

Variable Selection for Health Care Demand in Germany

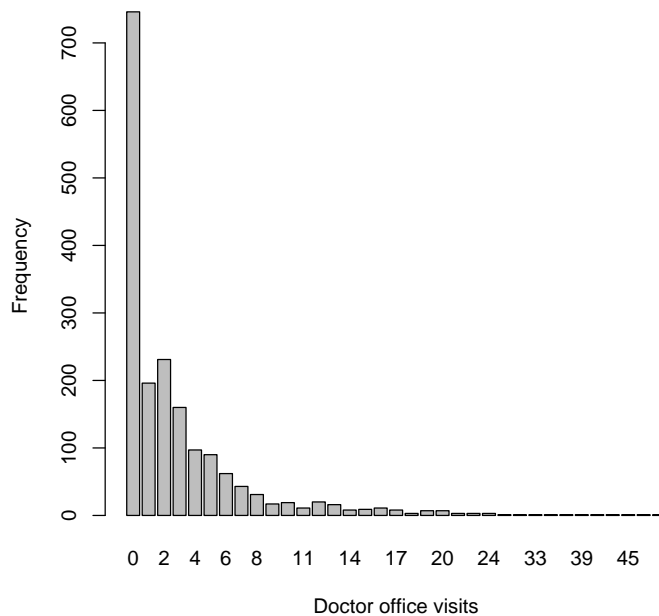
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This document reproduces the data analysis presented in [Wang et al. \(2015\)](#). In an effort to optimize the computing algorithms, the penalized regression can be slightly different. For a description of the theory behind application illustrated here we refer to the original manuscript. [Riphahn et al. \(2003\)](#) utilized a part of the German Socioeconomic Panel (GSOEP) data set to analyze the number of doctor visits. The original data have twelve annual waves from 1984 to 1995 for a representative sample of German households, which provide broad information on the health care utilization, current employment status, and the insurance arrangements under which subjects are protected. The data set contains number of doctor office visits for 1,812 West German men aged 25 to 65 years in the last three months of 1994. As shown in the figure, many doctor office visits are zeros, which can be difficult to fit with a Poisson or negative binomial model. Therefore, zero-inflated negative binomial (ZINB) model is considered.

```
R> library("mpath")
R> library("zic")
R> library("pscl")
R> data(docvisits)

R> barplot(with(docvisits, table(docvisits)), ylab = "Frequency",
           xlab = "Doctor office visits")
```



We include the linear spline variables *age30* to *age60* and their interaction terms with the health satisfaction *health*.

```
R> dt <- docvisits[, -(2:3)]
R> tmp <- model.matrix(~age30 * health + age35 * health +
  age40 * health + age45 * health + age50 * health +
  age55 * health + age60 * health, data = dt)[, -(1:9)]
R> dat <- cbind(dt, tmp)
```

Full ZINB model with all predictor variables.

```
R> m1 <- zeroinfl(docvisits ~ . | ., data = dat, dist = "negbin")
R> summary(m1)
```

Call:

```
zeroinfl(formula = docvisits ~ . | ., data = dat, dist = "negbin")
```

Pearson residuals:

	Min	1Q	Median	3Q	Max
	-1.073	-0.660	-0.394	0.301	9.910

Count model coefficients (negbin with log link):

	Estimate	Std. Error	z value	Pr(> z)
(Intercept)	2.41222	0.34563	6.98	3e-12 ***
health	-0.16382	0.03449	-4.75	2e-06 ***
handicap	0.26691	0.19452	1.37	0.17001
hdegree	-0.00201	0.00329	-0.61	0.54180
married	-0.14720	0.09284	-1.59	0.11282

