

# NAG Library Function Document

## nag\_regsn\_ridge (g02kbc)

### 1 Purpose

nag\_regsn\_ridge (g02kbc) calculates a ridge regression, with ridge parameters supplied by you.

### 2 Specification

```
#include <nag.h>
#include <nagg02.h>

void nag_regsn_ridge (Nag_OrderType order, Integer n, Integer m,
  const double x[], Integer pdx, const Integer isx[], Integer ip,
  const double y[], Integer lh, const double h[], double nep[],
  Nag_ParaOption wantb, double b[], Integer pdb, Nag_VIFOption wantvf,
  double vf[], Integer pdvf, Integer lpec, const Nag_PredictError pec[],
  double pe[], Integer pdpe, NagError *fail)
```

### 3 Description

A linear model has the form:

$$y = c + X\beta + \epsilon,$$

where

$y$  is an  $n$  by 1 matrix of values of a dependent variable;

$c$  is a scalar intercept term;

$X$  is an  $n$  by  $m$  matrix of values of independent variables;

$\beta$  is a  $m$  by 1 matrix of unknown values of parameters;

$\epsilon$  is an  $n$  by 1 matrix of unknown random errors such that variance of  $\epsilon = \sigma^2 I$ .

Let  $\tilde{X}$  be the mean-centred  $X$  and  $\tilde{y}$  the mean-centred  $y$ . Furthermore,  $\tilde{X}$  is scaled such that the diagonal elements of the cross product matrix  $\tilde{X}^T \tilde{X}$  are one. The linear model now takes the form:

$$\tilde{y} = \tilde{X}\tilde{\beta} + \epsilon.$$

Ridge regression estimates the parameters  $\tilde{\beta}$  in a penalised least squares sense by finding the  $\tilde{b}$  that minimizes

$$\|\tilde{X}\tilde{b} - \tilde{y}\|^2 + h\|\tilde{b}\|^2, \quad h > 0,$$

where  $\|\cdot\|$  denotes the  $\ell_2$ -norm and  $h$  is a scalar regularization or ridge parameter. For a given value of  $h$ , the parameters estimates  $\tilde{b}$  are found by evaluating

$$\tilde{b} = (\tilde{X}^T \tilde{X} + hI)^{-1} \tilde{X}^T \tilde{y}.$$

Note that if  $h = 0$  the ridge regression solution is equivalent to the ordinary least squares solution.

Rather than calculate the inverse of  $(\tilde{X}^T \tilde{X} + hI)$  directly, nag\_regsn\_ridge (g02kbc) uses the singular value decomposition (SVD) of  $\tilde{X}$ . After decomposing  $\tilde{X}$  into  $UDV^T$  where  $U$  and  $V$  are orthogonal matrices and  $D$  is a diagonal matrix, the parameter estimates become

$$\tilde{b} = V(D^T D + hI)^{-1} D U^T \tilde{y}.$$

A consequence of introducing the ridge parameter is that the effective number of parameters,  $\gamma$ , in the model is given by the sum of diagonal elements of

$$D^T D (D^T D + hI)^{-1},$$

see Moody (1992) for details.

Any multi-collinearity in the design matrix  $X$  may be highlighted by calculating the variance inflation factors for the fitted model. The  $j$ th variance inflation factor,  $v_j$ , is a scaled version of the multiple correlation coefficient between independent variable  $j$  and the other independent variables,  $R_j$ , and is given by

$$v_j = \frac{1}{1 - R_j^2}, \quad j = 1, 2, \dots, m.$$

The  $m$  variance inflation factors are calculated as the diagonal elements of the matrix:

$$(\tilde{X}^T \tilde{X} + hI)^{-1} \tilde{X}^T \tilde{X} (\tilde{X}^T \tilde{X} + hI)^{-1},$$

which, using the SVD of  $\tilde{X}$ , is equivalent to the diagonal elements of the matrix:

$$V(D^T D + hI)^{-1} D^T D (D^T D + hI)^{-1} V^T.$$

Given a value of  $h$ , any or all of the following prediction criteria are available:

(a) Generalized cross-validation (GCV):

$$\frac{ns}{(n - \gamma)^2};$$

(b) Unbiased estimate of variance (UEV):

$$\frac{s}{n - \gamma};$$

(c) Future prediction error (FPE):

$$\frac{1}{n} \left( s + \frac{2\gamma s}{n - \gamma} \right);$$

(d) Bayesian information criterion (BIC):

$$\frac{1}{n} \left( s + \frac{\log(n)\gamma s}{n - \gamma} \right);$$

(e) Leave-one-out cross-validation (LOOCV),

where  $s$  is the sum of squares of residuals.

Although parameter estimates  $\tilde{b}$  are calculated by using  $\tilde{X}$ , it is usual to report the parameter estimates  $b$  associated with  $X$ . These are calculated from  $\tilde{b}$ , and the means and scalings of  $X$ . Optionally, either  $\tilde{b}$  or  $b$  may be calculated.

