

# NAG Library Function Document

## nag\_rand\_exp\_smooth (g05pmc)

### 1 Purpose

nag\_rand\_exp\_smooth (g05pmc) simulates from an exponential smoothing model, where the model uses either single exponential, double exponential or a Holt–Winters method.

### 2 Specification

```
#include <nag.h>
#include <nagg05.h>

void nag_rand_exp_smooth (Nag_InitialValues mode, Integer n,
    Nag_ExpSmoothType itype, Integer p, const double param[],
    const double init[], double var, double r[], Integer state[],
    const double e[], Integer en, double x[], NagError *fail)
```

### 3 Description

nag\_rand\_exp\_smooth (g05pmc) returns  $\{x_t : t = 1, 2, \dots, n\}$ , a realization of a time series from an exponential smoothing model defined by one of five smoothing functions:

Single Exponential Smoothing

$$\begin{aligned}x_t &= m_{t-1} + \epsilon_t \\m_t &= \alpha x_t + (1 - \alpha)m_{t-1}\end{aligned}$$

Brown Double Exponential Smoothing

$$\begin{aligned}x_t &= m_{t-1} + \frac{r_{t-1}}{\alpha} + \epsilon_t \\m_t &= \alpha x_t + (1 - \alpha)m_{t-1} \\r_t &= \alpha(m_t - m_{t-1}) + (1 - \alpha)r_{t-1}\end{aligned}$$

Linear Holt Exponential Smoothing

$$\begin{aligned}x_t &= m_{t-1} + \phi r_{t-1} + \epsilon_t \\m_t &= \alpha x_t + (1 - \alpha)(m_{t-1} + \phi r_{t-1}) \\r_t &= \gamma(m_t - m_{t-1}) + (1 - \gamma)\phi r_{t-1}\end{aligned}$$

Additive Holt–Winters Smoothing

$$\begin{aligned}x_t &= m_{t-1} + \phi r_{t-1} + s_{t-1-p} + \epsilon_t \\m_t &= \alpha(x_t - s_{t-p}) + (1 - \alpha)(m_{t-1} + \phi r_{t-1}) \\r_t &= \gamma(m_t - m_{t-1}) + (1 - \gamma)\phi r_{t-1} \\s_t &= \beta(x_t - m_t) + (1 - \beta)s_{t-p}\end{aligned}$$

Multiplicative Holt–Winters Smoothing

$$\begin{aligned}x_t &= (m_{t-1} + \phi r_{t-1}) \times s_{t-1-p} + \epsilon_t \\m_t &= \alpha x_t / s_{t-p} + (1 - \alpha)(m_{t-1} + \phi r_{t-1}) \\r_t &= \gamma(m_t - m_{t-1}) + (1 - \gamma)\phi r_{t-1} \\s_t &= \beta x_t / m_t + (1 - \beta)s_{t-p}\end{aligned}$$

where  $m_t$  is the mean,  $r_t$  is the trend and  $s_t$  is the seasonal component at time  $t$  with  $p$  being the seasonal order. The errors,  $\epsilon_t$  are either drawn from a normal distribution with mean zero and variance  $\sigma^2$  or randomly sampled, with replacement, from a user-supplied vector.

