

# NAG Library Function Document

## nag\_tsa\_varma\_forecast (g13djc)

### 1 Purpose

nag\_tsa\_varma\_forecast (g13djc) computes forecasts of a multivariate time series. It is assumed that a vector ARMA model has already been fitted to the appropriately differenced/transformed time series using nag\_tsa\_varma\_estimate (g13ddc). The standard deviations of the forecast errors are also returned. A reference vector is set up so that, should future series values become available, the forecasts and their standard errors may be updated by calling nag\_tsa\_varma\_update (g13dkc).

### 2 Specification

```
#include <nag.h>
#include <naggl3.h>

void nag_tsa_varma_forecast (Integer k, Integer n, const double z[],
    Integer kmax, const Integer tr[], const Integer id[],
    const double delta[], Integer ip, Integer iq, Nag_IncludeMean mean,
    const double par[], Integer lpar, double qq[], const double v[],
    Integer lmax, double predz[], double sefz[], double ref[], Integer lref,
    NagError *fail)
```

### 3 Description

Let the vector  $Z_t = (z_{1t}, z_{2t}, \dots, z_{kt})^T$ , for  $t = 1, 2, \dots, n$ , denote a  $k$ -dimensional time series for which forecasts of  $Z_{n+1}, Z_{n+2}, \dots, Z_{n+l_{\max}}$  are required. Let  $W_t = (w_{1t}, w_{2t}, \dots, w_{kt})^T$  be defined as follows:

$$w_{it} = \delta_i(B)z_{it}^*, \quad i = 1, 2, \dots, k,$$

where  $\delta_i(B)$  is the differencing operator applied to the  $i$ th series and where  $z_{it}^*$  is equal to either  $z_{it}$ ,  $\sqrt{z_{it}}$  or  $\log_e(z_{it})$  depending on whether or not a transformation was required to stabilize the variance before fitting the model.

If the order of differencing required for the  $i$ th series is  $d_i$ , then the differencing operator for the  $i$ th series is defined by  $\delta_i(B) = 1 - \delta_{i1}B - \delta_{i2}B^2 - \dots - \delta_{id_i}B^{d_i}$  where  $B$  is the backward shift operator; that is,  $BZ_t = Z_{t-1}$ . The differencing parameters  $\delta_{ij}$ , for  $i = 1, 2, \dots, k$  and  $j = 1, 2, \dots, d_i$ , must be supplied by you. If the  $i$ th series does not require differencing, then  $d_i = 0$ .

$W_t$  is assumed to follow a multivariate ARMA model of the form:

$$W_t - \mu = \phi_1(W_{t-1} - \mu) + \phi_2(W_{t-2} - \mu) + \dots + \phi_p(W_{t-p} - \mu) + \epsilon_t - \theta_1\epsilon_{t-1} - \dots - \theta_q\epsilon_{t-q}, \quad (1)$$

where  $\epsilon_t = (\epsilon_{1t}, \epsilon_{2t}, \dots, \epsilon_{kt})^T$ , for  $t = 1, 2, \dots, n$ , is a vector of  $k$  residual series assumed to be Normally distributed with zero mean and positive definite covariance matrix  $\Sigma$ . The components of  $\epsilon_t$  are assumed to be uncorrelated at non-simultaneous lags. The  $\phi_i$  and  $\theta_j$  are  $k$  by  $k$  matrices of parameters. The matrices  $\phi_i$ , for  $i = 1, 2, \dots, p$ , are the autoregressive (AR) parameter matrices, and the matrices  $\theta_i$ , for  $i = 1, 2, \dots, q$ , the moving average (MA) parameter matrices. The parameters in the model are thus the  $p$  ( $k$  by  $k$ )  $\phi$ -matrices, the  $q$  ( $k$  by  $k$ )  $\theta$ -matrices, the mean vector  $\mu$  and the residual error covariance matrix  $\Sigma$ . The ARMA model (1) must be both stationary and invertible; see nag\_tsa\_arma\_roots (g13dxc) for a method of checking these conditions.