## 4 References

Hastie T, Tibshirani R and Friedman J (2003) *The Elements of Statistical Learning: Data Mining, Inference and Prediction* Springer Series in Statistics

Moody J.E. (1992) The effective number of parameters: An analysis of generalisation and regularisation in nonlinear learning systems *In: Neural Information Processing Systems* (eds J E Moody, S J Hanson, and R P Lippmann) 4 847–854 Morgan Kaufmann San Mateo CA

## 5 Arguments

1: **order** – Nag\_OrderType

*Input*

*On entry:* the **order** argument specifies the two-dimensional storage scheme being used, i.e., row-major ordering or column-major ordering. C language defined storage is specified by

**order** = Nag\_RowMajor. See Section 2.3.1.3 in How to Use the NAG Library and its Documentation for a more detailed explanation of the use of this argument.

*Constraint:* **order** = Nag\_RowMajor or Nag\_ColMajor.

- 2: **n** – Integer *Input*  
*On entry:*  $n$ , the number of observations.  
*Constraint:*  $n \geq 1$ .
- 3: **m** – Integer *Input*  
*On entry:* the number of independent variables available in the data matrix  $X$ .  
*Constraint:*  $m \leq n$ .
- 4: **x**[*dim*] – const double *Input*  
**Note:** the dimension, *dim*, of the array **x** must be at least  
 $\max(1, \mathbf{pdx} \times \mathbf{m})$  when **order** = Nag\_ColMajor;  
 $\max(1, \mathbf{n} \times \mathbf{pdx})$  when **order** = Nag\_RowMajor.  
The ( $i, j$ )th element of the matrix  $X$  is stored in  
 $\mathbf{x}[(j - 1) \times \mathbf{pdx} + i - 1]$  when **order** = Nag\_ColMajor;  
 $\mathbf{x}[(i - 1) \times \mathbf{pdx} + j - 1]$  when **order** = Nag\_RowMajor.  
*On entry:* the values of independent variables in the data matrix  $X$ .
- 5: **pdx** – Integer *Input*  
*On entry:* the stride separating row or column elements (depending on the value of **order**) in the array **x**.  
*Constraints:*  
if **order** = Nag\_ColMajor,  $\mathbf{pdx} \geq \mathbf{n}$ ;  
if **order** = Nag\_RowMajor,  $\mathbf{pdx} \geq \mathbf{m}$ .
- 6: **isx**[**m**] – const Integer *Input*  
*On entry:* indicates which  $m$  independent variables are included in the model.  
**isx**[ $j - 1$ ] = 1  
The  $j$ th variable in **x** will be included in the model.  
**isx**[ $j - 1$ ] = 0  
Variable  $j$  is excluded.  
*Constraint:* **isx**[ $j - 1$ ] = 0 or 1, for  $j = 1, 2, \dots, \mathbf{m}$ .
- 7: **ip** – Integer *Input*  
*On entry:*  $m$ , the number of independent variables in the model.  
*Constraints:*  
 $1 \leq \mathbf{ip} \leq \mathbf{m}$ ;  
Exactly **ip** elements of **isx** must be equal to 1.
- 8: **y**[**n**] – const double *Input*  
*On entry:* the  $n$  values of the dependent variable  $y$ .

- 9: **lh** – Integer *Input*  
*On entry:* the number of supplied ridge parameters.  
*Constraint:* **lh** > 0.
- 10: **h[lh]** – const double *Input*  
*On entry:* **h**[*j* – 1] is the value of the *j*th ridge parameter *h*.  
*Constraint:* **h**[*j* – 1] ≥ 0.0, for *j* = 1, 2, ..., **lh**.
- 11: **nep[lh]** – double *Output*  
*On exit:* **nep**[*j* – 1] is the number of effective parameters,  $\gamma$ , in the *j*th model, for *j* = 1, 2, ..., **lh**.
- 12: **wantb** – Nag\_ParaOption *Input*  
*On entry:* defines the options for parameter estimates.  
**wantb** = Nag\_NoPara  
Parameter estimates are not calculated and **b** is not referenced.  
**wantb** = Nag\_OrigPara  
Parameter estimates *b* are calculated for the original data.  
**wantb** = Nag\_StandPara  
Parameter estimates  $\tilde{b}$  are calculated for the standardized data.  
*Constraint:* **wantb** = Nag\_NoPara, Nag\_OrigPara or Nag\_StandPara.
- 13: **b[dim]** – double *Output*  
**Note:** the dimension, *dim*, of the array **b** must be at least  
 $\mathbf{pdb} \times \mathbf{lh}$  when **wantb** ≠ Nag\_NoPara and **order** = Nag\_ColMajor;  
 $\max(1, (\mathbf{ip} + 1) \times \mathbf{pdb})$  when **wantb** ≠ Nag\_NoPara and **order** = Nag\_RowMajor;  
1 otherwise.  
Where **B**(*i*, *j*) appears in this document, it refers to the array element  
 $\mathbf{b}[(j - 1) \times \mathbf{pdb} + i - 1]$  when **order** = Nag\_ColMajor;  
 $\mathbf{b}[(i - 1) \times \mathbf{pdb} + j - 1]$  when **order** = Nag\_RowMajor.  
*On exit:* if **wantb** ≠ Nag\_NoPara, **b** contains the intercept and parameter estimates for the fitted ridge regression model in the order indicated by **isx**. **B**(1, *j*), for *j* = 1, 2, ..., **lh**, contains the estimate for the intercept; **B**(*i* + 1, *j*) contains the parameter estimate for the *i*th independent variable in the model fitted with ridge parameter **h**[*j* – 1], for *i* = 1, 2, ..., **ip**.
- 14: **pdb** – Integer *Input*  
*On entry:* the stride separating row or column elements (depending on the value of **order**) in the array **b**.  
*Constraints:*  
if **order** = Nag\_ColMajor,  
if **wantb** ≠ Nag\_NoPara, **pdb** ≥ **ip** + 1;  
otherwise **pdb** ≥ 1.;  
if **order** = Nag\_RowMajor,  
if **wantb** ≠ Nag\_NoPara, **pdb** ≥ **lh**;  
otherwise **pdb** ≥ 1..