### 4 References

Chatfield C (1980) *The Analysis of Time Series* Chapman and Hall

## 5 Arguments

- 1: **mode** – Nag\_InitialValues *Input*  
*On entry:* indicates if nag\_rand\_exp\_smooth (g05pmc) is continuing from a previous call or, if not, how the initial values are computed.  
**mode** = Nag\_InitialValuesSupplied  
 Values for  $m_0$ ,  $r_0$  and  $s_{-j}$ , for  $j = 0, 1, \dots, p - 1$ , are supplied in **init**.  
**mode** = Nag\_ContinueNoUpdate  
 nag\_rand\_exp\_smooth (g05pmc) continues from a previous call using values that are supplied in **r**. **r** is not updated.  
**mode** = Nag\_ContinueAndUpdate  
 nag\_rand\_exp\_smooth (g05pmc) continues from a previous call using values that are supplied in **r**. **r** is updated.  
*Constraint:* **mode** = Nag\_InitialValuesSupplied, Nag\_ContinueNoUpdate or Nag\_ContinueAndUpdate.
- 2: **n** – Integer *Input*  
*On entry:* the number of terms of the time series being generated.  
*Constraint:*  $n \geq 0$ .
- 3: **itype** – Nag\_ExpSmoothType *Input*  
*On entry:* the smoothing function.  
**itype** = Nag\_SingleExponential  
 Single exponential.  
**itype** = Nag\_BrownsExponential  
 Brown's double exponential.  
**itype** = Nag\_LinearHolt  
 Linear Holt.  
**itype** = Nag\_AdditiveHoltWinters  
 Additive Holt–Winters.  
**itype** = Nag\_MultiplicativeHoltWinters  
 Multiplicative Holt–Winters.  
*Constraint:* **itype** = Nag\_SingleExponential, Nag\_BrownsExponential, Nag\_LinearHolt, Nag\_AdditiveHoltWinters or Nag\_MultiplicativeHoltWinters.
- 4: **p** – Integer *Input*  
*On entry:* if **itype** = Nag\_AdditiveHoltWinters or Nag\_MultiplicativeHoltWinters, the seasonal order,  $p$ , otherwise **p** is not referenced.  
*Constraint:* if **itype** = Nag\_AdditiveHoltWinters or Nag\_MultiplicativeHoltWinters,  $p > 1$ .
- 5: **param**[*dim*] – const double *Input*  
**Note:** the dimension, *dim*, of the array **param** must be at least  
 1 when **itype** = Nag\_SingleExponential or Nag\_BrownsExponential;  
 3 when **itype** = Nag\_LinearHolt;  
 4 when **itype** = Nag\_AdditiveHoltWinters or Nag\_MultiplicativeHoltWinters.  
*On entry:* the smoothing parameters.  
 If **itype** = Nag\_SingleExponential or Nag\_BrownsExponential, **param**[0] =  $\alpha$  and any remaining elements of **param** are not referenced.

If **itype** = Nag\_LinearHolt, **param**[0] =  $\alpha$ , **param**[1] =  $\gamma$ , **param**[2] =  $\phi$  and any remaining elements of **param** are not referenced.

If **itype** = Nag\_AdditiveHoltWinters or Nag\_MultiplicativeHoltWinters, **param**[0] =  $\alpha$ , **param**[1] =  $\gamma$ , **param**[2] =  $\beta$  and **param**[3] =  $\phi$  and any remaining elements of **param** are not referenced.

*Constraints:*

if **itype** = Nag\_SingleExponential,  $0.0 \leq \alpha \leq 1.0$ ;  
 if **itype** = Nag\_BrownsExponential,  $0.0 < \alpha \leq 1.0$ ;  
 if **itype** = Nag\_LinearHolt,  $0.0 \leq \alpha \leq 1.0$  and  $0.0 \leq \gamma \leq 1.0$  and  $\phi \geq 0.0$ ;  
 if **itype** = Nag\_AdditiveHoltWinters or Nag\_MultiplicativeHoltWinters,  $0.0 \leq \alpha \leq 1.0$  and  $0.0 \leq \gamma \leq 1.0$  and  $0.0 \leq \beta \leq 1.0$  and  $\phi \geq 0.0$ .

6: **init**[*dim*] – const double *Input*

**Note:** the dimension, *dim*, of the array **init** must be at least

1 when **itype** = Nag\_SingleExponential;  
 2 when **itype** = Nag\_BrownsExponential or Nag\_LinearHolt;  
 2 + **p** when **itype** = Nag\_AdditiveHoltWinters or Nag\_MultiplicativeHoltWinters.

*On entry:* if **mode** = Nag\_InitialValuesSupplied, the initial values for  $m_0$ ,  $r_0$  and  $s_{-j}$ , for  $j = 0, 1, \dots, p - 1$ , used to initialize the smoothing.

If **itype** = Nag\_SingleExponential, **init**[0] =  $m_0$  and any remaining elements of **init** are not referenced.

If **itype** = Nag\_BrownsExponential or Nag\_LinearHolt, **init**[0] =  $m_0$  and **init**[1] =  $r_0$  and any remaining elements of **init** are not referenced.

