Estimations procedures with RATS 8.0 or higher for Commandeur and Koopman's book: Introduction to State Space Time Series Analysis

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Abstract

This file consists of estimations in the time series software RATS *(*Regression Analysis of Time Series). In this file program files and procedures for the estimations in the book by Commandeur and Koopman's had been provided. The order of estimations is by the book chapters.

Keywords: time seriesRATS 8.0, state space models

Chapter 1

```
open data ukdriversksi.txt
calendar(m) 1969
data(format=free,org=columns,skips=1) 1969:01 1984:12 ksi
set logksi = log(ksi)
```

KSI = monthly number of drivers killed or seriously injured
LOGKSI= log of the
monthly number of drivers killed or seriously injured (KSI)

ENTRY	KSI	LOGKSI
1969:01	1687.000000	7.430707
1969:02	1508.000000	7.318540
1969:03	1507.000000	7.317876
1969:04	1385.000000	7.233455
1969:05	1632.000000	7.397562
1969:06	1511.000000	7.320527
1969:07	1559.000000	7.351800
1969:08	1630.000000	7.396335
1969:09	1579.000000	7.364547
1969:10	1653.000000	7.410347
1969:11	2152.000000	7.674153
1969:12	2148.000000	7.672292
1970:01	1752.000000	7.468513
1970:02	1765.000000	7.475906
1970:03	1717.000000	7.448334
1970:04	1558.000000	7.351158
1970:05	1575.000000	7.362011
1970:06	1520.000000	7.326466
1970:07	1805.000000	7.498316
1970:08	1800.000000	7.495542
1970:09	1719.000000	7.449498
1970:10	2008.000000	7.604894
1970:11	2242.000000	7.715124

1970:12	2478.000000	7.815207
1971:01	2030.000000	7.615791
1971:02	1655.000000	7.411556
1971:03	1693.000000	7.434257
1971:04	1623.000000	7.392032
1971:05	1805.000000	7.498316
1971:06	1746.000000	7.465083
1971:07	1795.000000	7.492760
1971:08	1926.000000	7.563201
1971:09	1619.000000	7.389564
1971:10	1992.000000	7.596894
1971:11	2233.000000	7.711101
1971:12	2192.000000	7.692570
1972:01	2080.000000	7.640123
1972:02	1768.000000	7.477604
1972:03	1835.000000	7.514800
1972:04	1569.000000	7.358194
1972:05	1976.000000	7.588830
1972:06	1853.000000	7.524561
1972:07	1965.000000	7.583248
1972:08	1689.000000	7.431892
1972:09	1778.000000	7.483244
1972:10	1976.000000	7.588830
1972:11	2397.000000	7.781973
1972:12	2654.000000	7.883823
1973:01	2097.000000	7.648263
1973:02	1963.000000	7.582229
1973:03	1677.000000	7.424762
1973:04	1941.000000	7.570959
1973:05	2003.000000	7.602401
1973:06	1813.000000	7.502738

1973:07	2012.000000	7.606885
1973:08	1912.000000	7.555905
1973:09	2084.000000	7.642044
1973:10	2080.000000	7.640123
1973:11	2118.000000	7.658228
1973:12	2150.000000	7.673223
1974:01	1608.000000	7.382746
1974:02	1503.000000	7.315218
1974:03	1548.000000	7.344719
1974:04	1382.000000	7.231287
1974:05	1731.000000	7.456455
1974:06	1798.000000	7.494430
1974:07	1779.000000	7.483807
1974:08	1887.000000	7.542744
1974:09	2004.000000	7.602900
1974:10	2077.000000	7.638680
1974:11	2092.000000	7.645876
1974:12	2051.000000	7.626083
1975:01	1577.000000	7.363280
1975:02	1356.000000	7.212294
1975:03	1652.000000	7.409742
1975:04	1382.000000	7.231287
1975:05	1519.000000	7.325808
1975:06	1421.000000	7.259116
1975:07	1442.000000	7.273786
1975:08	1543.000000	7.341484
1975:09	1656.000000	7.412160
1975:10	1561.000000	7.353082
1975:11	1905.000000	7.552237
1975:12	2199.000000	7.695758
1976:01	1473.000000	7.295056

1976:02	1655.000000	7.411556
1976:03	1407.000000	7.249215
1976:04	1395.000000	7.240650
1976:05	1530.000000	7.333023
1976:06	1309.000000	7.177019
1976:07	1526.000000	7.330405
1976:08	1327.000000	7.190676
1976:09	1627.000000	7.394493
1976:10	1748.000000	7.466228
1976:11	1958.000000	7.579679
1976:12	2274.000000	7.729296
1977:01	1648.000000	7.407318
1977:02	1401.000000	7.244942
1977:03	1411.000000	7.252054
1977:04	1403.000000	7.246368
1977:05	1394.000000	7.239933
1977:06	1520.000000	7.326466
1977:07	1528.000000	7.331715
1977:08	1643.000000	7.404279
1977:09	1515.000000	7.323171
1977:10	1685.000000	7.429521
1977:11	2000.000000	7.600902
1977:12	2215.000000	7.703008
1978:01	1956.000000	7.578657
1978:02	1462.000000	7.287561
1978:03	1563.000000	7.354362
1978:04	1459.000000	7.285507
1978:05	1446.000000	7.276556
1978:06	1622.000000	7.391415
1978:07	1657.000000	7.412764
1978:08	1638.000000	7.401231

1978:09	1643.000000	7.404279
1978:10	1683.000000	7.428333
1978:11	2050.000000	7.625595
1978:12	2262.000000	7.724005
1979:01	1813.000000	7.502738
1979:02	1445.000000	7.275865
1979:03	1762.000000	7.474205
1979:04	1461.000000	7.286876
1979:05	1556.000000	7.349874
1979:06	1431.000000	7.266129
1979:07	1427.000000	7.263330
1979:08	1554.000000	7.348588
1979:09	1645.000000	7.405496
1979:10	1653.000000	7.410347
1979:11	2016.000000	7.608871
1979:12	2207.000000	7.699389
1980:01	1665.000000	7.417580
1980:02	1361.000000	7.215975
1980:03	1506.000000	7.317212
1980:04	1360.000000	7.215240
1980:05	1453.000000	7.281386
1980:06	1522.000000	7.327781
1980:07	1460.000000	7.286192
1980:08	1552.000000	7.347300
1980:09	1548.000000	7.344719
1980:10	1827.000000	7.510431
1980:11	1737.000000	7.459915
1980:12	1941.000000	7.570959
1981:01	1474.000000	7.295735
1981:02	1458.000000	7.284821
1981:03	1542.000000	7.340836

