Week8 IC1 example

```
load("../../Spring2016/MTH225_Spring2016/EPA_mileage.Rdata")
str(epa)
```

```
## 'data.frame': 2884 obs. of  50 variables:
##  $ yr         : int  2009 2009 2009 2009 2009 2009 2009 2009 2009 2009 ...
##  $ mfr        : int  20 20 20 20 20 20 20 20 20 20 ...
##  $ mfr.name   : Factor w/ 32 levels "ASTON MARTIN",..: 5 5 5 5 5 5 5 5 5 5 ...
##  $ bidx       : int  1 1 3 3 4 4 201 201 202 202 ...
##  $ vid        : Factor w/ 686 levels "04-NHW2","05-GRN1",..: 529 529 529 529 524 524 510
##  $ cfg        : int  0 0 1 1 2 2 0 0 0 0 ...
##  $ carline    : Factor w/ 443 levels "128I","128I CONVERTIBLE",..: 234 234 235 235 234 23
##  $ car.truck  : Factor w/ 2 levels "C","T": 2 2 2 2 2 2 2 2 2 2 ...
##  $ cid        : int  215 215 215 215 144 144 148 148 148 148 ...
##  $ police     : Factor w/ 2 levels "N","Y": 1 1 1 1 1 1 1 1 1 1 ...
##  $ rhp        : int  235 235 235 235 173 173 220 220 220 220 ...
##  $ ec1        : logi  NA NA NA NA NA NA ...
##  $ ec2        : logi  NA NA NA NA NA NA ...
##  $ ec3        : logi  NA NA NA NA NA NA ...
##  $ ec4        : logi  NA NA NA NA NA NA ...
##  $ ec5        : logi  NA NA NA NA NA NA ...
##  $ evc        : int  102 102 102 102 102 102 102 102 102 102 ...
##  $ trns       : Factor w/ 17 levels "A4","A6","AU",..: 7 7 7 7 5 5 5 5 5 5 ...
##  $ drv        : Factor w/ 3 levels "4","F","R": 2 2 1 1 2 2 2 2 2 2 ...
##  $ od         : int  2 2 2 2 2 2 2 2 2 2 ...
##  $ etw        : int  4500 4500 4500 4500 4000 4000 3625 3625 3625 3625 ...
##  $ cmp        : num  10 10 10 10 10.5 10.5 9.5 9.5 9.5 9.5 ...
##  $ axle       : num  2.24 2.24 2.24 2.24 2.95 2.95 2.69 2.69 2.69 2.69 ...
##  $ n.v        : num  28.7 28.7 28.7 28.7 36 36 37.3 37.3 37.7 37.7 ...
##  $ a.c        : Factor w/ 2 levels "N","Y": 2 2 2 2 2 2 2 2 2 2 ...
##  $ dhp        : num  NA NA NA NA NA NA NA NA NA NA ...
##  $ sil        : int  1 1 1 1 1 1 1 1 1 1 ...
##  $ prc        : int  3 21 3 21 3 21 3 21 3 21 ...
##  $ prp        : int  31 31 32 32 32 32 31 31 31 31 ...
##  $ tnum       : int  1083480 1083479 1086540 1086539 1083587 1083586 1051401 1051400 1051
##  $ fuel       : int  61 61 61 61 61 61 61 61 61 61 ...
##  $ C.H        : Factor w/ 2 levels "C","H": 2 1 2 1 2 1 2 1 2 1 ...
##  $ avcd       : Factor w/ 3 levels "","1","A": 1 1 1 1 1 1 1 1 1 1 ...
##  $ wt         : num  NA NA NA NA NA NA NA NA NA NA ...
##  $ hc         : num  0.023 0.064 NA NA NA NA 0.002 0.049 0.001 0.037 ...
##  $ co         : num  0.4 1.07 NA NA NA NA 0.03 0.5 0.07 0.27 ...
##  $ co2        : int  275 459 NA NA NA NA 260 384 260 374 ...
##  $ nox        : num  NA 0 NA NA NA NA NA 0.03 NA 0.02 ...
##  $ pm         : num  NA NA NA NA NA NA NA NA NA NA ...
##  $ mpg        : num  32.2 19.3 29.9 18.4 35 23.8 34.1 23 34.1 23.7 ...
```

```