If **itype** = Nag\_AdditiveHoltWinters or Nag\_MultiplicativeHoltWinters, **init**[0] =  $m_0$ , **init**[1] =  $r_0$  and **init**[2] to **init**[2 +  $p - 1$ ] hold the values for  $s_{-j}$ , for  $j = 0, 1, \dots, p - 1$ . Any remaining elements of **init** are not referenced.

7: **var** – double *Input*

*On entry:* the variance,  $\sigma^2$  of the Normal distribution used to generate the errors  $\epsilon_i$ . If **var**  $\leq 0.0$  then Normally distributed errors are not used.

8: **r**[*dim*] – double *Input/Output*

**Note:** the dimension, *dim*, of the array **r** must be at least

13 when **itype** = Nag\_SingleExponential, Nag\_BrownsExponential or Nag\_LinearHolt;  
 13 + **p** when **itype** = Nag\_AdditiveHoltWinters or Nag\_MultiplicativeHoltWinters.

*On entry:* if **mode** = Nag\_ContinueNoUpdate or Nag\_ContinueAndUpdate, **r** must contain the values as returned by a previous call to nag\_rand\_exp\_smooth (g05pmc), **r** need not be set otherwise.

*On exit:* if **mode** = Nag\_ContinueNoUpdate, **r** is unchanged. Otherwise, **r** contains the information on the current state of smoothing.

*Constraint:* if **mode** = Nag\_ContinueNoUpdate or Nag\_ContinueAndUpdate, **r** must have been initialized by at least one call to nag\_rand\_exp\_smooth (g05pmc) or nag\_tsa\_exp\_smooth (g13amc) with **mode**  $\neq$  Nag\_ContinueNoUpdate, and **r** must not have been changed since that call.

9: **state**[*dim*] – Integer *Communication Array*

**Note:** the dimension, *dim*, of this array is dictated by the requirements of associated functions that must have been previously called. This array MUST be the same array passed as argument **state** in the previous call to nag\_rand\_init\_repeatable (g05kfc) or nag\_rand\_init\_nonrepeatable (g05kgc).

*On entry:* contains information on the selected base generator and its current state.

*On exit:* contains updated information on the state of the generator.

- 10: **e[en]** – const double *Input*  
*On entry:* if **en** > 0 and **var** ≤ 0.0, a vector from which the errors,  $\epsilon_t$  are randomly drawn, with replacement.  
 If **en** ≤ 0, **e** is not referenced.
- 11: **en** – Integer *Input*  
*On entry:* if **en** > 0, then the length of the vector **e**.  
 If both **var** ≤ 0.0 and **en** ≤ 0 then  $\epsilon_t = 0.0$ , for  $t = 1, 2, \dots, n$ .
- 12: **x[n]** – double *Output*  
*On exit:* the generated time series,  $x_t$ , for  $t = 1, 2, \dots, n$ .
- 13: **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  $\langle value \rangle$  had an illegal value.

### NE\_ENUM\_INT

On entry, **itype** =  $\langle value \rangle$  and **p** =  $\langle value \rangle$ .

Constraint: if **itype** = Nag\_AdditiveHoltWinters or Nag\_MultiplicativeHoltWinters, **p** > 1.

On entry, **p** =  $\langle value \rangle$ .

Constraint: if **itype** = Nag\_AdditiveHoltWinters or Nag\_MultiplicativeHoltWinters, **p** ≥ 2.

### NE\_INT

On entry, **n** =  $\langle value \rangle$ .

Constraint: **n** ≥ 0.

### NE\_INT\_ARRAY

On entry, some of the elements of the array **r** have been corrupted or have not been initialized.

### 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\_INVALID\_STATE

On entry, **state** vector has been corrupted or not initialized.

**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**

Model unsuitable for multiplicative Holt–Winter, try a different set of parameters.

On entry, **param**[*value*] = *value*.  
Constraint:  $0 \leq \mathbf{param}[i] \leq 1$ .

On entry, **param**[*value*] = *value*.  
Constraint: if **itype** = Nag\_BrownsExponential,  $0 < \mathbf{param}[i] \leq 1$ .