1981:04	1404.000000	7.247081
1981:05	1522.000000	7.327781
1981:06	1385.000000	7.233455
1981:07	1641.000000	7.403061
1981:08	1510.000000	7.319865
1981:09	1681.000000	7.427144
1981:10	1938.000000	7.569412
1981:11	1868.000000	7.532624
1981:12	1726.000000	7.453562
1982:01	1456.000000	7.283448
1982:02	1445.000000	7.275865
1982:03	1456.000000	7.283448
1982:04	1365.000000	7.218910
1982:05	1487.000000	7.304516
1982:06	1558.000000	7.351158
1982:07	1488.000000	7.305188
1982:08	1684.000000	7.428927
1982:09	1594.000000	7.374002
1982:10	1850.000000	7.522941
1982:11	1998.000000	7.599902
1982:12	2079.000000	7.639642
1983:01	1494.000000	7.309212
1983:02	1057.000000	6.963190
1983:03	1218.000000	7.104965
1983:04	1168.000000	7.063048
1983:05	1236.000000	7.119636
1983:06	1076.000000	6.981006
1983:07	1174.000000	7.068172
1983:08	1139.000000	7.037906
1983:09	1427.000000	7.263330
1983:10	1487.000000	7.304516

1983:11	1483.000000	7.301822
1983:12	1513.000000	7.321850
1984:01	1357.000000	7.213032
1984:02	1165.000000	7.060476
1984:03	1282.000000	7.156177
1984:04	1110.000000	7.012115
1984:05	1297.000000	7.167809
1984:06	1185.000000	7.077498
1984:07	1222.000000	7.108244
1984:08	1284.000000	7.157735
1984:09	1444.000000	7.275172
1984:10	1575.000000	7.362011
1984:11	1737.000000	7.459915
1984:12	1763.000000	7.474772

```
* Linear regression on trend
*
set trend = t
linreg logksi
# constant trend
```

Linear Regression - Estimation by Least Squares

Dependent Variable LOGKSI

Monthly Data From 1969:01 To 1984:12

Usable Observations	192
Degrees of Freedom	190
Centered R^2	0.2205911
R-Bar^2	0.2164889
Uncentered R^2	0.9995853
Mean of Dependent Variable	7.4061076031
Std Error of Dependent Variable	0.1713258861

```
Standard Error of Estimate      0.1516510996
Sum of Squared Residuals        4.3696306440
Regression F(1,190)             53.7745
Significance Level of F         0.0000000
Log Likelihood                  90.7142
Durbin-Watson Statistic         0.7114

   Variable              Coeff      Std Error      T-Stat     Signif
*******************************************************************************
1.  Constant              7.545842732  0.021974734   343.38721  0.00000000
2.  TREND                -0.001448032  0.000197465    -7.33311  0.00000000

prj fitted
graph(style=dots,overlay=line,ovsamescale,$
  footer="Figure 1.1 Scatter plot of log KSI against time; with regression line") 2
# logksi
# fitted
```

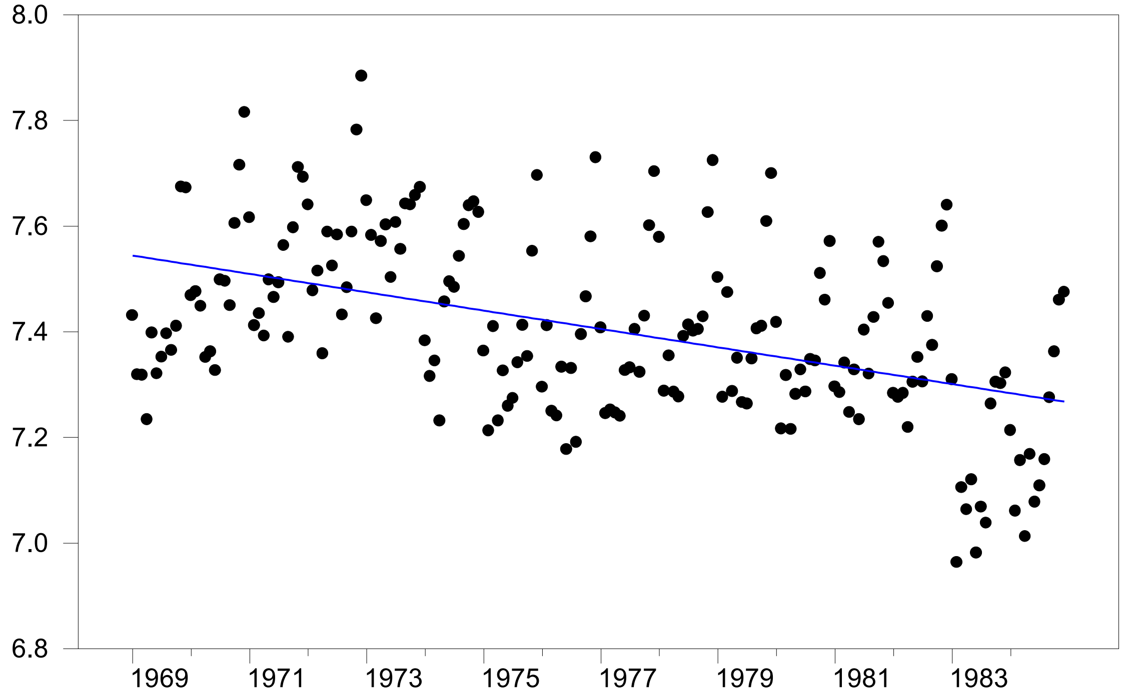


Figure 1.1 Scatter plot of log KSI against time; with regression line

graph(footer="Figure 1.2 Log KSI plotted as a time series")

logksi

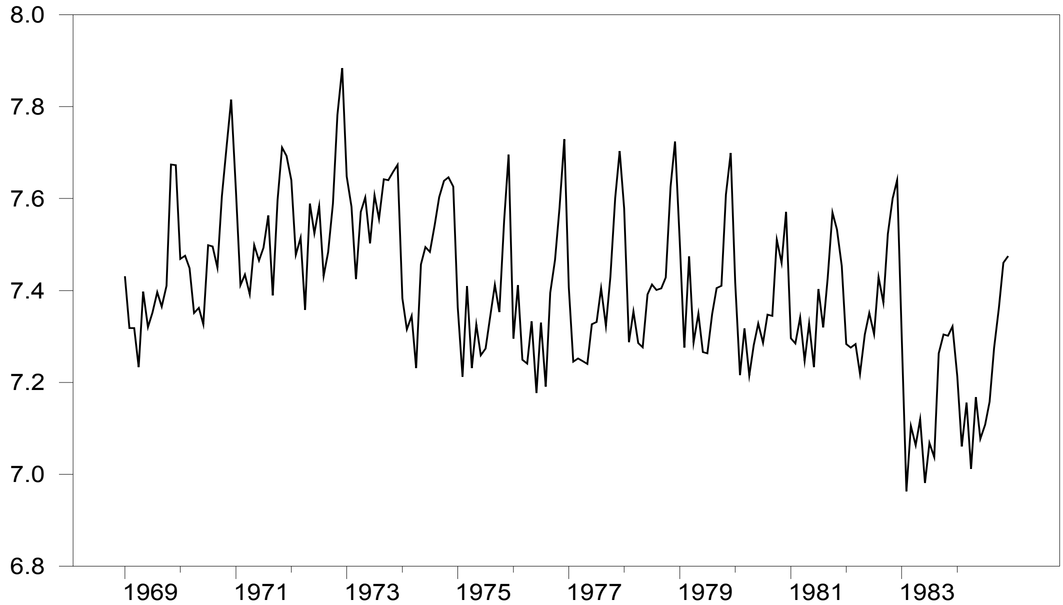


Figure 1.2 Log KSI plotted as a time series

graph(footer="Figure 1.3 Residuals of classical linear regression")