schooling	-0.00458	0.01539	-0.30	0.76616
hhincome	0.00441	0.01616	0.27	0.78504
children	0.01741	0.08841	0.20	0.84385
self	-0.35994	0.15389	-2.34	0.01934 *
civil	-0.26809	0.16062	-1.67	0.09511 .
bluec	0.10345	0.08615	1.20	0.22983
employed	-0.09392	0.10723	-0.88	0.38110
public	-0.01141	0.13959	-0.08	0.93487
addon	0.36473	0.23249	1.57	0.11670
age30TRUE	0.09414	0.36278	0.26	0.79525
age35TRUE	-0.25482	0.36728	-0.69	0.48780
age40TRUE	0.05154	0.39890	0.13	0.89720
age45TRUE	0.72053	0.38568	1.87	0.06173 .
age50TRUE	0.20245	0.34105	0.59	0.55278
age55TRUE	-0.51587	0.30727	-1.68	0.09318 .
age60TRUE	0.40081	0.31340	1.28	0.20093
`age30TRUE:health`	-0.01175	0.05206	-0.23	0.82146
`health:age35TRUE`	0.04319	0.05427	0.80	0.42605
`health:age40TRUE`	-0.01669	0.06167	-0.27	0.78664
`health:age45TRUE`	-0.10124	0.06145	-1.65	0.09946 .
`health:age50TRUE`	-0.02410	0.05336	-0.45	0.65150
`health:age55TRUE`	0.13292	0.05166	2.57	0.01008 *
`health:age60TRUE`	-0.09509	0.05593	-1.70	0.08909 .
Log(theta)	0.32239	0.09046	3.56	0.00037 ***

Zero-inflation model coefficients (binomial with logit link):

	Estimate	Std. Error	z value	Pr(> z)
(Intercept)	-2.31059	0.97764	-2.36	0.018 *
health	0.22741	0.09983	2.28	0.023 *
handicap	-0.33423	0.75516	-0.44	0.658
hdegree	-0.00243	0.01562	-0.16	0.876
married	-0.40373	0.24700	-1.63	0.102
schooling	0.01852	0.03825	0.48	0.628
hhincome	-0.03842	0.04432	-0.87	0.386
children	0.50569	0.23533	2.15	0.032 *
self	-0.24892	0.47771	-0.52	0.602
civil	0.02095	0.38325	0.05	0.956
bluec	0.02283	0.22215	0.10	0.918
employed	-0.08448	0.29703	-0.28	0.776
public	-0.23043	0.33817	-0.68	0.496
addon	0.29983	0.52438	0.57	0.567
age30TRUE	-1.67862	1.32598	-1.27	0.206
age35TRUE	0.90000	1.44345	0.62	0.533
age40TRUE	-0.64989	1.44217	-0.45	0.652
age45TRUE	2.99929	1.20006	2.50	0.012 *
age50TRUE	-2.95569	1.70089	-1.74	0.082 .
age55TRUE	0.33612	1.80886	0.19	0.853
age60TRUE	-2.33629	2.68475	-0.87	0.384
`age30TRUE:health`	0.22794	0.16279	1.40	0.161
`health:age35TRUE`	-0.11043	0.18081	-0.61	0.541

```

`health:age40TRUE` 0.11569 0.18628 0.62 0.535
`health:age45TRUE` -0.40960 0.16390 -2.50 0.012 *
`health:age50TRUE` 0.25083 0.22087 1.14 0.256
`health:age55TRUE` 0.10792 0.23375 0.46 0.644
`health:age60TRUE` 0.19599 0.33942 0.58 0.564

```

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Theta = 1.38

Number of iterations in BFGS optimization: 63

Log-likelihood: -3.63e+03 on 57 Df

```
R> cat("loglik of zero-inflated model", logLik(m1))
```

loglik of zero-inflated model -3626

```
R> cat("BIC of zero-inflated model", AIC(m1, k = log(dim(dat)[1])))
```

BIC of zero-inflated model 7679

```
R> cat("AIC of zero-inflated model", AIC(m1))
```

AIC of zero-inflated model 7366

Backward stepwise variable selection with significance level alpha=0.01.

```
R> fitbe <- be.zeroinfl(m1, data = dat, dist = "negbin",
  alpha = 0.01, trace = FALSE)
```

```
R> summary(fitbe)
```