On entry, **param**[*value*] = *value*.  
Constraint:  $\mathbf{param}[i] \geq 0$ .

**7 Accuracy**

Not applicable.

**8 Parallelism and Performance**

nag\_rand\_exp\_smooth (g05pmc) is threaded by NAG for parallel execution in multithreaded implementations of the NAG Library.

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**

None.

**10 Example**

This example reads 11 observations from a time series relating to the rate of the earth's rotation about its polar axis and fits an exponential smoothing model using nag\_tsa\_exp\_smooth (g13amc).

nag\_rand\_exp\_smooth (g05pmc) is then called multiple times to obtain simulated forecast confidence intervals.

**10.1 Program Text**

```

/* nag_rand_exp_smooth (g05pmc) 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 <nagg01.h>
#include <nagg05.h>
#include <nagg13.h>

#define BLIM(I, J) blim[J*2 + I]
#define BSIM(I, J) bsim[J*nsim + I]
#define GLIM(I, J) glim[J*2 + I]

```

```

#define GSIM(I, J) gsim[J*nsim + I]

int main(void)
{
    /* Integer scalar and array declarations */
    Integer exit_status = 0;
    Integer en, i, ival, j, k, lstate, n, nf, nsim, p, nq;
    Integer *state = 0;
    /* NAG structures */
    NagError fail;
    Nag_TailProbability tail;
    Nag_InitialValues mode;
    Nag_ExpSmoothType itype;
    /* Double scalar and array declarations */
    double ad, alpha, dv, tmp, var, z, bvar;
    double *blim = 0, *bsim = 0, *e = 0, *fse = 0, *fv = 0;
    double *glim = 0, *gsim = 0, *init = 0, *param = 0, *r = 0;
    double *res = 0, *tsim1 = 0, *tsim2 = 0, *y = 0, *yhat = 0;
    double q[2];
    /* Character scalar and array declarations */
    char smode[40], sitype[40];
    /* Choose the base generator */
    Nag_BaseRNG genid = Nag_Basic;
    Integer subid = 0;
    /* Set the seed */
    Integer seed[] = { 1762543 };
    Integer lseed = 1;

    /* Initialize the error structure */
    INIT_FAIL(fail);

    printf("nag_rand_exp_smooth (g05pmc) Example Program Results\n\n");

    /* Get the length of the state array */
    lstate = -1;
    nag_rand_init_repeatable(genid, subid, seed, lseed, state, &lstate, &fail);
    if (fail.code != NE_NOERROR) {
        printf("Error from nag_rand_init_repeatable (g05kfc).\n%s\n",
            fail.message);
        exit_status = 1;
        goto END;
    }

    /* Skip headings in data file */
#ifdef _WIN32
    scanf_s("%*[\n] ");
#else
    scanf("%*[\n] ");
#endif
    /* Read in the initial arguments and check array sizes */
#ifdef _WIN32
    scanf_s("%39s%39s%" NAG_IFMT "%" NAG_IFMT "%" NAG_IFMT "%lf%*[\n] ", smode,
        (unsigned)_countof(smode), sitype, (unsigned)_countof(sitype),
        &n, &nf, &nsim, &alpha);
#else
    scanf("%39s%39s%" NAG_IFMT "%" NAG_IFMT "%" NAG_IFMT "%lf%*[\n] ", smode,
        sitype, &n, &nf, &nsim, &alpha);
#endif

    /*
     * nag_enum_name_to_value (x04nac).
     * Converts NAG enum member name to value
     */
    mode = (Nag_InitialValues) nag_enum_name_to_value(smode);
    itype = (Nag_ExpSmoothType) nag_enum_name_to_value(sitype);

    /* Allocate arrays */
    if (!(blim = NAG_ALLOC(2 * nf, double)) ||
        !(bsim = NAG_ALLOC(nsim * nf, double)) ||
        !(e = NAG_ALLOC(1, double)) ||
        !(fse = NAG_ALLOC(nf, double)) ||