%resids

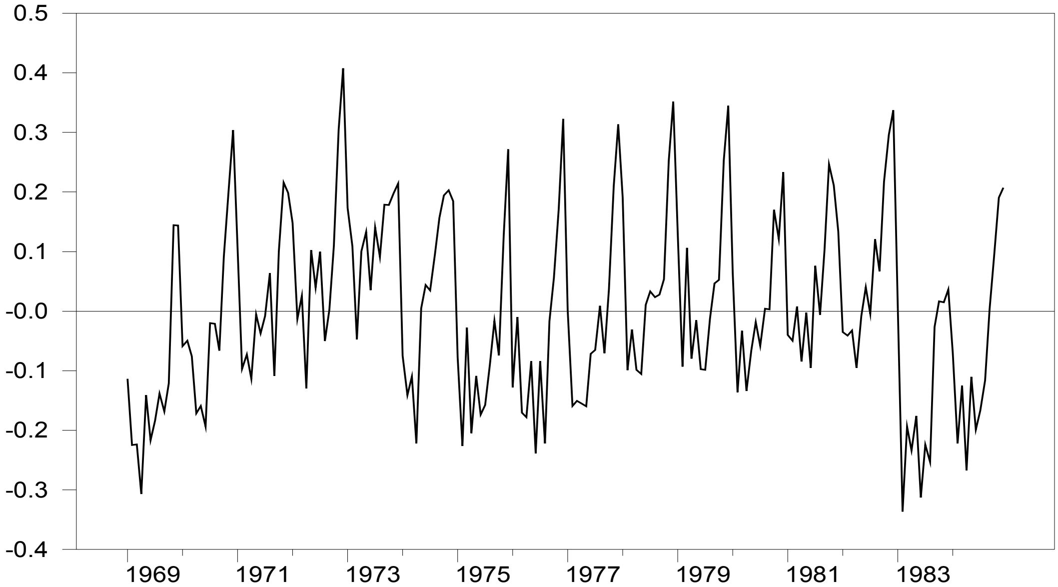


Figure 1.3 Residuals of classical linear regression

```
@regcorrs(number=14,footer="Figure 1.5 Correlogram of classical regression residuals")
```

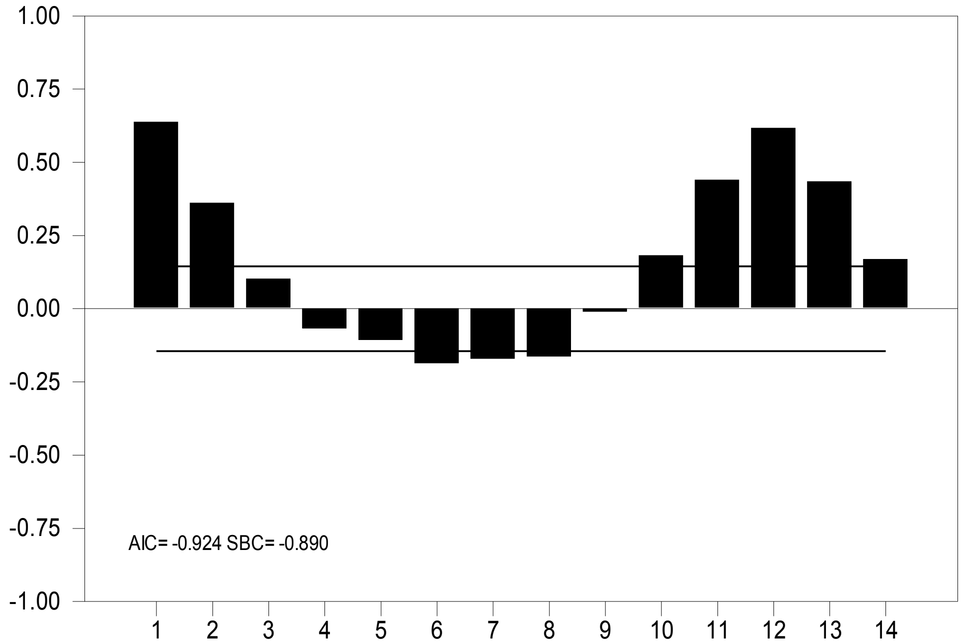


Figure 1.5 Correlogram of classical regression residuals

Chapter 1 commands

```
*
* Commandeur & Koopman, An Introduction to State Space Time Series Analysis.
* Chapter 1
*
open data ukdriversksi.txt
calendar(m) 1969
data(format=free,org=columns,skips=1) 1969:01 1984:12 ksi
set logksi = log(ksi)
*
* Linear regression on trend
*
set trend = t
linreg logksi
# constant trend
prj fitted
graph(style=dots,overlay=line,ovsamescale,$
  footer="Figure 1.1 Scatter plot of log KSI against time; with regression line") 2
# logksi
# fitted
*
graph(footer="Figure 1.2 Log KSI plotted as a time series")
# logksi
*
graph(footer="Figure 1.3 Residuals of classical linear regression")
# %resids
*
@regcorrs(number=14,footer="Figure 1.5 Correlogram of classical regression residuals")
```

Chapter 2

open data norwayfinland.txt

calendar(a) 1970

data(format=free,org=columns,skips=1) 1970:01 2003:01 year norway finland

ENTRY	YEAR	NORWAY	FINLAND
1970:01	1970.000000	560.000000	1055.000000
1971:01	1971.000000	533.000000	1143.000000
1972:01	1972.000000	490.000000	1156.000000
1973:01	1973.000000	511.000000	1086.000000
1974:01	1974.000000	509.000000	865.000000
1975:01	1975.000000	539.000000	910.000000
1976:01	1976.000000	471.000000	804.000000
1977:01	1977.000000	442.000000	709.000000
1978:01	1978.000000	434.000000	610.000000
1979:01	1979.000000	437.000000	650.000000
1980:01	1980.000000	362.000000	551.000000
1981:01	1981.000000	338.000000	555.000000
1982:01	1982.000000	401.000000	569.000000
1983:01	1983.000000	409.000000	604.000000
1984:01	1984.000000	407.000000	541.000000
1985:01	1985.000000	402.000000	541.000000
1986:01	1986.000000	452.000000	612.000000
1987:01	1987.000000	398.000000	581.000000
1988:01	1988.000000	378.000000	653.000000
1989:01	1989.000000	381.000000	734.000000
1990:01	1990.000000	332.000000	649.000000
1991:01	1991.000000	323.000000	632.000000
1992:01	1992.000000	325.000000	601.000000
1993:01	1993.000000	281.000000	484.000000
1994:01	1994.000000	283.000000	480.000000

1995:01	1995.000000	305.000000	441.000000
1996:01	1996.000000	255.000000	404.000000
1997:01	1997.000000	303.000000	438.000000
1998:01	1998.000000	352.000000	400.000000
1999:01	1999.000000	304.000000	431.000000
2000:01	2000.000000	341.000000	396.000000
2001:01	2001.000000	275.000000	433.000000
2002:01	2002.000000	312.000000	415.000000
2003:01	2003.000000	280.000000	379.000000

