hyper**

**theta1**

**hyperid** 98001  
**name** logit probability  
**short.name** prob  
**initial** -1  
**fixed** FALSE  
**prior** gaussian  
**param** -1 0.2  
**to.theta** function(x) log(x / (1 - x))  
**from.theta** function(x) exp(x) / (1 + exp(x))

**theta2**

**hyperid** 98002  
**name** log size 1  
**short.name** size1  
**initial** 2.30258509299405  
**fixed** FALSE  
**prior** pc.mgamma  
**param** 7  
**to.theta** function(x) log(x)  
**from.theta** function(x) exp(x)

**theta3**

**hyperid** 98003  
**name** log size 2  
**short.name** size2  
**initial** 2.30258509299405  
**fixed** FALSE  
**prior** pc.mgamma  
**param** 7  
**to.theta** function(x) log(x)  
**from.theta** function(x) exp(x)

**theta4**

**hyperid** 98004  
**name** log size 3  
**short.name** size3  
**initial** 2.30258509299405  
**fixed** TRUE  
**prior** pc.mgamma  
**param** 7  
**to.theta** function(x) log(x)  
**from.theta** function(x) exp(x)



#### **theta5**

**hyperid** 98005  
**name** log size 4  
**short.name** size4  
**initial** 2.30258509299405  
**fixed** TRUE  
**prior** pc.mgamma  
**param** 7  
**to.theta** function(x) log(x)  
**from.theta** function(x) exp(x)

#### **theta6**

**hyperid** 98006  
**name** log size 5  
**short.name** size5  
**initial** 2.30258509299405  
**fixed** TRUE  
**prior** pc.mgamma  
**param** 7  
**to.theta** function(x) log(x)  
**from.theta** function(x) exp(x)

#### **theta7**

**hyperid** 98007  
**name** log size 6  
**short.name** size6  
**initial** 2.30258509299405  
**fixed** TRUE  
**prior** pc.mgamma  
**param** 7  
**to.theta** function(x) log(x)  
**from.theta** function(x) exp(x)

#### **theta8**

**hyperid** 98008  
**name** log size 7  
**short.name** size7  
**initial** 2.30258509299405  
**fixed** TRUE  
**prior** pc.mgamma  
**param** 7  
**to.theta** function(x) log(x)  
**from.theta** function(x) exp(x)

#### **theta9**

**hyperid** 98009  
**name** log size 8  
**short.name** size8

```

    initial 2.30258509299405
    fixed TRUE
    prior pc.mgamma
    param 7
    to.theta function(x) log(x)
    from.theta function(x) exp(x)
theta10
    hyperid 98010
    name log size 9
    short.name size9
    initial 2.30258509299405
    fixed TRUE
    prior pc.mgamma
    param 7
    to.theta function(x) log(x)
    from.theta function(x) exp(x)
theta11
    hyperid 98011
    name log size 10
    short.name size10
    initial 2.30258509299405
    fixed TRUE
    prior pc.mgamma
    param 7
    to.theta function(x) log(x)
    from.theta function(x) exp(x)

status experimental
survival FALSE
discrete FALSE
link default log
pdf zeroinflated

```

### 0.0.1 Zero and $N$ -inflated Binomial likelihood: type 3

This is the case where

$$\begin{aligned}
 \text{Prob}(y|\dots) &= p_0 \times 1_{[y=0]} + \\
 &\quad p_N \times 1_{[y=N]} + \\
 &\quad (1 - p_0 - p_N) \times \text{binomial}(y, N, p)
 \end{aligned}$$

where:

$$p = \frac{\exp(\eta)}{1 + \exp(\eta)} \quad p_0 = \frac{p^{\alpha_0}}{1 + p^{\alpha_0} + (1 - p)^{\alpha_N}} \quad p_N = \frac{(1 - p)^{\alpha_N}}{1 + p^{\alpha_0} + (1 - p)^{\alpha_N}}$$

There are 2 hyperparameters,  $\alpha_0$  and  $\alpha_N$ , governing zero-inflation where: The zero-inflation parameters  $\alpha_0$  and  $\alpha_N$  are represented as  $\theta_0 = \log(\alpha_0)$ ;  $\theta_N = \log(\alpha_N)$  and the prior and initial value is given for  $\theta_0$  and  $\theta_N$  respectively.

Here is an example

```

nsim<-10000
x<-rnorm(nsim)
alpha0<-1.5
alphaN<-2.0
p = exp(x)/(1+exp(x))
p0 = p^alpha0 / (1 + p^alpha0 + (1-p)^alphaN)
pN = (1-p)^alphaN / (1 + p^alpha0 + (1-p)^alphaN)
P<-cbind(p0, pN, (1-p0 -pN))
N<-rpois(nsim,20)
y<-rep(0,nsim)
for(i in 1:nsim)
  y[i]<-sum(rmultinom(1,size = 1,P[i,])*c(0,N[i],rbinom(1,N[i],p[i])))
formula = y ~1 + x
r = inla(formula, family = "zeroninflatedbinomial3", Ntrials = N, verbose = TRUE,
  data = data.frame(y, x))

```

and the default settings

**doc** Zero and N inflated binomial, type 3

**hyper**

**theta1**

```

hyperid 93101
name alpha0
short.name alpha0
initial 1
fixed FALSE
prior loggamma
param 1 1
to.theta function(x) log(x)
from.theta function(x) exp(x)

```

**theta2**

```

hyperid 93102
name alphaN
short.name alphaN
initial 1
fixed FALSE
prior loggamma
param 1 1
to.theta function(x) log(x)
from.theta function(x) exp(x)

```

**status** experimental

**survival** FALSE

**discrete** FALSE

**link** default logit loga cauchit probit cloglog ccloglog loglog robit sn

**pdf** zeroinflated