```

```

!(fv = NAG_ALLOC(nf, double)) ||
!(glim = NAG_ALLOC(2 * nf, double)) ||
!(gsim = NAG_ALLOC(nsim * nf, double)) ||
!(res = NAG_ALLOC(n, double)) ||
!(tsim1 = NAG_ALLOC(nf, double)) ||
!(tsim2 = NAG_ALLOC(nf, double)) ||
!(y = NAG_ALLOC(n, double)) ||
!(yhat = NAG_ALLOC(n, double)) || !(state = NAG_ALLOC(lstate, Integer))
{
printf("Allocation failure\n");
exit_status = -1;
goto END;
}

/* Initialize the generator to a repeatable sequence */
nag_rand_init_repeatable(genid, subid, seed, lseed, state, &lstate, &fail);
if (fail.code != NE_NOERROR) {
printf("Error from nag_rand_init_repeatable (g05kfc).\n%s\n",
fail.message);
exit_status = 1;
goto END;
}

for (i = 0; i < n; i++)
#ifdef _WIN32
scanf_s("%lf ", &y[i]);
#else
scanf("%lf ", &y[i]);
#endif
#ifdef _WIN32
scanf_s("%*[\n] ");
#else
scanf("%*[\n] ");
#endif

/* Read in the itype dependent arguments (skipping headings) */
#ifdef _WIN32
scanf_s("%*[\n] ");
#else
scanf("%*[\n] ");
#endif
if (itype == Nag_SingleExponential) {
/* Single exponential smoothing required */
if (!(param = NAG_ALLOC(1, double)))
{
printf("Allocation failure\n");
exit_status = -1;
goto END;
}
#ifdef _WIN32
scanf_s("%lf%*[\n] ", &param[0]);
#else
scanf("%lf%*[\n] ", &param[0]);
#endif
p = 0;
ival = 1;
}
else if (itype == Nag_BrownsExponential) {
/* Browns exponential smoothing required */
if (!(param = NAG_ALLOC(2, double)))
{
printf("Allocation failure\n");
exit_status = -1;
goto END;
}
#ifdef _WIN32
scanf_s("%lf %lf%*[\n] ", &param[0], &param[1]);
#else
scanf("%lf %lf%*[\n] ", &param[0], &param[1]);
#endif
p = 0;
}

```

```

    ival = 2;
}
else if (itype == Nag_LinearHolt) {
    /* Linear Holt smoothing required */
    if (!(param = NAG_ALLOC(3, double)))
    {
        printf("Allocation failure\n");
        exit_status = -1;
        goto END;
    }
#ifdef _WIN32
    scanf_s("%lf %lf %lf%[^\\n] ", &param[0], &param[1], &param[2]);
#else
    scanf("%lf %lf %lf%[^\\n] ", &param[0], &param[1], &param[2]);
#endif
    p = 0;
    ival = 2;
}
else if (itype == Nag_AdditiveHoltWinters) {
    /* Additive Holt Winters smoothing required */
    if (!(param = NAG_ALLOC(4, double)))
    {
        printf("Allocation failure\n");
        exit_status = -1;
        goto END;
    }
#ifdef _WIN32
    scanf_s("%lf %lf %lf %lf %" NAG_IFMT "%[^\\n] ", &param[0], &param[1],
            &param[2], &param[3], &p);
#else
    scanf("%lf %lf %lf %lf %" NAG_IFMT "%[^\\n] ", &param[0], &param[1],
            &param[2], &param[3], &p);
#endif
    ival = p + 2;
}
else if (itype == Nag_MultiplicativeHoltWinters) {
    /* Multiplicative Holt Winters smoothing required */
    if (!(param = NAG_ALLOC(4, double)))
    {
        printf("Allocation failure\n");
        exit_status = -1;
        goto END;
    }
#ifdef _WIN32
    scanf_s("%lf %lf %lf %lf %" NAG_IFMT "%[^\\n] ", &param[0], &param[1],
            &param[2], &param[3], &p);
#else
    scanf("%lf %lf %lf %lf %" NAG_IFMT "%[^\\n] ", &param[0], &param[1],
            &param[2], &param[3], &p);
#endif
    ival = p + 2;
}
else {
    printf("%s is an unknown type\n", sitype);
    exit_status = -1;
    goto END;
}

/* Allocate arrays */
if (!(init = NAG_ALLOC(p + 2, double)) || !(r = NAG_ALLOC(p + 13, double)))
{
    printf("Allocation failure\n");
    exit_status = -1;
    goto END;
}

/* Read in the mode dependent arguments (skipping headings) */
#ifdef _WIN32
    scanf_s("%[^\\n] ");
#else
    scanf("%[^\\n] ");