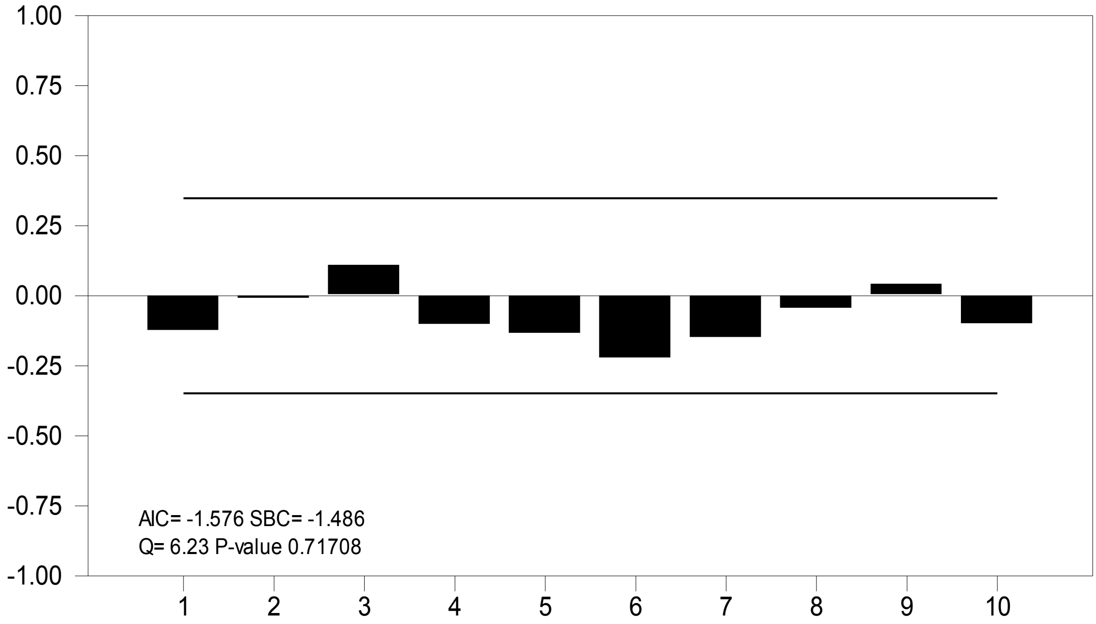
```
set lognorway = log(norway)
@LocalDLMInit(irreg=sigsqeps) lognorway
nonlin sigsqeps sigsqxi
compute sigsqxi=sigsqeps*.01
dlm(a=1.0,c=1.0,sv=sigsqeps,sw=sigsqxi,exact,y=lognorway,$
  method=bfgs,vhat=vhat,svhat=svhat)
set resids = %scalar(vhat)/sqrt(%scalar(svhat))
```

```
DLM - Estimation by BFGS
Convergence in    20 Iterations. Final criterion was  0.0000068 <=  0.0000100
Annual Data From 1970:01 To 2003:01
Usable Observations                    34
Rank of Observables                    33
Log Likelihood                    28.7933

   Variable                    Coeff      Std Error      T-Stat      Signif
*******************************************************************************
1.  SIGSQEPS                  0.0032675682 0.0017139951      1.90640  0.05659772
2.  SIGSQXI                   0.0047076220 0.0020504609      2.29588  0.02168247
```

@STAMPDiags(ncorr=10) resids

State Space Model Diagnostics

	Statistic	Sig. Level
Q(10-1)	6.23	0.7171
Normality	1.08	0.5822
H(11)	1.75	0.3688




```
dlm(a=1.0,c=1.0,sv=sigsqeps,sw=sigsqxi,exact,y=lognorway,$
  type=smooth) / xstates
set level = %scalar(xstates)
set irreg = lognorway-level
graph(footer="Figure 2.5 Stochastic level for Norwegian fatalities",$
  key=upright,klabels=||"log fatalities in Norway","stochastic level"||) 2
# lognorway
# level
graph(footer="Figure 2.6 Irregular component for Norwegian fatalities")
# irreg
```