Call:

```
zeroinfl(formula = eval(parse(text = out)), data = data, dist = dist)
```

Pearson residuals:

	Min	1Q	Median	3Q	Max
	-1.020	-0.646	-0.394	0.296	8.665

Count model coefficients (negbin with log link):

	Estimate	Std. Error	z value	Pr(> z)	
(Intercept)	2.5662	0.0955	26.86	< 2e-16	***
health	-0.2013	0.0143	-14.12	< 2e-16	***
handicap	0.3031	0.0849	3.57	0.00036	***
self	-0.3663	0.1178	-3.11	0.00187	**
civil	-0.3372	0.1043	-3.23	0.00123	**
Log(theta)	0.2360	0.0898	2.63	0.00858	**

Zero-inflation model coefficients (binomial with logit link):

	Estimate	Std. Error	z value	Pr(> z)	
(Intercept)	-2.9838	0.3722	-8.02	1.1e-15	***
health	0.3010	0.0461	6.53	6.4e-11	***
age50TRUE	-1.0004	0.2602	-3.84	0.00012	***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Theta = 1.266

Number of iterations in BFGS optimization: 17

Log-likelihood: -3.66e+03 on 9 Df

```
R> cat("loglik of zero-inflated model with backward selection",
      logLik(fitbe))
```

loglik of zero-inflated model with backward selection -3656

```
R> cat("BIC of zero-inflated model with backward selection",
      AIC(fitbe, k = log(dim(dat)[1])))
```

BIC of zero-inflated model with backward selection 7380

Compute LASSO estimates.

```
R> fit.lasso <- zipath(docvisits ~ . | ., data = dat, family = "negbin",
  nlambda = 100, lambda.zero.min.ratio = 0.001, maxit.em = 300,
  maxit.theta = 25, theta.fixed = FALSE, trace = FALSE,
  penalty = "enet", rescale = FALSE)
```

Estimated coefficient parameters with smallest BIC value.

```
R> minBic <- which.min(BIC(fit.lasso))
```

```
R> coef(fit.lasso, minBic)
```

\$count

(Intercept)	health	handicap
2.30551	-0.17372	0.15521
hdegree	married	schooling
0.00000	0.00000	0.00000
hhincome	children	self
0.00000	0.00000	0.00000
civil	bluec	employed
0.00000	0.00000	0.00000
public	addon	age30TRUE
0.05674	0.00000	0.00000
age35TRUE	age40TRUE	age45TRUE
0.00000	0.00000	0.00000
age50TRUE	age55TRUE	age60TRUE
0.03801	0.09879	0.00000
`age30TRUE:health`	`health:age35TRUE`	`health:age40TRUE`
0.00000	0.00000	0.00000
`health:age45TRUE`	`health:age50TRUE`	`health:age55TRUE`
0.00000	0.00000	0.00000
`health:age60TRUE`		
0.00000		

\$zero

(Intercept)	health	handicap
-------------	--------	----------

-2.6985	0.2521	0.0000
hdegree	married	schooling
0.0000	0.0000	0.0000
hhincome	children	self
0.0000	0.1956	0.0000
civil	bluec	employed
0.0000	0.0000	0.0000
public	addon	age30TRUE
0.0000	0.0000	0.0000
age35TRUE	age40TRUE	age45TRUE
0.0000	0.0000	0.0000
age50TRUE	age55TRUE	age60TRUE
-0.3978	0.0000	0.0000
`age30TRUE:health`	`health:age35TRUE`	`health:age40TRUE`
0.0000	0.0000	0.0000
`health:age45TRUE`	`health:age50TRUE`	`health:age55TRUE`
0.0000	0.0000	0.0000
`health:age60TRUE`		
0.0000		

```
R> cat("theta estimate", fit.lasso$theta[minBic])
```

theta estimate 1.367

Compute standard errors of coefficients and theta:

```
R> se(fit.lasso, minBic, log = FALSE)
```

```
$count
(Intercept)      health      handicap      public      age50TRUE
      0.15053      0.01800      0.10394      0.09111      0.10278
      age55TRUE
      0.11073
```

```
$zero
(Intercept)      health      children      age50TRUE
      0.28676      0.03501      0.15432      0.18317
```

```
$theta
[1] 0.1294
```