The ARMA model (1) may be rewritten as

$$\phi(B)(\delta(B)Z_t^* - \mu) = \theta(B)\epsilon_t,$$

where  $\phi(B)$  and  $\theta(B)$  are the autoregressive and moving average polynomials and  $\delta(B)$  denotes the  $k$  by  $k$  diagonal matrix whose  $i$ th diagonal elements is  $\delta_i(B)$  and  $Z_t^* = (z_{1t}^*, z_{2t}^* \dots z_{kt}^*)^T$ .

This may be rewritten as

$$\phi(B)\delta(B)Z_t^* = \phi(B)\mu + \theta(B)\epsilon_t$$

or

$$Z_t^* = \tau + \psi(B)\epsilon_t = \tau + \epsilon_t + \psi_1\epsilon_{t-1} + \psi_2\epsilon_{t-2} + \dots$$

where  $\psi(B) = \delta^{-1}(B)\phi^{-1}(B)\theta(B)$  and  $\tau = \delta^{-1}(B)\mu$  is a vector of length  $k$ .

Forecasts are computed using a multivariate version of the procedure described in Box and Jenkins (1976). If  $\hat{Z}_n^*(l)$  denotes the forecast of  $Z_{n+l}^*$ , then  $\hat{Z}_n^*(l)$  is taken to be that linear function of  $Z_n^*, Z_{n-1}^*, \dots$  which minimizes the elements of  $E\{e_n(l)e_n'(l)\}$  where  $e_n(l) = Z_{n+l}^* - \hat{Z}_n^*(l)$  is the forecast error.  $\hat{Z}_n^*(l)$  is referred to as the linear minimum mean square error forecast of  $Z_{n+l}^*$ .

The linear predictor which minimizes the mean square error may be expressed as

$$\hat{Z}_n^*(l) = \tau + \psi_l\epsilon_n + \psi_{l+1}\epsilon_{n-1} + \psi_{l+2}\epsilon_{n-2} + \dots$$

The forecast error at  $t$  for lead  $l$  is then

$$e_n(l) = Z_{n+l}^* - \hat{Z}_n^*(l) = \epsilon_{n+l} + \psi_1\epsilon_{n+l-1} + \psi_2\epsilon_{n+l-2} + \dots + \psi_{l-1}\epsilon_{n+1}.$$

Let  $d = \max(d_i)$ , for  $i = 1, 2, \dots, k$ . Unless  $q = 0$  the function requires estimates of  $\epsilon_t$ , for  $t = d + 1, \dots, n$ , which are obtainable from `nag_tsa_varma_estimate` (g13ddc). The terms  $\epsilon_t$  are assumed to be zero, for  $t = n + 1, \dots, n + l_{\max}$ . You may use `nag_tsa_varma_update` (g13dkc) to update these  $l_{\max}$  forecasts should further observations,  $Z_{n+1}, Z_{n+2}, \dots$ , become available. Note that when  $l_{\max}$  or more further observations are available then `nag_tsa_varma_forecast` (g13djc) must be used to produce new forecasts for  $Z_{n+l_{\max}+1}, Z_{n+l_{\max}+2}, \dots$ , should they be required.

When a transformation has been used the forecasts and their standard errors are suitably modified to give results in terms of the original series,  $Z_t$ ; see Granger and Newbold (1976).

## 4 References

Box G E P and Jenkins G M (1976) *Time Series Analysis: Forecasting and Control* (Revised Edition) Holden-Day

Granger C W J and Newbold P (1976) Forecasting transformed series *J. Roy. Statist. Soc. Ser. B* **38** 189–203

Wei W W S (1990) *Time Series Analysis: Univariate and Multivariate Methods* Addison-Wesley

## 5 Arguments

The quantities **k**, **n**, **kmax**, **ip**, **iq**, **par**, **npar**, **qq** and **v** from `nag_tsa_varma_estimate` (g13ddc) are suitable for input to `nag_tsa_varma_forecast` (g13djc).

1: **k** – Integer *Input*

*On entry:*  $k$ , the dimension of the multivariate time series.

*Constraint:*  $k \geq 1$ .

2: **n** – Integer *Input*

*On entry:*  $n$ , the number of observations in the series,  $Z_t$ , prior to differencing.

*Constraint:*  $n \geq 3$ .