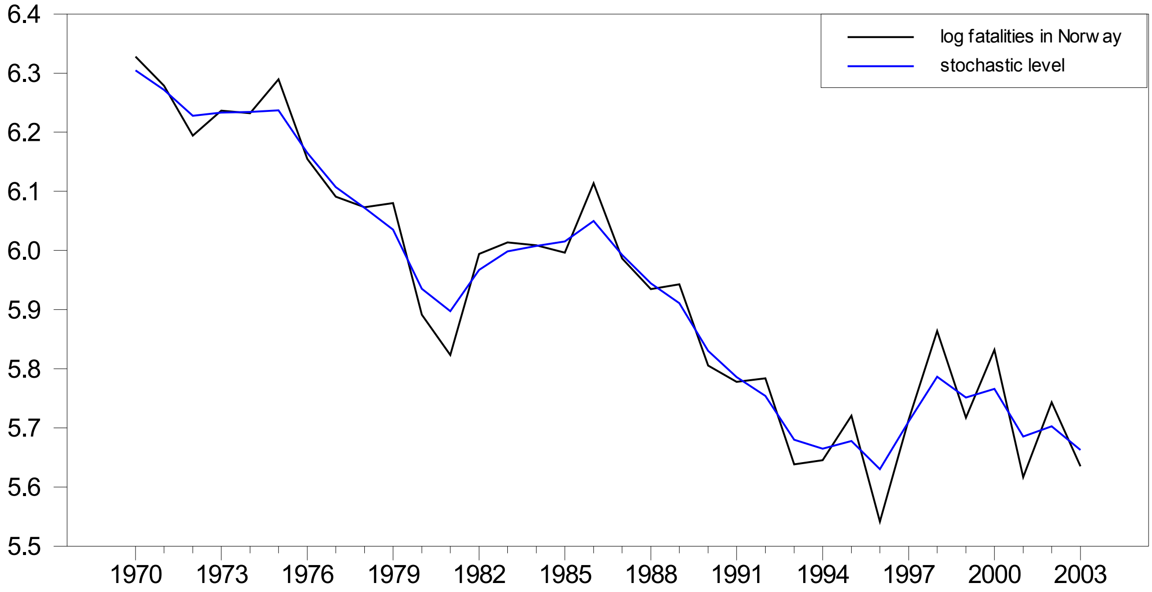


Figure 2.5 Stochastic level for Norwegian fatalities

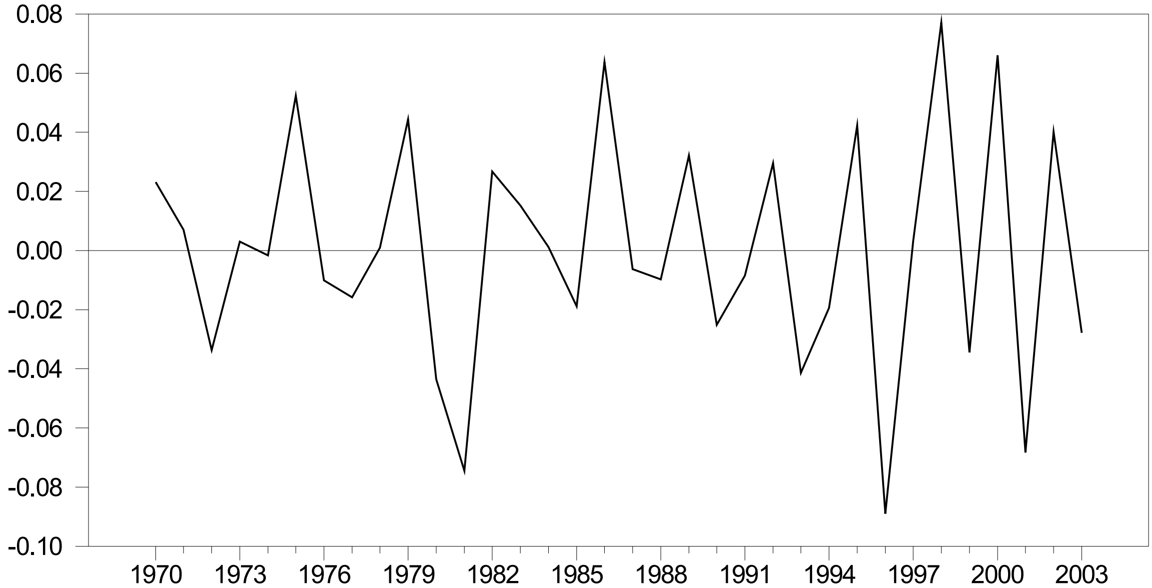
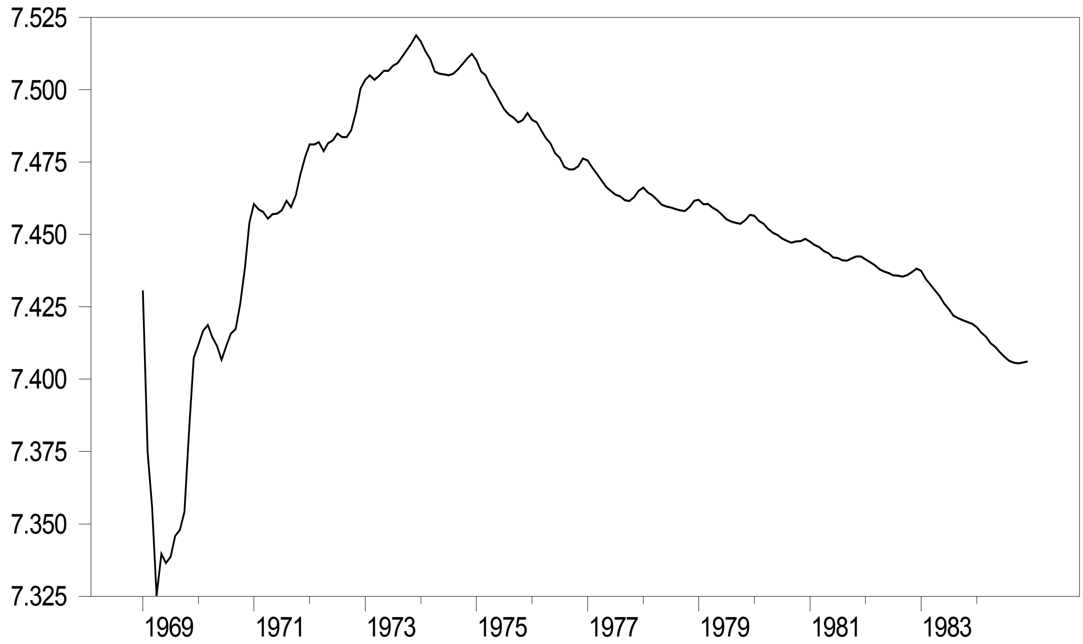


Figure 2.6 Irregular component for Norwegian fatalities

Chapter 2. UK data.

```
*

open data ukdriversksi.txt

calendar(m) 1969

data(format=free,org=columns,skips=1) 1969:01 1984:12 ksi
```

```
set logksi = log(ksi)

compute sigsqeps=.0001

nonlin sigsqeps sigsqxi=0.0

dlm(a=1.0,c=1.0,sv=sigsqeps,sw=sigsqxi,exact,y=logksi,$

  method=bfgs,vhat=vhat,svhat=svhat) / xstates

DLM - Estimation by BFGS

Convergence in    26 Iterations. Final criterion was  0.0000056 <=  0.0000100

Monthly Data From 1969:01 To 1984:12

Usable Observations                    192

Rank of Observables                    191

Log Likelihood                  63.3139


   Variable                    Coeff      Std Error      T-Stat      Signif
*******************************************************************************
1.  SIGSQEPS                   0.0293525003 0.0029913200      9.81256  0.00000000

       set kflevel = %scalar(xstates)

       graph(footer="Sequential estimates of overall process mean")

       # kflevel
```



Sequential estimates of overall process mean

```
disp "Overall mean" kflevel(%regend())
Overall mean       7.40611

set level = kflevel(%regend())
graph(footer="Figure 2.1 Deterministic level",$
 key=upright,klabels=||"Log UK drivers KSI","Deterministic Level"||) 2
# logksi
# level
set irreg = logksi-level
graph(footer="Figure 2.2 Irregular Component for Deterministic Level")
# irreg
```