Compute AIC, BIC, log-likelihood values of the selected model.

```
R> AIC(fit.lasso)[minBic]
```

```
0.048
7351
```

```
R> BIC(fit.lasso)[minBic]
```

```
0.048
7412
```

```
R> logLik(fit.lasso)[minBic]
```

```
[1] -3665
```

Compute log-likelihood value via 10-fold cross-validation using 2 CPU cores.

```
R> n <- dim(dat)[1]
R> K <- 10
R> set.seed(197)
R> foldid <- split(sample(1:n), rep(1:K, length = n))
R> fitcv <- cv.zipath(docvisits ~ . | ., data = dat, family = "negbin",
  nlambda = 100, lambda.count = fit.lasso$lambda.count[1:30],
  lambda.zero = fit.lasso$lambda.zero[1:30], maxit.em = 300,
  maxit.theta = 1, theta.fixed = FALSE, penalty = "enet",
  rescale = FALSE, foldid = foldid, n.cores = 2)
R> cat("cross-validated loglik", max(fitcv$cv))
```

```
cross-validated loglik -367.8
```

Compute MCP estimates. We compute solution paths for the first 30 pairs of shrinkage parameters (the EM algorithm can be slow), and then evaluate results as for the LASSO estimates. For cross-validation, set maximum number of iterations in estimating scaling parameter 1 (maxit.theta=1) to reduce computation costs.

```
R> tmp <- zipath(docvisits ~ . | ., data = dat, family = "negbin",
  gamma.count = 2.7, gamma.zero = 2.7, lambda.zero.min.ratio = 0.1,
  maxit = 1, maxit.em = 1, maxit.theta = 2, theta.fixed = FALSE,
  penalty = "mnet")
R> fit.mcp <- zipath(docvisits ~ . | ., data = dat, family = "negbin",
  gamma.count = 2.7, gamma.zero = 2.7, lambda.count = tmp$lambda.count[1:30],
  lambda.zero = tmp$lambda.zero[1:30], maxit.em = 300,
  maxit.theta = 25, theta.fixed = FALSE, penalty = "mnet")
```

Estimated coefficient parameters with smallest BIC value.

```
R> minBic <- which.min(BIC(fit.mcp))
R> coef(fit.mcp, minBic)
```

```
$count
      (Intercept)      health      handicap
      2.4826      -0.1951      0.2302
      hdegree      married      schooling
      0.0000      0.0000      0.0000
      hhincome      children      self
      0.0000      0.0000      -0.3653
      civil      bluec      employed
     -0.3132      0.0000      0.0000
      public      addon      age30TRUE
      0.0000      0.0000      0.0000
     age35TRUE      age40TRUE      age45TRUE
      0.0000      0.0000      0.0000
```

	age50TRUE	age55TRUE	age60TRUE
	0.0000	0.2122	0.0000
`age30TRUE:health`	`health:age35TRUE`	`health:age40TRUE`	
	0.0000	0.0000	0.0000
`health:age45TRUE`	`health:age50TRUE`	`health:age55TRUE`	
	0.0000	0.0000	0.0000
`health:age60TRUE`			
	0.0000		

\$zero

(Intercept)	health	handicap
-3.3598	0.3178	0.0000
hdegree	married	schooling
0.0000	0.0000	0.0000
hhincome	children	self
0.0000	0.4378	0.0000
civil	bluec	employed
0.0000	0.0000	0.0000
public	addon	age30TRUE
0.0000	0.0000	0.0000
age35TRUE	age40TRUE	age45TRUE
0.0000	0.0000	0.0000
age50TRUE	age55TRUE	age60TRUE
-0.6762	0.0000	0.0000
`age30TRUE:health`	`health:age35TRUE`	`health:age40TRUE`
	0.0000	0.0000
`health:age45TRUE`	`health:age50TRUE`	`health:age55TRUE`
	0.0000	0.0000
`health:age60TRUE`		
	0.0000	

```
R> cat("theta estimate", fit.mcp$theta[minBic])
```

theta estimate 1.276

Compute standard errors of coefficients and theta:

```
R> se(fit.mcp, minBic, log = FALSE)
```