The total number of observations must exceed the total number of parameters in the model; that is

if **mean** = Nag\_MeanZero,  $n \times k > (\mathbf{ip} + \mathbf{iq}) \times k \times k + k \times (k + 1)/2$ ;

if **mean** = Nag\_MeanInclude,  $n \times k > (\mathbf{ip} + \mathbf{iq}) \times k \times k + k + k \times (k + 1)/2$ ,

(see the arguments **ip**, **iq** and **mean**).

- 3: **z**[**kmax** × **n**] – const double *Input*  
**Note:** the  $(i, j)$ th element of the matrix  $Z$  is stored in  $\mathbf{z}[(j - 1) \times \mathbf{kmax} + i - 1]$ .  
*On entry:*  $\mathbf{z}[(t - 1) \times \mathbf{kmax} + i - 1]$  must contain the  $i$ th series at time  $t$ , for  $t = 1, 2, \dots, n$  and  $i = 1, 2, \dots, k$ .
- 4: **kmax** – Integer *Input*  
*On entry:* the stride separating row elements in the two-dimensional data stored in the arrays **z**, **delta**, **qq**, **v**, **predz**, **sefz**.  
*Constraint:* **kmax**  $\geq$  **k**.
- 5: **tr**[**k**] – const Integer *Input*  
*On entry:* **tr**[ $i - 1$ ] indicates whether the  $i$ th series is to be transformed, for  $i = 1, 2, \dots, k$ .  
**tr**[ $i - 1$ ] = -1  
A square root transformation is used.  
**tr**[ $i - 1$ ] = 0  
No transformation is used.  
**tr**[ $i - 1$ ] = 1  
A log transformation is used.  
*Constraint:* **tr**[ $i - 1$ ] = -1, 0 or 1, for  $i = 1, 2, \dots, k$ .
- 6: **id**[**k**] – const Integer *Input*  
*On entry:* **id**[ $i - 1$ ] must specify,  $d_i$ , the order of differencing required for the  $i$ th series.  
*Constraint:*  $0 \leq \mathbf{id}[i - 1] < \mathbf{n} - \max(\mathbf{ip}, \mathbf{iq})$ , for  $i = 1, 2, \dots, k$ .
- 7: **delta**[*dim*] – const double *Input*  
**Note:** the dimension, *dim*, of the array **delta** must be at least **kmax** ×  $d$ , where  $d = \max(\mathbf{id}[i - 1])$ .  
*On entry:* if **id**[ $i - 1$ ] > 0, then **delta**[( $j - 1$ ) × **kmax** +  $i - 1$ ] must be set equal to  $\delta_{ij}$ , for  $j = 1, 2, \dots, d_i$  and  $i = 1, 2, \dots, k$ .  
If  $d = 0$ , **delta** is not referenced.
- 8: **ip** – Integer *Input*  
*On entry:*  $p$ , the number of AR parameter matrices.  
*Constraint:* **ip**  $\geq$  0.
- 9: **iq** – Integer *Input*  
*On entry:*  $q$ , the number of MA parameter matrices.  
*Constraint:* **iq**  $\geq$  0.
- 10: **mean** – Nag\_IncludeMean *Input*  
*On entry:* **mean** = Nag\_MeanInclude, if components of  $\mu$  have been estimated and **mean** = Nag\_MeanZero, if all elements of  $\mu$  are to be taken as zero.  
*Constraint:* **mean** = Nag\_MeanInclude or Nag\_MeanZero.
- 11: **par**[**lpar**] – const double *Input*  
*On entry:* must contain the parameter estimates read in row by row in the order  $\phi_1, \phi_2, \dots, \phi_p, \theta_1, \theta_2, \dots, \theta_q, \mu$ .  
Thus,

if  $\mathbf{ip} > 0$ ,  $\mathbf{par}[(l-1) \times k \times k + (i-1) \times k + j - 1]$  must be set equal to an estimate of the  $(i, j)$ th element of  $\phi_l$ , for  $l = 1, 2, \dots, p$ ,  $i = 1, 2, \dots, k$  and  $j = 1, 2, \dots, k$ ;

if  $\mathbf{iq} > 0$ ,  $\mathbf{par}[p \times k \times k + (l-1) \times k \times k + (i-1) \times k + j - 1]$  must be set equal to an estimate of the  $(i, j)$ th element of  $\theta_l$ , for  $l = 1, 2, \dots, q$ ,  $i = 1, 2, \dots, k$  and  $j = 1, 2, \dots, k$ ;

if  $\mathbf{mean} = \text{Nag\_MeanInclude}$ ,  $\mathbf{par}[(p+q) \times k \times k + i - 1]$  must be set equal to an estimate of the  $i$ th component of  $\mu$ , for  $i = 1, 2, \dots, k$ .