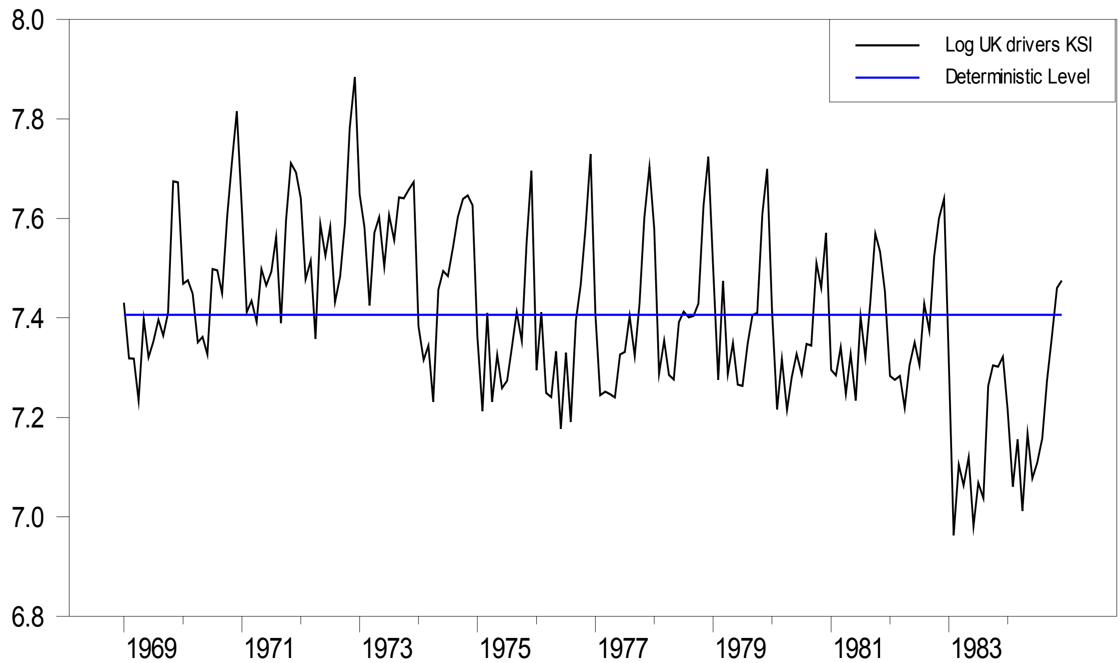


Figure 2.1 Deterministic level

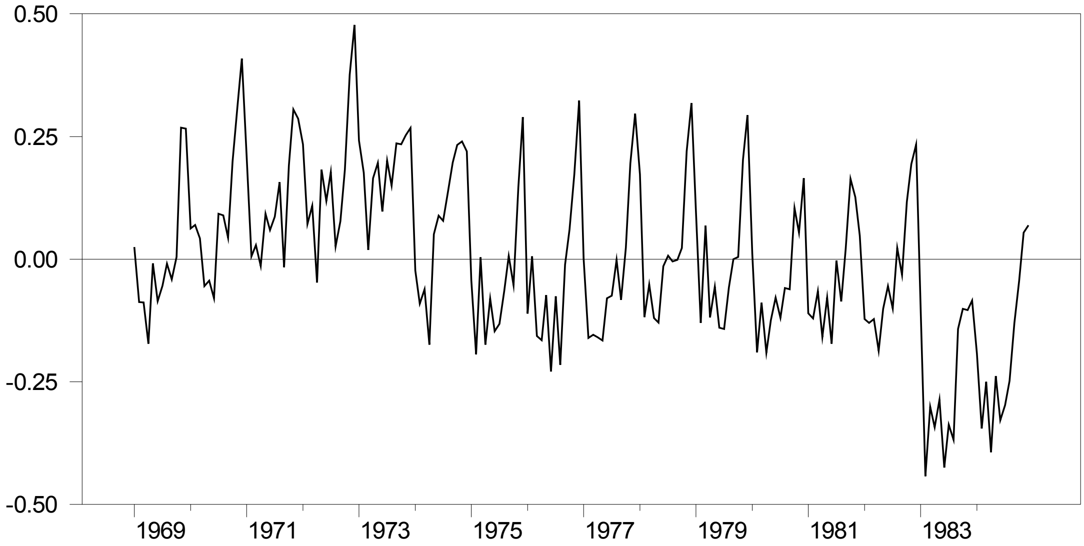


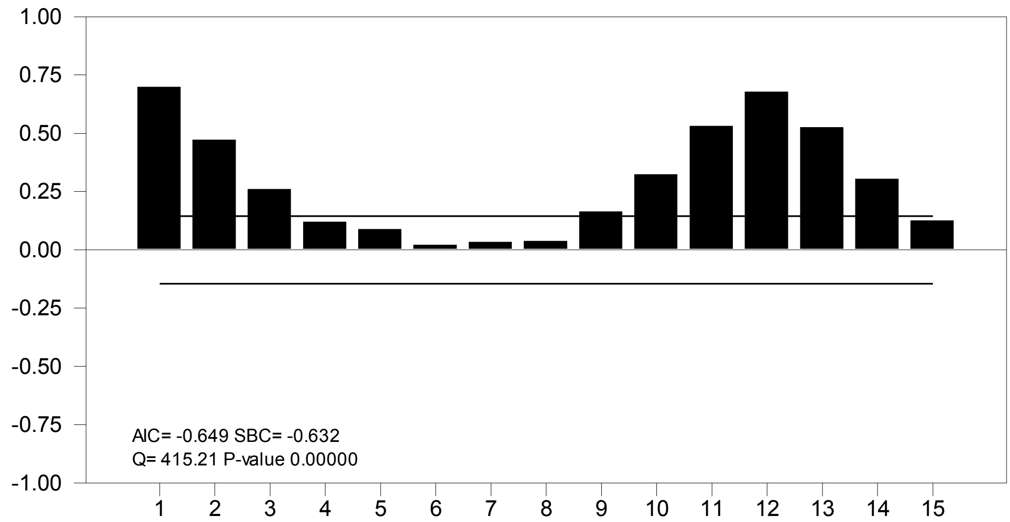
Figure 2.2 Irregular Component for Deterministic Level

set resids = %scalar(vhat)/sqrt(%scalar(svhat))

@STAMPDiags(ncorrs=15) resids

State Space Model Diagnostics

	Statistic	Sig. Level
Q(15-0)	415.21	0.0000
Normality	0.65	0.7242
H(64)	2.06	0.0044

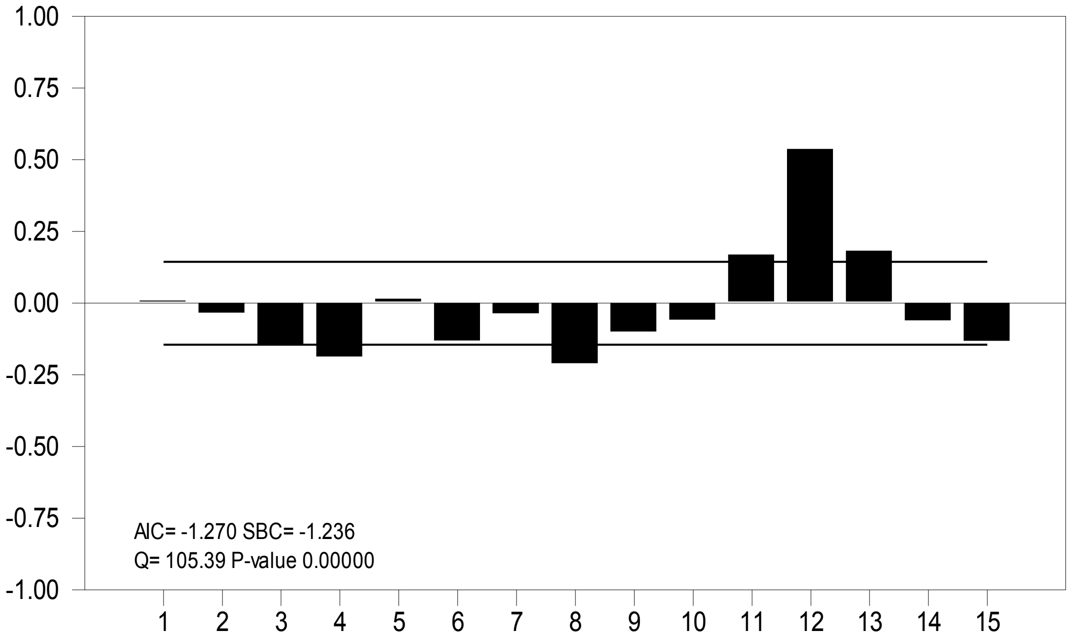


Same model, but freeing up the variance on the drift in the level.