\$count

(Intercept)	health	handicap	self	civil
0.12485	0.01815	0.10373	0.12196	0.11842
age55TRUE				
0.08550				

\$zero

(Intercept)	health	children	age50TRUE
0.40887	0.04505	0.17730	0.25170

\$theta

```
[1] 0.1332
```


Compute AIC, BIC, log-likelihood values of the selected model.

```
R> AIC(fit.mcp)[minBic]

0.0228
7320

R> BIC(fit.mcp)[minBic]

0.0228
7380

R> logLik(fit.mcp)[minBic]

[1] -3649
```

Compute log-likelihood value via 10-fold cross-validation using 2 CPU cores.

```
R> fitcv <- cv.zipath(docvisits ~ . | ., data = dat, family = "negbin",
  gamma.count = 2.7, gamma.zero = 2.7, lambda.count = tmp$lambda.count[1:30],
  lambda.zero = tmp$lambda.zero[1:30], maxit.em = 300,
  maxit.theta = 1, theta.fixed = FALSE, penalty = "mnet",
  rescale = FALSE, foldid = foldid, n.cores = 2)
R> cat("cross-validated loglik", max(fitcv$cv))

cross-validated loglik -368
```

Compute SCAD estimates.

```
R> tmp <- zipath(docvisits ~ . | ., data = dat, family = "negbin",
  gamma.count = 2.5, gamma.zero = 2.5, lambda.zero.min.ratio = 0.01,
  maxit = 1, maxit.em = 1, maxit.theta = 2, theta.fixed = FALSE,
  penalty = "snet")
R> fit.scad <- zipath(docvisits ~ . | ., data = dat, family = "negbin",
  gamma.count = 2.5, gamma.zero = 2.5, lambda.count = tmp$lambda.count[1:30],
  lambda.zero = tmp$lambda.zero[1:30], maxit.em = 300,
  maxit.theta = 25, theta.fixed = FALSE, penalty = "snet")
```

Estimated coefficient parameters with smallest BIC value.

```
R> minBic <- which.min(BIC(fit.scad))
R> coef(fit.scad, minBic)
```

\$count		
(Intercept)	health	handicap
2.4866	-0.1951	0.2261
hdegree	married	schooling
0.0000	0.0000	0.0000
hhincome	children	self
0.0000	0.0000	-0.3692
civil	bluec	employed
-0.3313	0.0000	0.0000
public	addon	age30TRUE
0.0000	0.0000	0.0000

age35TRUE	age40TRUE	age45TRUE
0.0000	0.0000	0.0000
age50TRUE	age55TRUE	age60TRUE
0.0000	0.2142	0.0000
`age30TRUE:health`	`health:age35TRUE`	`health:age40TRUE`
0.0000	0.0000	0.0000
`health:age45TRUE`	`health:age50TRUE`	`health:age55TRUE`
0.0000	0.0000	0.0000
`health:age60TRUE`		
0.0000		

\$zero

(Intercept)	health	handicap
-3.3323	0.3155	0.0000
hdegree	married	schooling
0.0000	0.0000	0.0000
hhincome	children	self
0.0000	0.4247	0.0000
civil	bluec	employed
0.0000	0.0000	0.0000
public	addon	age30TRUE
0.0000	0.0000	0.0000
age35TRUE	age40TRUE	age45TRUE
0.0000	0.0000	0.0000
age50TRUE	age55TRUE	age60TRUE
-0.6697	0.0000	0.0000
`age30TRUE:health`	`health:age35TRUE`	`health:age40TRUE`
0.0000	0.0000	0.0000
`health:age45TRUE`	`health:age50TRUE`	`health:age55TRUE`
0.0000	0.0000	0.0000
`health:age60TRUE`		
0.0000		

```
R> cat("theta estimate", fit.scad$theta[minBic])
```

theta estimate 1.284

Compute standard errors of coefficients and theta:

```
R> se(fit.scad, minBic, log = FALSE)
```