- 15: **wantvf** – Nag\_VIFOption *Input*  
*On entry:* defines the options for variance inflation factors.  
**wantvf** = Nag\_NoVIF  
 Variance inflation factors are not calculated and the array **vf** is not referenced.  
**wantvf** = Nag\_WantVIF  
 Variance inflation factors are calculated.  
*Constraints:*  
**wantvf** = Nag\_NoVIF or Nag\_WantVIF;  
 if **wantb** = Nag\_NoPara, **wantvf** = Nag\_WantVIF.
- 16: **vf**[*dim*] – double *Output*  
**Note:** the dimension, *dim*, of the array **vf** must be at least  
 $\mathbf{pdvf} \times \mathbf{lh}$  when **wantvf**  $\neq$  Nag\_NoVIF and **order** = Nag\_ColMajor;  
 $\max(1, \mathbf{ip} \times \mathbf{pdvf})$  when **wantvf**  $\neq$  Nag\_NoVIF and **order** = Nag\_RowMajor;  
 1 otherwise.  
 Where  $\mathbf{VF}(i, j)$  appears in this document, it refers to the array element  
 $\mathbf{vf}[(j - 1) \times \mathbf{pdvf} + i - 1]$  when **order** = Nag\_ColMajor;  
 $\mathbf{vf}[(i - 1) \times \mathbf{pdvf} + j - 1]$  when **order** = Nag\_RowMajor.  
*On exit:* if **wantvf** = Nag\_WantVIF, the variance inflation factors. For the *i*th independent variable in a model fitted with ridge parameter  $\mathbf{h}[j - 1]$ ,  $\mathbf{VF}(i, j)$  is the value of  $v_i$ , for  $i = 1, 2, \dots, \mathbf{ip}$ .
- 17: **pdvf** – Integer *Input*  
*On entry:* the stride separating row or column elements (depending on the value of **order**) in the array **vf**.  
*Constraints:*  
 if **order** = Nag\_ColMajor,  
   if **wantvf**  $\neq$  Nag\_NoVIF, **pdvf**  $\geq$  **ip**;  
   otherwise **pdvf**  $\geq$  1.;  
 if **order** = Nag\_RowMajor,  
   if **wantvf**  $\neq$  Nag\_NoVIF, **pdvf**  $\geq$  **lh**;  
   otherwise **pdvf**  $\geq$  1..
- 18: **lpec** – Integer *Input*  
*On entry:* the number of prediction error statistics to return; set **lpec**  $\leq$  0 for no prediction error estimates.
- 19: **pec**[**lpec**] – const Nag\_PredictError *Input*  
*On entry:* if **lpec**  $>$  0, **pec**[*j* - 1] defines the *j*th prediction error, for  $j = 1, 2, \dots, \mathbf{lpec}$ ; otherwise **pec** is not referenced.  
**pec**[*j* - 1] = Nag\_BIC  
 Bayesian information criterion (BIC).  
**pec**[*j* - 1] = Nag\_FPE  
 Future prediction error (FPE).  
**pec**[*j* - 1] = Nag\_GCV  
 Generalized cross-validation (GCV).  
**pec**[*j* - 1] = Nag\_LOOCV  
 Leave-one-out cross-validation (LOOCV).

$\mathbf{pec}[j-1] = \text{Nag\_EUV}$   
 Unbiased estimate of variance (UEV).