*Constraint:* the first  $\mathbf{ip} \times \mathbf{k} \times \mathbf{k}$  elements of  $\mathbf{par}$  must satisfy the stationarity condition and the next  $\mathbf{iq} \times \mathbf{k} \times \mathbf{k}$  elements of  $\mathbf{par}$  must satisfy the invertibility condition.

12: **lpar** – Integer *Input*

*On entry:* the dimension of the array **par**.

*Constraints:*

if  $\mathbf{mean} = \text{Nag\_MeanZero}$ ,  $\mathbf{lpar} \geq \max(1, (\mathbf{ip} + \mathbf{iq}) \times \mathbf{k} \times \mathbf{k})$ ;

if  $\mathbf{mean} = \text{Nag\_MeanInclude}$ ,  $\mathbf{lpar} \geq (\mathbf{ip} + \mathbf{iq}) \times \mathbf{k} \times \mathbf{k} + \mathbf{k}$ .

13: **qq[kmax × k]** – double *Input/Output*

**Note:** the  $(i, j)$ th element of the matrix is stored in  $\mathbf{qq}[(j-1) \times \mathbf{kmax} + i - 1]$ .

*On entry:*  $\mathbf{qq}[(j-1) \times \mathbf{kmax} + i - 1]$  must contain an estimate of the  $(i, j)$ th element of  $\Sigma$ . The lower triangle only is needed.

*Constraint:* **qq** must be positive definite.

*On exit:* if **fail.code** = NE\_EIGENVALUES, NE\_G13D\_AR, NE\_G13D\_MA, NE\_NEARLY\_POS\_DEF, NE\_NOT\_POS\_DEF, NE\_OVERFLOW\_LIKELY or NE\_TRANSFORMATION, then the upper triangle is set equal to the lower triangle.

14: **v[dim]** – const double *Input*

**Note:** the dimension,  $dim$ , of the array **v** must be at least  $\mathbf{kmax} \times (\mathbf{n} - d)$ , where  $d = \max(\mathbf{id}[i - 1])$ .

*On entry:*  $\mathbf{v}[(t-1) \times \mathbf{kmax} + i - 1]$  must contain an estimate of the  $i$ th component of  $\epsilon_{t+d}$ , for  $i = 1, 2, \dots, k$  and  $t = 1, 2, \dots, n - d$ .

If  $q = 0$ , **v** is not used.

15: **lmax** – Integer *Input*

*On entry:* the number,  $l_{\max}$ , of forecasts required.

*Constraint:*  $\mathbf{lmax} \geq 1$ .

16: **predz[kmax × lmax]** – double *Output*

**Note:** the  $(i, j)$ th element of the matrix is stored in  $\mathbf{predz}[(j-1) \times \mathbf{kmax} + i - 1]$ .

*On exit:*  $\mathbf{predz}[(l-1) \times \mathbf{kmax} + i - 1]$  contains the forecast of  $z_{i,n+l}$ , for  $i = 1, 2, \dots, k$  and  $l = 1, 2, \dots, l_{\max}$ .

17: **sefz[kmax × lmax]** – double *Output*

**Note:** the  $(i, j)$ th element of the matrix is stored in  $\mathbf{sefz}[(j-1) \times \mathbf{kmax} + i - 1]$ .

*On exit:*  $\mathbf{sefz}[(l-1) \times \mathbf{kmax} + i - 1]$  contains an estimate of the standard error of the forecast of  $z_{i,n+l}$ , for  $i = 1, 2, \dots, k$  and  $l = 1, 2, \dots, l_{\max}$ .