\$count

(Intercept)	health	handicap	self	civil
0.12479	0.01813	0.10377	0.12196	0.11884
age55TRUE				
0.08557				

\$zero

(Intercept)	health	children	age50TRUE
0.4028	0.0446	0.1757	0.2480

```
$theta
[1] 0.1337
```

Compute AIC, BIC, log-likelihood values of the selected model.

```
R> AIC(fit.scad)[minBic]
```

```
0.0228
7320
```

```
R> BIC(fit.scad)[minBic]
```

```
0.0228
7380
```

```
R> logLik(fit.scad)[minBic]
```

```
[1] -3649
```

Compute log-likelihood value via 10-fold cross-validation using 2 CPU cores.

```
R> fitcv <- cv.zipath(docvisits ~ . | ., data = dat, family = "negbin",
  gamma.count = 2.5, gamma.zero = 2.5, lambda.count = tmp$lambda.count[1:30],
  lambda.zero = tmp$lambda.zero[1:30], maxit.em = 300,
  maxit.theta = 1, theta.fixed = FALSE, penalty = "snet",
  rescale = FALSE, foldid = foldid, n.cores = 2)
R> cat("cross-validated loglik", max(fitcv$cv))
```

```
cross-validated loglik -368.3
```

Running time for the entire analysis.

```
R> print(proc.time() - ptm)
```

```
      user  system elapsed
520.037    0.815  528.704
```

```
R> sessionInfo()
```

```
R version 3.5.3 (2019-03-11)
Platform: x86_64-pc-linux-gnu (64-bit)
Running under: Ubuntu 18.04.2 LTS
```

Matrix products: default

BLAS: /usr/lib/x86_64-linux-gnu/blas/libblas.so.3.7.1

LAPACK: /usr/lib/x86_64-linux-gnu/lapack/liblapack.so.3.7.1

locale:

```
[1] LC_CTYPE=en_US.UTF-8      LC_NUMERIC=C
[3] LC_TIME=en_US.UTF-8      LC_COLLATE=en_US.UTF-8
[5] LC_MONETARY=en_US.UTF-8  LC_MESSAGES=en_US.UTF-8
[7] LC_PAPER=en_US.UTF-8     LC_NAME=C
[9] LC_ADDRESS=C             LC_TELEPHONE=C
[11] LC_MEASUREMENT=en_US.UTF-8 LC_IDENTIFICATION=C
```

attached base packages:

```
[1] stats      graphics  grDevices  utils      datasets  methods
[7] base
```

other attached packages:

```
[1] pscl_1.5.2  zic_0.9.1   mpath_0.3-11
```

loaded via a namespace (and not attached):

```
[1] Rcpp_1.0.0      lattice_0.20-38  codetools_0.2-16
[4] glmnet_2.0-16   foreach_1.4.4    MASS_7.3-51.1
[7] grid_3.5.3      gtable_0.2.0     coda_0.19-2
[10] doParallel_1.0.14 bst_0.3-16       rpart_4.1-13
[13] Matrix_1.2-17   splines_3.5.3    iterators_1.0.10
[16] tools_3.5.3     survival_2.43-3  numDeriv_2016.8-1
[19] parallel_3.5.3  compiler_3.5.3   gbm_2.1.5
[22] gridExtra_2.3
```

References

Regina T Riphahn, Achim Wambach, and Andreas Million. Incentive effects in the demand for health care: a bivariate panel count data estimation. *Journal of Applied Econometrics*, 18(4):387–405, 2003.

Zhu Wang, Shuangge Ma, and Ching-Yun Wang. Variable selection for zero-inflated and overdispersed data with application to health care demand in germany. *Biometrical Journal*, 33(29):5192–208, 2015. URL <http://dx.doi.org/10.1002/bimj.201400143>.