*Constraint:* if  $\mathbf{lpec} > 0$ ,  $\mathbf{pec}[j-1] = \text{Nag\_BIC}$ ,  $\text{Nag\_FPE}$ ,  $\text{Nag\_GCV}$ ,  $\text{Nag\_LOOCV}$  or  $\text{Nag\_EUV}$ , for  $j = 1, 2, \dots, \mathbf{lpec}$ .

20:  $\mathbf{pe}[\mathit{dim}]$  – double *Output*

**Note:** the dimension,  $\mathit{dim}$ , of the array  $\mathbf{pe}$  must be at least

$\mathbf{pdpe} \times \mathbf{lh}$  when  $\mathbf{lpec} > 0$  and  $\mathbf{order} = \text{Nag\_ColMajor}$ ;  
 $\max(1, \mathbf{lpec} \times \mathbf{pdpe})$  when  $\mathbf{lpec} > 0$  and  $\mathbf{order} = \text{Nag\_RowMajor}$ ;  
 1 otherwise.

Where  $\mathbf{PE}(i, j)$  appears in this document, it refers to the array element

$\mathbf{pe}[(j-1) \times \mathbf{pdpe} + i - 1]$  when  $\mathbf{order} = \text{Nag\_ColMajor}$ ;  
 $\mathbf{pe}[(i-1) \times \mathbf{pdpe} + j - 1]$  when  $\mathbf{order} = \text{Nag\_RowMajor}$ .

*On exit:* if  $\mathbf{lpec} \leq 0$ ,  $\mathbf{pe}$  is not referenced; otherwise  $\mathbf{PE}(i, j)$  contains the prediction error of criterion  $\mathbf{pec}[i-1]$  for the model fitted with ridge parameter  $\mathbf{h}[j-1]$ , for  $i = 1, 2, \dots, \mathbf{lpec}$  and  $j = 1, 2, \dots, \mathbf{lh}$ .

21:  $\mathbf{pdpe}$  – Integer *Input*

*On entry:* the stride separating row or column elements (depending on the value of  $\mathbf{order}$ ) in the array  $\mathbf{pe}$ .

*Constraints:*

if  $\mathbf{order} = \text{Nag\_ColMajor}$ ,  
     if  $\mathbf{lpec} > 0$ ,  $\mathbf{pdpe} \geq \mathbf{lpec}$ ;  
     otherwise  $\mathbf{pdpe} \geq 1$ .;  
 if  $\mathbf{order} = \text{Nag\_RowMajor}$ ,  
     if  $\mathbf{lpec} > 0$ ,  $\mathbf{pdpe} \geq \mathbf{lh}$ ;  
     otherwise  $\mathbf{pdpe} \geq 1$ .

22:  $\mathbf{fail}$  – NagError \* *Input/Output*

The NAG error argument (see Section 2.7 in How to Use the NAG Library and its Documentation).

## 6 Error Indicators and Warnings

### NE\_ALLOC\_FAIL

Dynamic memory allocation failed.

See Section 3.2.1.2 in How to Use the NAG Library and its Documentation for further information.

### NE\_BAD\_PARAM

On entry, argument  $\langle \mathit{value} \rangle$  had an illegal value.

### NE\_CONSTRAINT

On entry,  $\mathbf{wantb} = \text{Nag\_NoPara}$  and  $\mathbf{wantvf} = \text{Nag\_NoVIF}$ .

### NE\_ENUM\_INT\_2

On entry,  $\mathbf{pdb} = \langle \mathit{value} \rangle$  and  $\mathbf{ip} = \langle \mathit{value} \rangle$ .

Constraint: if  $\mathbf{wantb} \neq \text{Nag\_NoPara}$ ,  $\mathbf{pdb} \geq \mathbf{ip} + 1$ .

On entry, **pdvf** =  $\langle value \rangle$  and **ip** =  $\langle value \rangle$ .  
 Constraint: if **wantvf**  $\neq$  Nag\_NoVIF, **pdvf**  $\geq$  **ip**.

On entry, **wantb** =  $\langle value \rangle$ , **pdb** =  $\langle value \rangle$ , **lh** =  $\langle value \rangle$ .  
 Constraint: if **wantb**  $\neq$  Nag\_NoPara, **pdb**  $\geq$  **lh**;  
 otherwise **pdb**  $\geq$  1.

On entry, **wantvf** =  $\langle value \rangle$ , **pdvf** =  $\langle value \rangle$ , **lh** =  $\langle value \rangle$ .  
 Constraint: if **wantvf**  $\neq$  Nag\_NoVIF, **pdvf**  $\geq$  **lh**;  
 otherwise **pdvf**  $\geq$  1.

### NE\_INT

On entry, **lh** =  $\langle value \rangle$ .  
 Constraint: **lh**  $>$  0.

On entry, **n** =  $\langle value \rangle$ .  
 Constraint: **n**  $\geq$  1.

### NE\_INT\_2

On entry, **m** =  $\langle value \rangle$  and **n** =  $\langle value \rangle$ .  
 Constraint: **m**  $\leq$  **n**.