18: **ref[lref]** – double *Output*

*On exit:* the reference vector which may be used to update forecasts using `nag_tsa_varma_update` (g13dkc). The first  $(\mathbf{lmax} - 1) \times \mathbf{k} \times \mathbf{k}$  elements contain the  $\psi$  weight matrices,

$\psi_1, \psi_2, \dots, \psi_{l_{\max}-1}$ . The next  $\mathbf{k} \times \mathbf{lmax}$  elements contain the forecasts of the transformed series  $\hat{Z}_{n+1}^*, \hat{Z}_{n+2}^*, \dots, \hat{Z}_{n+l_{\max}}^*$  and the next  $\mathbf{k} \times \mathbf{lmax}$  contain the variances of the forecasts of the transformed variables. The last  $\mathbf{k}$  elements are used to store the transformations for the series.

- 19: **lref** – Integer *Input*  
 On entry: the dimension of the array **ref**.  
 Constraint: **lref**  $\geq (\mathbf{lmax} - 1) \times \mathbf{k} \times \mathbf{k} + 2 \times \mathbf{k} \times \mathbf{lmax} + \mathbf{k}$ .
- 20: **fail** – NagError \* *Input/Output*  
 The NAG error argument (see Section 3.6 in the Essential Introduction).

## 6 Error Indicators and Warnings

### NE\_ALLOC\_FAIL

Dynamic memory allocation failed.

### NE\_BAD\_PARAM

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

### NE\_EIGENVALUES

An excessive number of iterations were needed by `nag_tsa_arma_roots` (g13dxc) to evaluate the eigenvalues of the matrices used to test for stationarity and invertibility.

### NE\_G13D\_AR

On entry, the AR parameter matrices are outside the stationarity region.

### NE\_G13D\_MA

On entry, the MA parameter matrices are outside the invertibility region.

### NE\_INT

On entry, **ip** =  $\langle value \rangle$ .  
 Constraint: **ip**  $\geq 0$ .

On entry, **iq** =  $\langle value \rangle$ .  
 Constraint: **iq**  $\geq 0$ .

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

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

On entry, **lpar** is too small: **lpar** =  $\langle value \rangle$  but must be at least  $\langle value \rangle$ .

On entry, **lref** is too small: **lref** =  $\langle value \rangle$  but must be at least  $\langle value \rangle$ .

On entry, **n** =  $\langle value \rangle$ .  
 Constraint: **n**  $\geq 3$ .

### NE\_INT\_2

On entry, **kmax** =  $\langle value \rangle$  and **k** =  $\langle value \rangle$ .  
 Constraint: **kmax**  $\geq \mathbf{k}$ .

**NE\_INT\_ARRAY**

On entry,  $\mathbf{id}[\langle value \rangle] = \langle value \rangle$  and  $\mathbf{n} - \max(\mathbf{ip}, \mathbf{iq}) = \langle value \rangle$ .

Constraint:  $0 \leq \mathbf{id}[i - 1] < \mathbf{n} - \max(\mathbf{ip}, \mathbf{iq})$ .

On entry,  $\mathbf{tr}[i - 1] = \langle value \rangle$  and  $\mathbf{k} = \langle value \rangle$ .

Constraint:  $\mathbf{tr}[i - 1] = -1, 0$  or  $1$ , for  $i = 1, 2, \dots, k$ .

On entry,  $\mathbf{tr}[\langle value \rangle] = \langle value \rangle$ . Constraint:  $\mathbf{tr}[i] = -1, 0$  or  $1$ .

**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.

**NE\_NEARLY\_POS\_DEF**

The covariance matrix may be nearly non positive definite.

**NE\_NOT\_POS\_DEF**

On entry, the covariance matrix  $\mathbf{qq}$  is not positive definite.

**NE\_OBSERV\_LT\_P**

On entry, the total number of observations is less than the total number of parameters (including the covariance matrix). Number of observations =  $\langle value \rangle$  and number of parameters =  $\langle value \rangle$ .

**NE\_OVERFLOW\_LIKELY**

The forecasts will overflow if computed.

**NE\_TRANSFORMATION**

On entry, one (or more) of the transformations requested is invalid.

**7 Accuracy**

The matrix computations are believed to be stable.