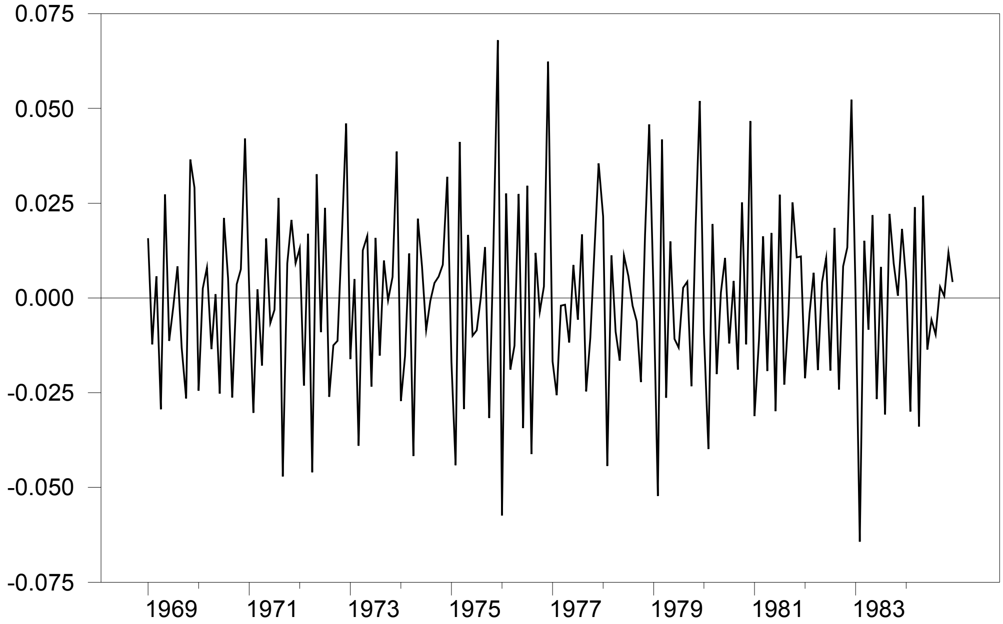
```
* Estimate and do the diagnostics using the Kalman filter

nonlin sigsqeps sigsqxi
dlm(a=1.0,c=1.0,sv=sigsqeps,sw=sigsqxi,exact,y=logksi,$
  method=bfgs,vhat=vhat,svhat=svhat) / xstates
set resids = %scalar(vhat)/sqrt(%scalar(svhat))
@STAMPDiags(ncorrs=15) resids
```

```
DLM - Estimation by BFGS
Convergence in    25 Iterations. Final criterion was  0.0000008 <=  0.0000100
Monthly Data From 1969:01 To 1984:12
Usable Observations                  192
Rank of Observables                  191
Log Likelihood                  123.8776

   Variable                    Coeff      Std Error      T-Stat      Signif
*********************************************************************************
**
1.  SIGSQEPS                 0.0022215505 0.0012633410      1.75847  0.07866715
2.  SIGSQXI                 0.0118659664 0.0024847809      4.77546  0.00000179
```

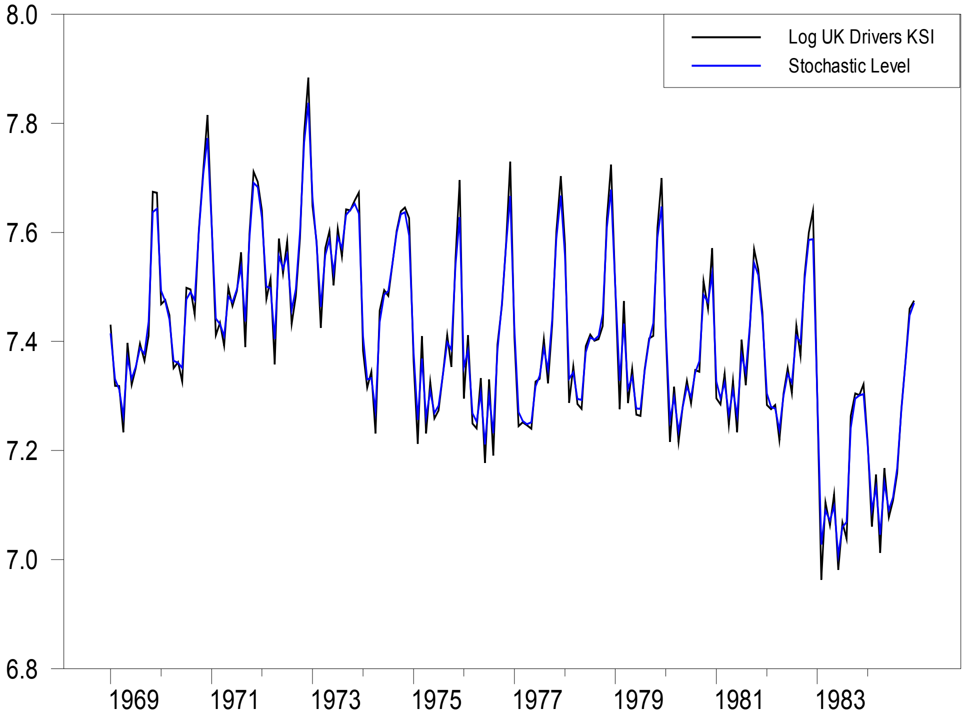
```
State Space Model Diagnostics
        Statistic Sig. Level
Q(15-1)      105.39     0.0000
Normality     13.59     0.0011
H(64)         1.06     0.8048
```




```
* Compute estimated components using Kalman smoothing
*
dlm(a=1.0,c=1.0,sv=sigsqeps,sw=sigsqxi,exact,y=logksi,$
  type=smooth) / xstates
set level = %scalar(xstates(t))
set irreg = logksi-level
graph(footer="2.3 Stochastic Level",$
 key=upright,klabels=||"Log UK Drivers KSI","Stochastic Level"||) 2
# logksi
# level
graph(footer="2.4 Irregular component for local level model")
# irreg
```



2.4 Irregular component for local level model



2.3 Stochastic Level

CHAPTER 3

```
open data norwayfinland.txt
calendar(a) 1970
data(format=free,org=columns,skips=1) 1970:01 2003:01 year norway finland
@LocalDLM(type=trend,shocks=both,a=at,c=ct,f=ft)
@LocalDLMInit(irreg=sigsqeps,trend=sigsqzeta) logfinland
compute sigsqxi=sigsqeps*.01
nonlin sigsqeps sigsqxi sigsqzeta
dlm(a=at,c=ct,sv=sigsqeps,f=ft,sw=%diag(||sigsqxi,sigsqzeta||),exact,y=logfinland,$
  method=bfgs,vhat=vhat,svhat=svhat)
DLM - Estimation by BFGS
Convergence in    13 Iterations. Final criterion was  0.0000004 <=  0.0000100
Annual Data From 1970:01 To 2003:01
Usable Observations                    34
Rank of Observables                    32
Log Likelihood                    26.8099

    Variable                     Coeff      Std Error      T-Stat      Signif
************************************************************
1.  SIGSQEPS                  0.004457791  0.002700676     1.65062  0.09881606
2.  SIGSQXI                  -0.004160160  0.008282009    -0.50231  0.61544747
3.  SIGSQZETA                 0.002812008  0.003114884     0.90277  0.36665060

* This time sigsqxi comes in negative, so we fix it at zero
nonlin sigsqeps sigsqxi=0.0 sigsqzeta
dlm(a=at,c=ct,sv=sigsqeps,f=ft,sw=%diag(||sigsqxi,sigsqzeta||),exact,y=logfinland,$
  method=bfgs,vhat=vhat,svhat=svhat)
set resids = %scalar(vhat)/sqrt(%scalar(svhat))
@STAMPDiags(ncorr=10) resids
DLM - Estimation by BFGS
Convergence in     7 Iterations. Final criterion was  0.0000024 <=  0.0000100
```