```



```

#endif
    if (mode == Nag_InitialValuesSupplied) {
        /* User supplied initial values */
        for (i = 0; i < ival; i++)
#ifdef _WIN32
            scanf_s("%lf ", &init[i]);
#else
            scanf("%lf ", &init[i]);
#endif
    }
#ifdef _WIN32
    scanf_s("%*[\n] ");
#else
    scanf("%*[\n] ");
#endif
    }
    else if (mode == Nag_ContinueAndUpdate) {
        /* Continuing from a previously saved R */
        for (i = 0; i < p + 13; i++)
#ifdef _WIN32
            scanf_s("%lf ", &r[i]);
#else
            scanf("%lf ", &r[i]);
#endif
    }
#ifdef _WIN32
    scanf_s("%*[\n] ");
#else
    scanf("%*[\n] ");
#endif
    }
    else if (mode == Nag_EstimateInitialValues) {
        /* Initial values calculated from first k observations */
#ifdef _WIN32
        scanf_s("%" NAG_IFMT "%*[\n] ", &k);
#else
        scanf("%" NAG_IFMT "%*[\n] ", &k);
#endif
    }
    else {
        printf("%s is an unknown mode\n", smode);
        exit_status = -1;
        goto END;
    }

    /* Fit a smoothing model (parameter r in
    * nag_rand_exp_smooth (g05pmc) and state in g13amc are in
    the same format) */
    nag_tsa_exp_smooth(mode, itype, p, param, n, y, k, init, nf, fv, fse, yhat,
        res, &dv, &ad, r, &fail);
    if (fail.code != NE_NOERROR) {
        printf("Error from nag_tsa_exp_smooth (g13amc).\n%s\n", fail.message);
        exit_status = 1;
        goto END;
    }

    /* Simulate forecast values from the model, and don't update r */
    var = dv * dv;
    en = n;

    /* Change the mode used to continue from fit model */
    mode = Nag_ContinueAndUpdate;

    /* Simulate nsim forecasts */
    for (i = 0; i < nsim; i++) {
        /* Simulations assuming Gaussian errors */
        nag_rand_exp_smooth(mode, nf, itype, p, param, init, var, r, state,
            e, 0, tsim1, &fail);
        if (fail.code != NE_NOERROR) {
            printf("Error from nag_rand_exp_smooth (g05pmc).\n%s\n", fail.message);
            exit_status = 1;
            goto END;
        }
    }