##  $ target.a   : num  37.7 37.7 37.7 37.7 28 ...
##  $ target.b   : num  0.634 0.634 0.634 0.634 0.558 ...
##  $ target.c   : num  0.024 0.024 0.024 0.024 0.021 ...
##  $ set.a      : num  13.5 13.5 13.5 13.5 10.8 ...
##  $ set.b      : num  0.104 0.104 0.104 0.104 0.129 ...
##  $ set.c      : num  0.0259 0.0259 0.0259 0.0259 0.0181 ...
##  $ engine.code: Factor w/ 441 levels "07 L537","1",..: 352 352 354 354 236 236 357 357 35
##  $ eng.family : Factor w/ 305 levels "9ADXT04.23UD",..: 33 33 33 33 48 48 45 45 47 47 ...
##  $ vpc        : int  6 6 6 6 4 4 4 4 4 4 ...
##  $ cstdwn     : num  16.1 16.1 16.1 16.1 17.4 ...
```

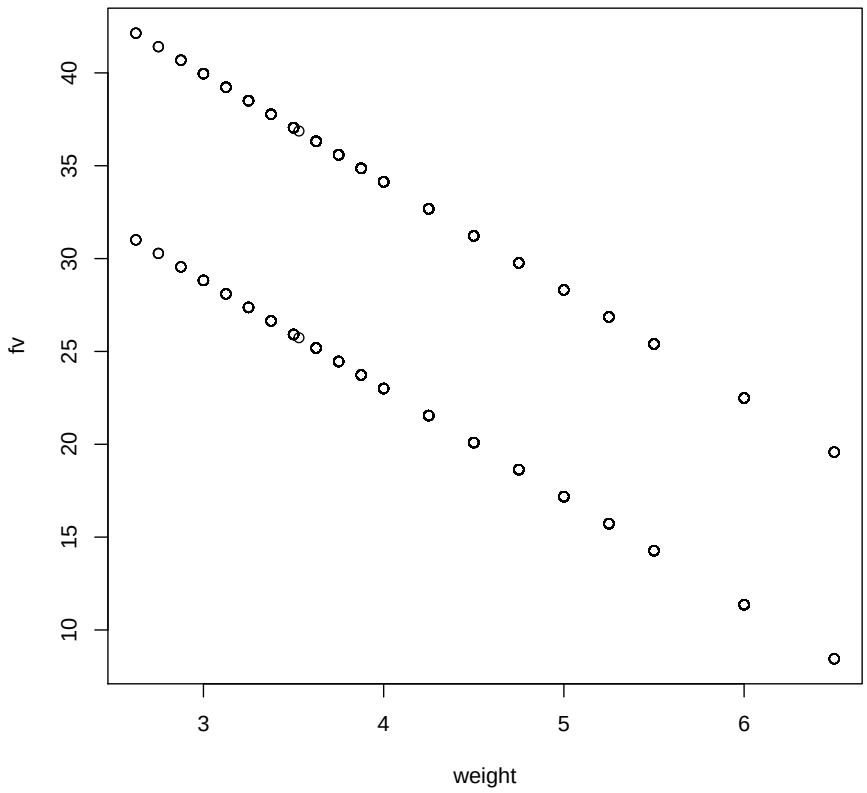
```
cityhighway<-as.numeric(epa$C.H=='H')  #city or highway
weight<-epa$etw/1000                   #etw has vehicle weight
N<-length(weight)                      #number of observations
mpg<-epa$mpg
```

Ordinary least squares model

```
lm2<-lm(mpg~epa$C.H+weight)
summary(lm2)

##
## Call:
## lm(formula = mpg ~ epa$C.H + weight)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -15.788  -2.277   0.064   2.111  39.232
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) 46.28948    0.41455  111.66   <2e-16 ***
## epa$C.HH    11.13104    0.15790   70.49   <2e-16 ***
## weight      -5.82189    0.09196  -63.31   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 4.24 on 2881 degrees of freedom
## Multiple R-squared:  0.7576,Adjusted R-squared:  0.7574
## F-statistic:  4502 on 2 and 2881 DF,  p-value: < 2.2e-16

fv<-lm2$fitted.values
plot(fv~weight)
```



Call STAN for Bayesian model

```
library(rstan)                                  #make sure rstan is available

## Loading required package:  ggplot2
##
## Attaching package:  'ggplot2'
## The following object is masked _by_ '.GlobalEnv':
##
##    mpg
## Loading required package:  StanHeaders
## rstan (Version 2.14.1, packaged:  2016-12-28 14:55:41 UTC, GitRev:
5fa1e80eb817)
## For execution on a local, multicore CPU with excess RAM we recommend
calling
## rstan_options(auto_write = TRUE)
## options(mc.cores = parallel::detectCores())
```

```
rstan_options(auto_write = TRUE)              #use multiple cores
options(mc.cores = parallel::detectCores())   #if we have them
stanfit<-stan("week8_IC1_covariance_example.stan")     #call STAN using defaults
```

```
## In file included from /usr/lib64/R/library/RcppEigen/include/Eigen/Core:276:0,
##                  from /usr/lib64/R/library/RcppEigen/include/Eigen/Dense:1,
##                  from /usr/lib64/R/library/StanHeaders/include/stan/math/prim/mat/fun/Eig
##                  from /usr/lib64/R/library/StanHeaders/include/stan/math/rev/mat/fun/Eige
##                  from /usr/lib64/R/library/StanHeaders/include/stan/math/rev/core/matrix_
##                  from /usr/lib64/R/library/StanHeaders/include/stan/math/rev/core.hpp:14,
##                  from /usr/lib64/R/library/StanHeaders/include/stan/math/rev/mat.hpp:4,
##                  from /usr/lib64/R/library/StanHeaders/include/stan/math.hpp:4,
##                  from /usr/lib64/R/library/StanHeaders/include/src/stan/model/model_heade
##                  from file5caf47e26a20.cpp:8:
## /usr/lib64/R/library/RcppEigen/include/Eigen/src/Core/Functors.h:973:28: warning: templat
##  struct functor_traits<std::binder2nd<T> >
##                             ^~~~~~~~~
## In file included from /usr/include/c++/6.3.1/bits/stl_function.h:1127:0,
##                  from /usr/include/c++/6.3.1/string:48,
##                  from /usr/include/c++/6.3.1/bits/locale_classes.h:40,
##                  from /usr/include/c++/6.3.1/bits/ios_base.h:41,
##                  from /usr/include/c++/6.3.1/ios:42,
##                  from /usr/include/c++/6.3.1/istream:38,
##                  from /usr/include/c++/6.3.1/sstream:38,
##                  from /usr/lib64/R/library/StanHeaders/include/stan/math/memory/stack_all
##                  from /usr/lib64/R/library/StanHeaders/include/stan/math/rev/core/autodif
##                  from /usr/lib64/R/library/StanHeaders/include/stan/math/rev/core.hpp:4,
##                  from /usr/lib64/R/library/StanHeaders/include/stan/math/rev/mat.hpp:4,
##                  from /usr/lib64/R/library/StanHeaders/include/stan/math.hpp:4,
##                  from /usr/lib64/R/library/StanHeaders/include/src/stan/model/model_heade
##                  from file5caf47e26a20.cpp:8:
## /usr/include/c++/6.3.1/backward/binders.h:143:11: note: declared here
##      class binder2nd
##            ^~~~~~~~~
## In file included from /usr/lib64/R/library/RcppEigen/include/Eigen/Core:276:0,
##                  from /usr/lib64/R/library/RcppEigen/include/Eigen/Dense:1,
##                  from /usr/lib64/R/library/StanHeaders/include/stan/math/prim/mat/fun/Eig
##                  from /usr/lib64/R/library/StanHeaders/include/stan/math/rev/mat/fun/Eige
##                  from /usr/lib64/R/library/StanHeaders/include/stan/math/rev/core/matrix_
##                  from /usr/lib64/R/library/StanHeaders/include/stan/math/rev/core.hpp:14,
##                  from /usr/lib64/R/library/StanHeaders/include/stan/math/rev/mat.hpp:4,
##                  from /usr/lib64/R/library/StanHeaders/include/stan/math.hpp:4,
##                  from /usr/lib64/R/library/StanHeaders/include/src/stan/model/model_heade
##                  from file5caf47e26a20.cpp:8:
## /usr/lib64/R/library/RcppEigen/include/Eigen/src/Core/Functors.h:977:28: warning: templat
##  struct functor_traits<std::binder1st<T> >
```

```
##                               ^~~~~~~~~
## In file included from /usr/include/c++/6.3.1/bits/stl_function.h:1127:0,
##                  from /usr/include/c++/6.3.1/string:48,
##                  from /usr/include/c++/6.3.1/bits/locale_classes.h:40,
##                  from /usr/include/c++/6.3.1/bits/ios_base.h:41,
##                  from /usr/include/c++/6.3.1/ios:42,
##                  from /usr/include/c++/6.3.1/istream:38,
##                  from /usr/include/c++/6.3.1/sstream:38,
##                  from /usr/lib64/R/library/StanHeaders/include/stan/math/memory/stack_all
##                  from /usr/lib64/R/library/StanHeaders/include/stan/math/rev/core/autodif
##                  from /usr/lib64/R/library/StanHeaders/include/stan/math/rev/core.hpp:4,
##                  from /usr/lib64/R/library/StanHeaders/include/stan/math/rev/mat.hpp:4,
##                  from /usr/lib64/R/library/StanHeaders/include/stan/math.hpp:4,
##                  from /usr/lib64/R/library/StanHeaders/include/src/stan/model/model_heade
##                  from file5caf47e26a20.cpp:8:
## /usr/include/c++/6.3.1/backward/binders.h:108:11: note: declared here
##      class binder1st
##            ^~~~~~~~~
## In file included from /usr/lib64/R/library/RcppEigen/include/Eigen/Core:326:0,
##                  from /usr/lib64/R/library/RcppEigen/include/Eigen/Dense:1,
##                  from /usr/lib64/R/library/StanHeaders/include/stan/math/prim/mat/fun/Eig
##                  from /usr/lib64/R/library/StanHeaders/include/stan/math/rev/mat/fun/Eige
##                  from /usr/lib64/R/library/StanHeaders/include/stan/math/rev/core/matrix_
##                  from /usr/lib64/R/library/StanHeaders/include/stan/math/rev/core.hpp:14,
##                  from /usr/lib64/R/library/StanHeaders/include/stan/math/rev/mat.hpp:4,
##                  from /usr/lib64/R/library/StanHeaders/include/stan/math.hpp:4,
##                  from /usr/lib64/R/library/StanHeaders/include/src/stan/model/model_heade
##                  from file5caf47e26a20.cpp:8:
## /usr/lib64/R/library/RcppEigen/include/Eigen/src/Core/products/GeneralBlockPanelKernel.h
## /usr/lib64/R/library/RcppEigen/include/Eigen/src/Core/products/GeneralBlockPanelKernel.h
##          if(nr==4) traits.initAcc(C3);
##          ~~
## /usr/lib64/R/library/RcppEigen/include/Eigen/src/Core/products/GeneralBlockPanelKernel.h
##                    traits.initAcc(C4);
##                    ~~~~~~
## /usr/lib64/R/library/RcppEigen/include/Eigen/src/Core/products/GeneralBlockPanelKernel.h
##          if(nr==4) R3 = ploadu<ResPacket>(r3);
##          ~~
## /usr/lib64/R/library/RcppEigen/include/Eigen/src/Core/products/GeneralBlockPanelKernel.h
##                    traits.acc(C0, alphav, R0);
##                    ~~~~~~
## /usr/lib64/R/library/RcppEigen/include/Eigen/src/Core/products/GeneralBlockPanelKernel.h
##          if(nr==4) traits.acc(C3, alphav, R3);
##          ~~
## /usr/lib64/R/library/RcppEigen/include/Eigen/src/Core/products/GeneralBlockPanelKernel.h
```

```
##                     pstoreu(r0, R0);
##                     ^~~~~~~
## In file included from /usr/lib64/R/library/RcppEigen/include/Eigen/SparseLU:29:0,
##                  from /usr/lib64/R/library/RcppEigen/include/Eigen/Sparse:22,
##                  from /usr/lib64/R/library/StanHeaders/include/stan/math/prim/mat/fun/csr
##                  from /usr/lib64/R/library/StanHeaders/include/stan/math/prim/mat.hpp:85,
##                  from /usr/lib64/R/library/StanHeaders/include/stan/math/rev/mat.hpp:11,
##                  from /usr/lib64/R/library/StanHeaders/include/stan/math.hpp:4,
##                  from /usr/lib64/R/library/StanHeaders/include/src/stan/model/model_heade
##                  from file5caf47e26a20.cpp:8:
## /usr/lib64/R/library/RcppEigen/include/Eigen/src/SparseLU/SparseLU_gemm_kernel.h: In func
## /usr/lib64/R/library/RcppEigen/include/Eigen/src/SparseLU/SparseLU_gemm_kernel.h:78:9: wa
##          if(RK==4) b30 = pset1<Packet>(Bc0[3]);
##          ^~
## /usr/lib64/R/library/RcppEigen/include/Eigen/src/SparseLU/SparseLU_gemm_kernel.h:79:19: r
##                     b01 = pset1<Packet>(Bc1[0]);
##                     ^~~
## In file included from /usr/lib64/R/library/BH/include/boost/numeric/ublas/matrix.hpp:19:0
##                  from /usr/lib64/R/library/BH/include/boost/numeric/odeint/util/ublas_wra
##                  from /usr/lib64/R/library/BH/include/boost/numeric/odeint.hpp:25,
##                  from /usr/lib64/R/library/StanHeaders/include/stan/math/prim/arr/functor
##                  from /usr/lib64/R/library/StanHeaders/include/stan/math/prim/arr.hpp:36,
##                  from /usr/lib64/R/library/StanHeaders/include/stan/math/prim/mat.hpp:299
##                  from /usr/lib64/R/library/StanHeaders/include/stan/math/rev/mat.hpp:11,
##                  from /usr/lib64/R/library/StanHeaders/include/stan/math.hpp:4,
##                  from /usr/lib64/R/library/StanHeaders/include/src/stan/model/model_heade
##                  from file5caf47e26a20.cpp:8:
## /usr/lib64/R/library/BH/include/boost/numeric/ublas/matrix_expression.hpp: In member func
## /usr/lib64/R/library/BH/include/boost/numeric/ublas/matrix_expression.hpp:2224:17: warnin
##                  if (it2_ != it2_end_)
##                  ^~
## /usr/lib64/R/library/BH/include/boost/numeric/ublas/matrix_expression.hpp:2227:21: note:
##                     if (it2_ != it2_end_) {
##                     ^~
## In file included from /usr/lib64/R/library/BH/include/boost/multi_array/base.hpp:28:0,
##                  from /usr/lib64/R/library/BH/include/boost/multi_array.hpp:21,
##                  from /usr/lib64/R/library/BH/include/boost/numeric/odeint/util/multi_arr
##                  from /usr/lib64/R/library/BH/include/boost/numeric/odeint.hpp:61,
##                  from /usr/lib64/R/library/StanHeaders/include/stan/math/prim/arr/functor
##                  from /usr/lib64/R/library/StanHeaders/include/stan/math/prim/arr.hpp:36,
##                  from /usr/lib64/R/library/StanHeaders/include/stan/math/prim/mat.hpp:299
##                  from /usr/lib64/R/library/StanHeaders/include/stan/math/rev/mat.hpp:11,
##                  from /usr/lib64/R/library/StanHeaders/include/stan/math.hpp:4,
##                  from /usr/lib64/R/library/StanHeaders/include/src/stan/model/model_heade
##                  from file5caf47e26a20.cpp:8:
```

```