**8 Parallelism and Performance**

nag\_tsa\_varma\_forecast (g13djc) is threaded by NAG for parallel execution in multithreaded implementations of the NAG Library.

nag\_tsa\_varma\_forecast (g13djc) 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 Users' Note for your implementation for any additional implementation-specific information.

**9 Further Comments**

The same differencing operator does not have to be applied to all the series. For example, suppose we have  $k = 2$ , and wish to apply the second order differencing operator  $\nabla^2$  to the first series and the first-order differencing operator  $\nabla$  to the second series:

$$\begin{aligned} w_{1t} &= \nabla^2 z_{1t} = (1 - B)^2 z_{1t} = (1 - 2B + B^2)Z_{1t}, & \text{and} \\ w_{2t} &= \nabla z_{2t} = (1 - B)z_{2t}. \end{aligned}$$

Then  $d_1 = 2, d_2 = 1, d = \max(d_1, d_2) = 2$ , and

$$\mathbf{delta} = \begin{bmatrix} \delta_{11} & \delta_{12} \\ \delta_{21} & \delta_{22} \end{bmatrix} = \begin{bmatrix} 2 & -1 \\ 1 & \end{bmatrix}.$$

**Note:** although differencing may already have been applied prior to the model fitting stage, the differencing parameters supplied in **delta** are part of the model definition and are still required by this function to produce the forecasts.

`nag_tsa_varma_forecast` (g13djc) should not be used when the moving average parameters lie close to the boundary of the invertibility region. The function does test for both invertibility and stationarity but if in doubt, you may use `nag_tsa_arma_roots` (g13dxc), before calling this function, to check that the VARMA model being used is invertible.

On a successful exit, the quantities **k**, **lmax**, **kmax**, **ref** and **lref** will be suitable for input to `nag_tsa_varma_update` (g13dkc).

## 10 Example

This example computes forecasts of the next five values in two series each of length 48. No transformation is to be used and no differencing is to be applied to either of the series. `nag_tsa_varma_estimate` (g13ddc) is first called to fit an AR(1) model to the series. The mean vector  $\mu$  is to be estimated and  $\phi_1(2, 1)$  constrained to be zero.

### 10.1 Program Text

```

/* nag_tsa_varma_forecast (g13djc) Example Program.
 *
 * Copyright 2005 Numerical Algorithms Group.
 *
 * Mark 8, 2004.
 */

#include <stdio.h>
#include <nag.h>
#include <nag_stdlib.h>
#include <nagg13.h>

int main(void)
{
    /* Scalars */
    double      cgetol, rlogl;
    Integer     exit_status = 0, i, i2, idmax, idmin, ip, iprint, iq, ishow;
    Integer     j, l2, lref, lmax, loop, maxcal, n, nd, niter, k, l, npar;
    Integer     kmax, icm;
    /* Arrays */
    double      *cm = 0, *delta = 0, *g = 0, *par = 0, *predz = 0, *qq = 0;
    double      *ref = 0, *sefz = 0, *v = 0, *w = 0, *z = 0;
    Integer     *id = 0, *tr = 0;
    char        nag_enum_arg[40];
    /* Nag types */
    Nag_Boolean *parhld = 0;
    Nag_Boolean exact;
    Nag_IncludeMean mean;
    NagError    fail;

#define DELTA(I, J) delta[(J - 1) * kmax + I - 1]
#define PREDZ(I, J) predz[(J - 1) * kmax + I - 1]
#define QQ(I, J)    qq[(J - 1) * kmax + I - 1]
#define SEFZ(I, J) sefz[(J - 1) * kmax + I - 1]
#define Z(I, J)    z[(J - 1) * kmax + I - 1]

    INIT_FAIL(fail);

    printf("nag_tsa_varma_forecast (g13djc) Example Program Results\n\n");

    /* Skip heading in data file */