On entry, **pdpe** =  $\langle value \rangle$  and **lpec** =  $\langle value \rangle$ .  
 Constraint: **pdpe**  $\geq$  **lpec**.

On entry, **pdx** =  $\langle value \rangle$  and **m** =  $\langle value \rangle$ .  
 Constraint: **pdx**  $\geq$  **m**.

On entry, **pdx** =  $\langle value \rangle$  and **n** =  $\langle value \rangle$ .  
 Constraint: **pdx**  $\geq$  **n**.

### NE\_INT\_3

On entry, **pdpe** =  $\langle value \rangle$ , **lpec** =  $\langle value \rangle$  and **lh** =  $\langle value \rangle$ .  
 Constraint: if **lpec**  $>$  0, **pdpe**  $\geq$  **lh**;  
 otherwise **pdpe**  $\geq$  1.

### NE\_INT\_ARG\_CONS

**ip** does not equal the sum of elements in **isx**.

### NE\_INT\_ARRAY\_VAL\_1\_OR\_2

On entry, **isx**[ $i - 1$ ]  $\neq$  0 or 1 for at least one  $i$ .

### NE\_INTERNAL\_ERROR

An internal error has occurred in this function. Check the function call and any array sizes. If the call is correct then please contact NAG for assistance.

An unexpected error has been triggered by this function. Please contact NAG.  
 See Section 3.6.6 in How to Use the NAG Library and its Documentation for further information.

### NE\_NO\_LICENCE

Your licence key may have expired or may not have been installed correctly.  
 See Section 3.6.5 in How to Use the NAG Library and its Documentation for further information.

### NE\_REAL\_ARRAY\_CONS

On entry, **h**[ $i - 1$ ]  $<$  0 for at least one  $i$ .

## 7 Accuracy

The accuracy of `nag_regsn_ridge` (g02kbc) is closely related to that of the singular value decomposition.

## 8 Parallelism and Performance

`nag_regsn_ridge` (g02kbc) is threaded by NAG for parallel execution in multithreaded implementations of the NAG Library.

`nag_regsn_ridge` (g02kbc) makes calls to BLAS and/or LAPACK routines, which may be threaded within the vendor library used by this implementation. Consult the documentation for the vendor library for further information.

Please consult the x06 Chapter Introduction for information on how to control and interrogate the OpenMP environment used within this function. Please also consult the Users' Note for your implementation for any additional implementation-specific information.

## 9 Further Comments

`nag_regsn_ridge` (g02kbc) allocates internally  $\max(5 \times (n - 1), 2 \times ip \times ip) + (n + 3) \times ip + n$  elements of double precision storage.

## 10 Example

This example reads in data from an experiment to model body fat, and a selection of ridge regression models are calculated.

### 10.1 Program Text

```

/* nag_regsn_ridge (g02kbc) Example Program.
 *
 * NAGPRODCODE Version.
 *
 * Copyright 2016 Numerical Algorithms Group.
 *
 * Mark 26, 2016.
 */
/* Pre-processor includes */
#include <stdio.h>
#include <math.h>
#include <nag.h>
#include <nag_stdlib.h>
#include <nagg02.h>

int main(void)
{
    /*Integer scalar and array declarations */
    Integer exit_status = 0;
    Integer i, ip, ip1, j, lh, lpec, m, n, pl;
    Integer pdb, pdpe, pdvf, pdx;
    Integer *isx = 0;
    /*Double scalar and array declarations */
    double *b = 0, *h = 0, *nep = 0, *pe = 0, *vf = 0, *x = 0, *y = 0;
    /*Character scalar and array declarations */
    char spec[40], swantb[40];
    /*NAG Types */
    Nag_OrderType order;
    Nag_ParaOption wantb;
    Nag_VIFOption wantvf;
    Nag_PredictError *pec = 0;
    NagError fail;

    INIT_FAIL(fail);