```

```

/* Bootstrapping errors */
bvar = 0.0e0;
nag_rand_exp_smooth(mode, nf, itype, p, param, init, bvar, r, state,
                    res, en, tsim2, &fail);
if (fail.code != NE_NOERROR) {
    printf("Error from nag_rand_exp_smooth (g05pmc).\n%s\n", fail.message);
    exit_status = 1;
    goto END;
}

/* Copy and transpose the simulated values */
for (j = 0; j < nf; j++) {
    GSIM(i, j) = tsim1[j];
    BSIM(i, j) = tsim2[j];
}

/* Calculate CI based on the quantiles for each simulated forecast */
q[0] = alpha / 2.0e0;
q[1] = 1.0e0 - q[0];
nq = 2;
for (i = 0; i < nf; i++) {
    nag_double_quantiles(nsim, &GSIM(0, i), nq, q, &GLIM(0, i), &fail);
    if (fail.code != NE_NOERROR) {
        printf("Error from nag_double_quantiles (g01amc).\n%s\n", fail.message);
        exit_status = 1;
        goto END;
    }
    nag_double_quantiles(nsim, &BSIM(0, i), nq, q, &BLIM(0, i), &fail);
    if (fail.code != NE_NOERROR) {
        printf("Error from nag_double_quantiles (g01amc).\n%s\n", fail.message);
        exit_status = 1;
        goto END;
    }
}

/* Display the forecast values and associated prediction intervals */
printf("Initial values used:\n");
for (i = 0; i < ival; i++)
    printf("%4" NAG_IFMT " %12.3f \n", i + 1, init[i]);
printf("\n");
printf("Mean Deviation      = %13.4e\n", dv);
printf("Absolute Deviation = %13.4e\n\n", ad);
printf("      Observed      1-Step\n");
printf("Period  Values      Forecast      Residual\n\n");
for (i = 0; i < n; i++)
    printf("%4" NAG_IFMT " %11.3f %11.3f %11.3f\n", i + 1, y[i],
          yhat[i], res[i]);
printf("\n");
tail = Nag_LowerTail;
z = nag_deviates_normal(tail, q[1], &fail);
if (fail.code != NE_NOERROR) {
    printf("Error from nag_deviates_normal (g01fac).\n%s\n", fail.message);
    exit_status = 1;
    goto END;
}
printf("
                                     Simulated CI"
      "
          Simulated CI\n");
printf(" Obs.  Forecast      Estimated CI      (Gaussian Errors)"
      "
          (Bootstrap Errors)\n");
for (i = 0; i < nf; i++) {
    tmp = z * fse[i];
    printf("%3" NAG_IFMT " %10.3f %10.3f %10.3f"
          " %10.3f %10.3f %10.3f %10.3f\n", n + i + 1, fv[i], fv[i] - tmp,
          fv[i] + tmp, GLIM(0, i), GLIM(1, i), BLIM(0, i), BLIM(1, i));
}
printf(" %5.1f%% CIs were produced\n", 100.0e0 * (1.0e0 - alpha));

END:
    NAG_FREE(blim);

```

```

NAG_FREE(bsim);
NAG_FREE(e);
NAG_FREE(fse);
NAG_FREE(fv);
NAG_FREE(glim);
NAG_FREE(gsim);
NAG_FREE(init);
NAG_FREE(param);
NAG_FREE(r);
NAG_FREE(res);
NAG_FREE(tsim1);
NAG_FREE(tsim2);
NAG_FREE(y);
NAG_FREE(yhat);
NAG_FREE(state);

return exit_status;
}

```

## 10.2 Program Data

```

nag_rand_exp_smooth (g05pmc) Example Program Data
Nag_InitialValues Nag_LinearHolt
11 5 100 0.05 : mode,itype,n,nf,nsim,alpha
180 135 213 181 148 204 228 225 198 200 187 : y
dependent arguments for itype=Nag_LinearHolt
0.01 1.0 1.0 : param[0],param[1],param[2]
dependent arguments for mode=Nag_ContinueAndUpdate
11 : k

```

## 10.3 Program Results

nag\_rand\_exp\_smooth (g05pmc) Example Program Results

Initial values used:

```

1      168.018
2      3.800

```

```

Mean Deviation      = 2.5473e+01
Absolute Deviation = 2.1233e+01

```

Period	Observed Values	1-Step Forecast	Residual
1	180.000	171.818	8.182
2	135.000	175.782	-40.782
3	213.000	178.848	34.152
4	181.000	183.005	-2.005
5	148.000	186.780	-38.780
6	204.000	189.800	14.200
7	228.000	193.492	34.508
8	225.000	197.732	27.268
9	198.000	202.172	-4.172
10	200.000	206.256	-6.256
11	187.000	210.256	-23.256

Obs.	Forecast	Estimated CI		Simulated CI (Gaussian Errors)		Simulated CI (Bootstrap Errors)	
12	213.854	163.928	263.781	161.431	258.001	173.073	248.363
13	217.685	167.748	267.622	172.660	262.100	177.311	252.638
14	221.516	171.556	271.475	169.259	263.107	179.344	256.921
15	225.346	175.347	275.345	180.721	272.776	183.672	260.804
16	229.177	179.115	279.238	184.790	263.591	186.398	264.173

95.0% CIs were produced

**Example Program**  
Exponential Smoothing  
(95% confidence intervals (CIs) are shown)