```

```

scanf("%*[^\\n]");
scanf("%ld%ld%ld%ld %39s %ld%*[^\\n]",
      &k, &n, &ip, &iq, nag_enum_arg, &lmax);
/* nag_enum_name_to_value (x04nac).
 * Converts NAG enum member name to value
 */
mean = (Nag_IncludeMean) nag_enum_name_to_value(nag_enum_arg);

npar = (ip + iq) * k * k;
if (mean == Nag_MeanInclude)
{
  npar += k;
}
if (k > 0 && n >= 1 && npar >= 1 && lmax >= 1)
{
  kmax = k;
  icm = npar;
  lref = (lmax - 1) * k * k + 2 * k * lmax + k;
  /* Allocate memory */
  if (!(tr = NAG_ALLOC(k, Integer)) ||
      !(cm = NAG_ALLOC(npar * icm, double)) ||
      !(g = NAG_ALLOC(npar, double)) ||
      !(par = NAG_ALLOC(npar, double)) ||
      !(predz = NAG_ALLOC(lmax * kmax, double)) ||
      !(qq = NAG_ALLOC(k * kmax, double)) ||
      !(ref = NAG_ALLOC(lref, double)) ||
      !(sefz = NAG_ALLOC(lmax * kmax, double)) ||
      !(v = NAG_ALLOC(n * kmax, double)) ||
      !(w = NAG_ALLOC(n * kmax, double)) ||
      !(z = NAG_ALLOC(n * kmax, double)) ||
      !(id = NAG_ALLOC(k, Integer)) ||
      !(parhld = NAG_ALLOC(npar, Nag_Boolean)))
  {
    printf("Allocation failure\\n");
    exit_status = -1;
    goto END;
  }
}
else
{
  printf("Invalid parameters\\n");
  exit_status = -1;
  goto END;
}

for (i = 1; i <= k; ++i)
{
  scanf("%ld", &id[i-1]);
}
scanf("%*[^\\n]");

idmin = 0;
idmax = 0;
for (i = 1; i <= k; ++i)
{
  idmin = MIN(id[i-1], idmin);
  idmax = MAX(id[i-1], idmax);
}

if (idmin >= 0)
{
  if (!(delta = NAG_ALLOC(k * idmax, double)))
  {
    printf("Allocation failure\\n");
    exit_status = -1;
    goto END;
  }
  for (i = 1; i <= k; ++i)
  {
    for (j = 1; j <= n; ++j)
    {

```



```

        scanf("%lf ", &z(i, j));
    }
}
scanf("%*[\n]");

for (i = 1; i <= k; ++i)
{
    scanf("%ld ", &tr[i-1]);
}
scanf("%*[\n]");

if (idmax > 0)
{
    for (i = 1; i <= k; ++i)
    {
        for (j = 1; j <= id[i-1]; ++j)
        {
            scanf("%lf", &DELTA(i, j));
        }
        scanf("%*[\n] ");
    }
}

/* nag_tsa_multi_diff (g13dlc).
 * Multivariate time series, differences and/or transforms
 */
nag_tsa_multi_diff(k, n, z, tr, id, delta, w, &nd, &fail);
if (fail.code != NE_NOERROR)
{
    printf("Error from nag_tsa_multi_diff (g13dlc).\n%s\n",
           fail.message);
    exit_status = 1;
    goto END;
}

for (i = 1; i <= npar; ++i)
{
    par[i-1] = 0.0;
    parhld[i-1] = Nag_FALSE;
}
for (i = 1; i <= k; ++i)
{
    for (j = 1; j <= i; ++j)
    {
        QQ(i, j) = 0.0;
    }
}
parhld[2] = Nag_TRUE;
exact = Nag_TRUE;
/* ** Set iprint < 0 for no monitoring */
iprint = -1;
cgetol = 1.0e-4;
maxcal = npar * 40 * (npar + 5);
ishow = 0;
/* nag_tsa_varma_estimate (g13ddc).
 * Multivariate time series, estimation of VARMA model
 */
nag_tsa_varma_estimate(k, nd, ip, iq, mean, par, npar, qq, kmax, w,
                      parhld, exact, iprint, cgetol, maxcal, ishow,
                      0, &niter, &rlogl, v, g, cm, icm, &fail);
if (fail.code != NE_NOERROR)
{
    printf("\n nag_tsa_varma_estimate (g13ddc) message: %s\n\n",
           fail.message);
    exit_status = 1;
    goto END;
}

if (fail.code == NE_NOERROR || fail.code == NE_G13D_MAXCAL ||
    fail.code == NE_MAX_LOGLIK || fail.code == NE_G13D_BOUND ||
    fail.code == NE_G13D_DERIV ||