```



```

    printf("%s\n", "nag_regsn_ridge (g02kbc) Example Program Results");
    /* Skip heading in data file */
#ifdef _WIN32
    scanf_s("%*[\n] ");
#else
    scanf("%*[\n] ");
#endif
    /* Read in the problem size information */
#ifdef _WIN32
    scanf_s("%" NAG_IFMT "%" NAG_IFMT "%" NAG_IFMT "%" NAG_IFMT "%39s%*[\n] ",
            &n, &m, &lh, &lpec, swantb, (unsigned)_countof(swantb));
#else
    scanf("%" NAG_IFMT "%" NAG_IFMT "%" NAG_IFMT "%" NAG_IFMT "%39s%*[\n] ",
            &n, &m, &lh, &lpec, swantb);
#endif
    wantb = (Nag_ParaOption) nag_enum_name_to_value(swantb);
    if (!(isx = NAG_ALLOC(m, Integer)))
    {
        printf("Allocation failure\n");
        exit_status = -1;
        goto END;
    }
    /* Read in the ISX flags */
    for (i = 0; i < m; i++)
#ifdef _WIN32
        scanf_s("%" NAG_IFMT " ", &isx[i]);
#else
        scanf("%" NAG_IFMT " ", &isx[i]);
#endif
    /* Total number of variables */
    ip = 0;
    for (j = 0; j < m; j++) {
        if (isx[j] == 1)
            ip = ip + 1;
    }
#ifdef NAG_COLUMN_MAJOR
    pdb = ip + 1;
#define B(I, J)  b[(J-1)*pdb + I-1]
    pdpe = lpec;
#define PE(I, J) pe[(J-1)*pdpe + I-1]
    pdvf = ip;
#define VF(I, J) vf[(J-1)*pdvf + I-1]
    pdx = n;
#define X(I, J)  x[(J-1)*pdx + I-1]
    order = Nag_ColMajor;
#else
    pdb = lh;
#define B(I, J)  b[(I-1)*pdb + J-1]
    pdpe = lh;
#define PE(I, J) pe[(I-1)*pdpe + J-1]
    pdvf = lh;
#define VF(I, J) vf[(I-1)*pdvf + J-1]
    pdx = m;
#define X(I, J)  x[(I-1)*pdx + J-1]
    order = Nag_RowMajor;
#endif
    if (!(b = NAG_ALLOC(pdb * (order == Nag_RowMajor ? (ip + 1) : lh), double))
        || !(h = NAG_ALLOC(lh, double)) || !(nep = NAG_ALLOC(lh, double))
        || !(pe = NAG_ALLOC(pdpe * (order == Nag_RowMajor ? lpec : lh), double))
        || !(vf = NAG_ALLOC(pdvf * (order == Nag_RowMajor ? ip : lh), double))
        || !(x = NAG_ALLOC(pdx * (order == Nag_RowMajor ? n : m), double))
        || !(y = NAG_ALLOC(n, double))
        || !(pec = NAG_ALLOC(lpec, Nag_PredictError)))
    {
        printf("Allocation failure\n");
        exit_status = -1;
    }

```

```

        goto END;
    }
    /* Read in the data */
    if (lpec > 0) {
        for (i = 0; i < lpec; i++) {
#ifdef _WIN32
            scanf_s("%39s ", spec, (unsigned)_countof(spec));
#else
            scanf("%39s ", spec);
#endif
            pec[i] = (Nag_PredictError) nag_enum_name_to_value(spec);
        }
#ifdef _WIN32
        scanf_s("%*[\n] ");
#else
        scanf("%*[\n] ");
#endif
    }
    for (i = 1; i <= n; i++) {
        for (j = 1; j <= m; j++)
#ifdef _WIN32
            scanf_s("%lf ", &X(i, j));
#else
            scanf("%lf ", &X(i, j));
#endif
#ifdef _WIN32
            scanf_s("%lf ", &y[i - 1]);
#else
            scanf("%lf ", &y[i - 1]);
#endif
    }
#ifdef _WIN32
    scanf_s("%*[\n] ");
#else
    scanf("%*[\n] ");
#endif
    /* Read in the ridge coefficients */
    for (i = 0; i < lh; i++)
#ifdef _WIN32
        scanf_s("%lf ", &h[i]);
#else
        scanf("%lf ", &h[i]);
#endif
#ifdef _WIN32
    scanf_s("%*[\n] ");
#else
    scanf("%*[\n] ");
#endif
    /* Output the variance inflation factors and parameter estimates */
    wantvf = Nag_WantVIF;
    /* Run the analysis */
    /*
     * nag_regsn_ridge (g02kbc)
     * Ridge regression
     */
    nag_regsn_ridge(order, n, m, x, pdx, isx, ip, y, lh, h, nep, wantb, b, pdb,
                    wantvf, vf, pdvf, lpec, pec, pe, pdpe, &fail);
    if (fail.code != NE_NOERROR) {
        printf("Error from nag_regsn_ridge (g02kbc).\n%s\n", fail.message);
        exit_status = 1;
        goto END;
    }
    /* Output results */
    ipl = ip - 1;
    /* Summaries */
    printf("%s%10" NAG_IFMT "\n", "Number of parameters used = ", ip + 1);
    printf("%s\n", "Effective number of parameters (NEP):");
    printf("%s\n", "    Ridge    ");
    printf("%s%s\n", "    Coeff.    ", "NEP");
    for (i = 1; i <= lh; i++)
        printf(" %10.4f %10.4f\n", h[i - 1], nep[i - 1]);