## /usr/lib64/R/library/BH/include/boost/multi_array/concept_checks.hpp: In static member fu
## /usr/lib64/R/library/BH/include/boost/multi_array/concept_checks.hpp:42:43: warning: type
##        typedef typename Array::index_range index_range;
##                                           ^~~~~~~~~~~
## /usr/lib64/R/library/BH/include/boost/multi_array/concept_checks.hpp:43:37: warning: type
##        typedef typename Array::index index;
##                                     ^~~~~
## /usr/lib64/R/library/BH/include/boost/multi_array/concept_checks.hpp: In static member fu
## /usr/lib64/R/library/BH/include/boost/multi_array/concept_checks.hpp:53:43: warning: type
##        typedef typename Array::index_range index_range;
##                                           ^~~~~~~~~~~
## /usr/lib64/R/library/BH/include/boost/multi_array/concept_checks.hpp:54:37: warning: type
##        typedef typename Array::index index;
##                                     ^~~~~
## In file included from /usr/lib64/R/library/StanHeaders/include/stan/math/rev/core.hpp:42:
##                  from /usr/lib64/R/library/StanHeaders/include/stan/math/rev/mat.hpp:4,
##                  from /usr/lib64/R/library/StanHeaders/include/stan/math.hpp:4,
##                  from /usr/lib64/R/library/StanHeaders/include/src/stan/model/model_header
##                  from file5caf47e26a20.cpp:8:
## /usr/lib64/R/library/StanHeaders/include/stan/math/rev/core/set_zero_all_adjoints.hpp: At
## /usr/lib64/R/library/StanHeaders/include/stan/math/rev/core/set_zero_all_adjoints.hpp:14:
##      static void set_zero_all_adjoints() {
##                  ^~~~~~~~~~~~~~~~~~~~~
```

```
print(stanfit)
```

```
## Inference for Stan model: week8_IC1_covariance_example.
## 4 chains, each with iter=2000; warmup=1000; thin=1;
## post-warmup draws per chain=1000, total post-warmup draws=4000.
##
##             mean se_mean   sd     2.5%      25%      50%      75%    97.5%
## city       -3.72    0.01 0.42    -4.51    -4.01    -3.72    -3.43    -2.93
## highway     7.40    0.01 0.41     6.61     7.11     7.40     7.69     8.20
## beta       -5.82    0.00 0.09    -6.00    -5.88    -5.82    -5.75    -5.65
## sigma       4.24    0.00 0.06     4.13     4.20     4.24     4.28     4.35
## lp__    -5609.74    0.04 1.45 -5613.60 -5610.43 -5609.43 -5608.69 -5607.94
##         n_eff Rhat
## city      992    1
## highway  1020    1
## beta      990    1
## sigma    1832    1
## lp__     1212    1
##
## Samples were drawn using NUTS(diag_e) at Mon Mar 13 08:19:04 2017.
## For each parameter, n_eff is a crude measure of effective sample size,
## and Rhat is the potential scale reduction factor on split chains (at
```

```
## convergence, Rhat=1).
```

Launch shinystan

```
library(shinystan)                                    #launch shinystan

## Loading required package:  shiny
##
## This is shinystan version 2.3.0

launch_shinystan(stanfit)

##
## Creating shinystan object...
##
## Launching ShinyStan interface...  for large models this  may take
some time.
##
## Listening on http://127.0.0.1:6222
```