```

```

fail.code == NE_HESS_NOT_POS_DEF)
{
/* nag_tsa_varma_forecast (g13djc).
 * Multivariate time series, forecasts and their standard
 * errors
 */
nag_tsa_varma_forecast(k, n, z, kmax, tr, id, delta, ip, iq, mean,
                      par, npar, qq, v, lmax, predz, sefz, ref,
                      lref, &fail);
if (fail.code != NE_NOERROR)
{
printf(
"\n nag_tsa_varma_forecast (g13djc) message: %s\n\n",
fail.message);
exit_status = 1;
goto END;
}

printf("\n");
printf("Forecast summary table\n");
printf("-----\n\n");
printf("Forecast origin is set at t = %4ld\n\n", n);

loop = lmax / 5;
if (lmax % 5 != 0)
{
++loop;
}

for (j = 1; j <= loop; ++j)
{
i2 = (j - 1) * 5;
l2 = MIN(i2 + 5, lmax);
printf("%s%13s", "Lead Time", "");
for (i = i2 + 1; i <= l2; ++i)
{
printf("%10ld%s", i,
(i % 5 == 0 || i == l2?"\n":" "));
}
printf("\n");

for (i = 1; i <= k; ++i)
{
printf(
"%-7s%21d%-15s", "Series", i, ": Forecast");
for (l = i2 + 1; l <= l2; ++l)
{
printf("%10.2f%s", PREDZ(i, l),
(l % 5 == 0 || l == l2?"\n":" "));
}

printf("%9s%-18s", "", ": Standard Error ");
for (l = i2 + 1; l <= l2; ++l)
{
printf("%7.2f%s", SEFZ(i, l),
(l % 5 == 0 || l == l2?"\n":" "));
}
printf("\n");
}
}
}

}

END:
NAG_FREE(tr);
NAG_FREE(cm);
NAG_FREE(delta);
NAG_FREE(g);
NAG_FREE(par);
NAG_FREE(predz);
NAG_FREE(qq);

```

```

NAG_FREE(ref);
NAG_FREE(sefz);
NAG_FREE(v);
NAG_FREE(w);
NAG_FREE(z);
NAG_FREE(id);
NAG_FREE(parhld);

return exit_status;
}

```

## 10.2 Program Data

```

nag_tsa_varma_forecast (g13djc) Example Program Data
2 48 1 0 Nag_MeanInclude 5 : k, n, ip, iq, mean, lmax
0 0 : id[i-1], i=1,k
-1.490 -1.620 5.200 6.230 6.210 5.860 4.090 3.180
2.620 1.490 1.170 0.850 -0.350 0.240 2.440 2.580
2.040 0.400 2.260 3.340 5.090 5.000 4.780 4.110
3.450 1.650 1.290 4.090 6.320 7.500 3.890 1.580
5.210 5.250 4.930 7.380 5.870 5.810 9.680 9.070
7.290 7.840 7.550 7.320 7.970 7.760 7.000 8.350
7.340 6.350 6.960 8.540 6.620 4.970 4.550 4.810
4.750 4.760 10.880 10.010 11.620 10.360 6.400 6.240
7.930 4.040 3.730 5.600 5.350 6.810 8.270 7.680
6.650 6.080 10.250 9.140 17.750 13.300 9.630 6.800
4.080 5.060 4.940 6.650 7.940 10.760 11.890 5.850
9.010 7.500 10.020 10.380 8.150 8.370 10.730 12.140 : End of time series
0 0 : tr[i-1], i=1,k

```

## 10.3 Program Results

```

nag_tsa_varma_forecast (g13djc) Example Program Results

```

```

Forecast summary table
-----

```

```

Forecast origin is set at t = 48

```

Lead Time		1	2	3	4	5
Series 1: Forecast		7.82	7.28	6.77	6.33	5.95
: Standard Error		1.72	2.23	2.51	2.68	2.79
Series 2: Forecast		10.31	9.25	8.65	8.30	8.10
: Standard Error		2.32	2.68	2.78	2.82	2.83