```

```

/* Parameter estimates */
if (wantb != Nag_NoPara) {
    printf("\n");
    if (wantb == Nag_OrigPara) {
        printf("%s\n", "Parameter Estimates (Original scalings)");
    }
    else {
        printf("%s\n", "Parameter Estimates (Standardised)");
    }
    pl = MIN(ip, 4);
    printf("%s\n", " Ridge ");
    printf("%s ", " Coeff. ");
    printf("%s ", "Intercept ");
    for (i = 1; i <= pl; i++)
        printf("%10" NAG_IFMT "%s", i, i % 4 ? " " : "\n");
    printf("\n");
    if (pl < ip1) {
        for (i = pl + 1; i <= ip1; i++)
            printf("%10" NAG_IFMT "%s", i, i % 5 ? " " : "\n");
        printf("\n");
    }
    pl = MIN(ip + 1, 5);
    for (i = 1; i <= lh; i++) {
        printf("%10.4f", h[i - 1]);
        for (j = 1; j <= pl; j++)
            printf("%10.4f%s", B(j, i), j % 5 ? " " : "\n");
        printf("\n");
        if (pl < ip) {
            for (j = pl + 1; j <= ip; j++)
                printf("%10.4f%s", B(j, i), j % 5 ? " " : "\n");
            printf("\n");
        }
    }
}
/* Variance inflation factors */
if (wantvf != Nag_NoVIF) {
    printf("\n");
    printf("%s\n", "Variance Inflation Factors");
    pl = MIN(ip, 5);
    printf("%s\n", " Ridge ");
    printf("%s", " Coeff. ");
    for (i = 1; i <= pl; i++)
        printf("%10" NAG_IFMT "%s", i, i % 5 ? " " : "\n");
    printf("\n");
    if (pl < ip) {
        for (i = pl + 1; i <= ip; i++)
            printf("%10" NAG_IFMT "%s", i, i % 5 ? " " : "\n");
        printf("\n");
    }
    for (i = 1; i <= lh; i++) {
        printf("%10.4f", h[i - 1]);
        for (j = 1; j <= pl; j++)
            printf("%10.4f%s", VF(j, i), j % 5 ? " " : "\n");
        printf("\n");
        if (pl < ip) {
            for (j = pl + 1; j <= ip; j++)
                printf("%10.4f%s", VF(j, i), j % 5 ? " " : "\n");
            printf("\n");
        }
    }
}
/* Prediction error criterion */
if (lpec > 0) {
    printf("\n");
    printf("%s\n", "Prediction error criterion");
    pl = MIN(lpec, 5);
    printf("%s\n", " Ridge ");
    printf("%s", " Coeff. ");
    for (i = 1; i <= pl; i++)
        printf("%10" NAG_IFMT "%s", i, i % 5 ? " " : "\n");
    printf("\n");
}

```

```

if (pl < lpec) {
  for (i = pl + 1; i <= lpec; i++)
    printf("%10" NAG_IFMT "%s", i, i % 5 ? " " : "\n");
  printf("\n");
}
for (i = 1; i <= lh; i++) {
  printf("%10.4f", h[i - 1]);
  for (j = 1; j <= pl; j++)
    printf("%10.4f%s", PE(j, i), j % 5 ? " " : "\n");
  if (pl < ip) {
    for (j = pl + 1; j <= ip; j++)
      printf("%10.4f%s", PE(j, i), j % 5 ? " " : "\n");
  }
}
printf("\n");
printf("%s\n", "Key:");
for (i = 1; i <= lpec; i++) {
  if (pec[i - 1] == Nag_LOOCV) {
    printf(" %5" NAG_IFMT " Leave one out cross-validation\n", i);
  }
  else if (pec[i - 1] == Nag_GCV) {
    printf(" %5" NAG_IFMT " Generalized cross-validation\n", i);
  }
  else if (pec[i - 1] == Nag_EUV) {
    printf(" %5" NAG_IFMT " Unbiased estimate of variance\n", i);
  }
  else if (pec[i - 1] == Nag_FPE) {
    printf(" %5" NAG_IFMT " Final prediction error\n", i);
  }
  else if (pec[i - 1] == Nag_BIC) {
    printf(" %5" NAG_IFMT " Bayesian information criterion\n", i);
  }
}
}
}

END:
NAG_FREE(b);
NAG_FREE(h);
NAG_FREE(nep);
NAG_FREE(pe);
NAG_FREE(vf);
NAG_FREE(x);
NAG_FREE(y);
NAG_FREE(isx);
NAG_FREE(pec);

return exit_status;
}

```

## 10.2 Program Data

```

nag_regsn_ridge (g02kbc) Example Program Data
20 3 16 5 Nag_OrigPara : n, m, lh, lpec, wantb
1 1 1 : isx
Nag_LOOCV Nag_GCV Nag_EUV Nag_FPE Nag_BIC : pec
19.5 43.1 29.1 11.9
24.7 49.8 28.2 22.8
30.7 51.9 37.0 18.7
29.8 54.3 31.1 20.1
19.1 42.2 30.9 12.9
25.6 53.9 23.7 21.7
31.4 58.5 27.6 27.1
27.9 52.1 30.6 25.4
22.1 49.9 23.2 21.3
25.5 53.5 24.8 19.3
31.1 56.6 30.0 25.4
30.4 56.7 28.3 27.2
18.7 46.5 23.0 11.7
19.7 44.2 28.6 17.8
14.6 42.7 21.3 12.8

```

```

29.5  54.4  30.1  23.9
27.7  55.3  25.7  22.6
30.2  58.6  24.6  25.4
22.7  48.2  27.1  14.8
25.2  51.0  27.5  21.1 : End of observations
0.0  0.002  0.004  0.006  0.008  0.010  0.012  0.014  0.016  0.018  0.020  0.022
0.024  0.026  0.028  0.030 : Ridge co-efficients

```

### 10.3 Program Results

nag\_regsn\_ridge (g02kbc) Example Program Results

Number of parameters used = 4

Effective number of parameters (NEP):

Ridge Coeff.	NEP
0.0000	4.0000
0.0020	3.2634
0.0040	3.1475
0.0060	3.0987
0.0080	3.0709
0.0100	3.0523
0.0120	3.0386
0.0140	3.0278
0.0160	3.0189
0.0180	3.0112
0.0200	3.0045
0.0220	2.9984
0.0240	2.9928
0.0260	2.9876
0.0280	2.9828
0.0300	2.9782

Parameter Estimates (Original scalings)

Ridge Coeff.	Intercept	1	2	3
0.0000	117.0847	4.3341	-2.8568	-2.1861
0.0020	22.2748	1.4644	-0.4012	-0.6738
0.0040	7.7209	1.0229	-0.0242	-0.4408
0.0060	1.8363	0.8437	0.1282	-0.3460
0.0080	-1.3396	0.7465	0.2105	-0.2944
0.0100	-3.3219	0.6853	0.2618	-0.2619
0.0120	-4.6734	0.6432	0.2968	-0.2393
0.0140	-5.6511	0.6125	0.3222	-0.2228
0.0160	-6.3891	0.5890	0.3413	-0.2100
0.0180	-6.9642	0.5704	0.3562	-0.1999
0.0200	-7.4236	0.5554	0.3681	-0.1916
0.0220	-7.7978	0.5429	0.3779	-0.1847
0.0240	-8.1075	0.5323	0.3859	-0.1788
0.0260	-8.3673	0.5233	0.3926	-0.1737
0.0280	-8.5874	0.5155	0.3984	-0.1693
0.0300	-8.7758	0.5086	0.4033	-0.1653

Variance Inflation Factors

Ridge Coeff.	1	2	3
0.0000	708.8429	564.3434	104.6060
0.0020	50.5592	40.4483	8.2797
0.0040	16.9816	13.7247	3.3628
0.0060	8.5033	6.9764	2.1185
0.0080	5.1472	4.3046	1.6238
0.0100	3.4855	2.9813	1.3770
0.0120	2.5434	2.2306	1.2356
0.0140	1.9581	1.7640	1.1463
0.0160	1.5698	1.4541	1.0859
0.0180	1.2990	1.2377	1.0428
0.0200	1.1026	1.0805	1.0105
0.0220	0.9556	0.9627	0.9855
0.0240	0.8427	0.8721	0.9655
0.0260	0.7541	0.8007	0.9491
0.0280	0.6832	0.7435	0.9353

	0.0300	0.6257	0.6969	0.9235		
Prediction error criterion						
Ridge						
Coeff.	1	2	3	4	5	
0.0000	8.0368	7.6879	6.1503	7.3804	8.6052	
0.0020	7.5464	7.4238	6.2124	7.2261	8.2355	
0.0040	7.5575	7.4520	6.2793	7.2675	8.2515	
0.0060	7.5656	7.4668	6.3100	7.2876	8.2611	
0.0080	7.5701	7.4749	6.3272	7.2987	8.2661	
0.0100	7.5723	7.4796	6.3381	7.3053	8.2685	
0.0120	7.5732	7.4823	6.3455	7.3095	8.2695	
0.0140	7.5734	7.4838	6.3508	7.3122	8.2696	
0.0160	7.5731	7.4845	6.3548	7.3140	8.2691	
0.0180	7.5724	7.4848	6.3578	7.3151	8.2683	
0.0200	7.5715	7.4847	6.3603	7.3158	8.2671	
0.0220	7.5705	7.4843	6.3623	7.3161	8.2659	
0.0240	7.5694	7.4838	6.3639	7.3162	8.2645	
0.0260	7.5682	7.4832	6.3654	7.3162	8.2630	
0.0280	7.5669	7.4825	6.3666	7.3161	8.2615	
0.0300	7.5657	7.4818	6.3677	7.3159	8.2600	

Key:

- 1 Leave one out cross-validation
  - 2 Generalized cross-validation
  - 3 Unbiased estimate of variance
  - 4 Final prediction error
  - 5 Bayesian information criterion
-