Annual Data From 1970:01 To 2003:01

Usable Observations 34

Rank of Observables 32

Log Likelihood 26.7401

Variable	Coeff	Std Error	T-Stat	Signif

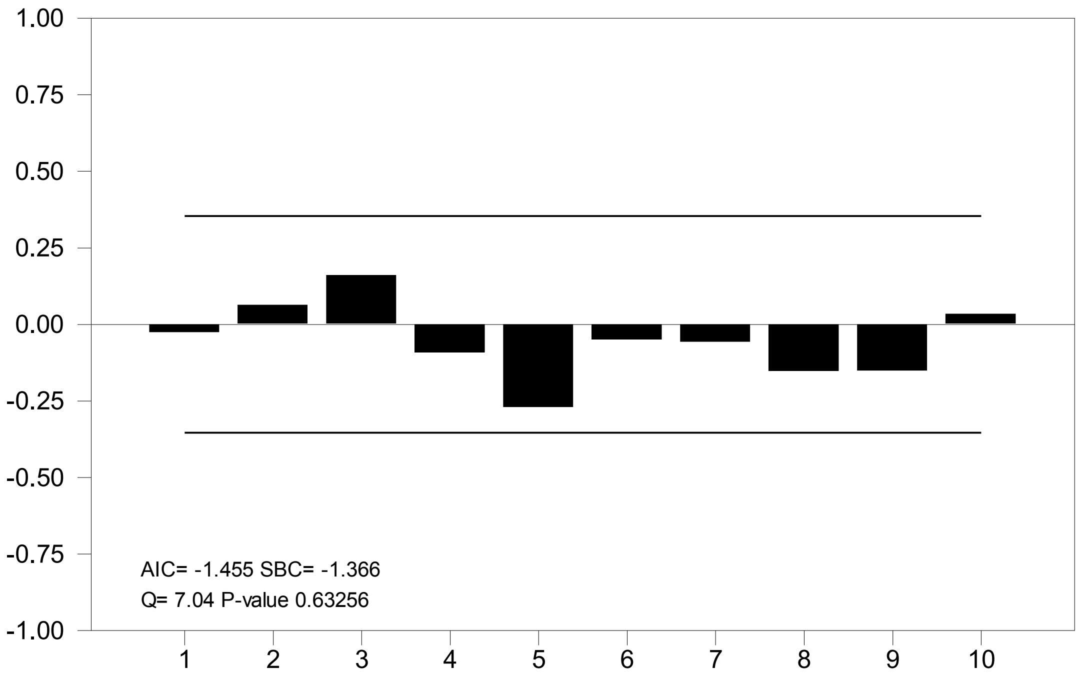
****

1. SIGSQEPS 0.0032007481 0.0010712559 2.98785 0.00280951

2. SIGSQZETA 0.0015330319 0.0008827859 1.73658 0.08246061

State Space Model Diagnostics

	Statistic	Sig. Level
Q(10-1)	7.04	0.6326
Normality	0.52	0.7718
H(11)	0.74	0.6290



Redo with smoothing to get the components

```
dlm(a=at,c=ct,sv=sigsqeps,f=ft,sw=%diag(||sigsqxi,sigsqzeta||),exact,y=logfinland,$
  type=smooth) / xstates
set level = %scalar(xstates)
set irreg = logfinland-level
set slope = xstates(t)(2)
spgraph(vfields=2,footer="Figure 3.5 Deterministic level/stochastic slope model")
graph(key=upright,klabels=||"log fatalities Finland","deterministic level, stochastic slope"||) 2
# logfinland
# level
graph(key=upright,klabels=||"stochastic slope"||)
# slope
spgraph(done)
graph(footer="Figure 3.6 Irregular component for Finnish fatalities")
# irreg
```

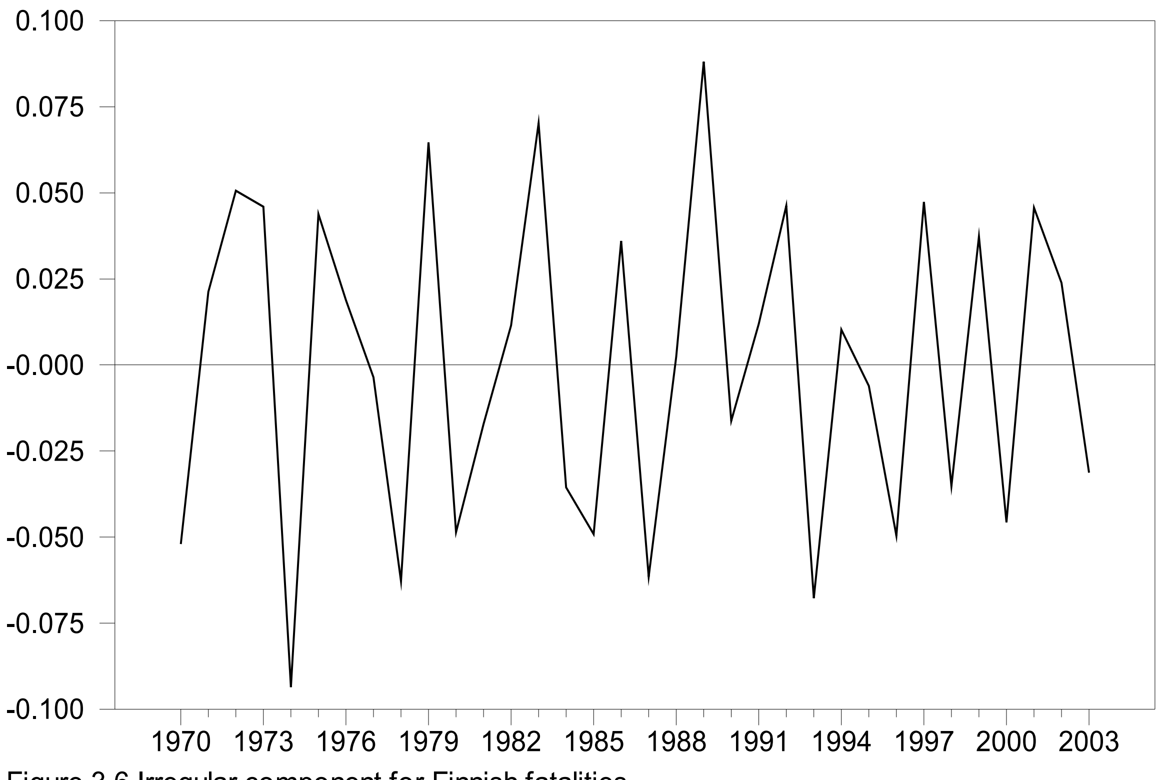


Figure 3.6 Irregular component for Finnish fatalities

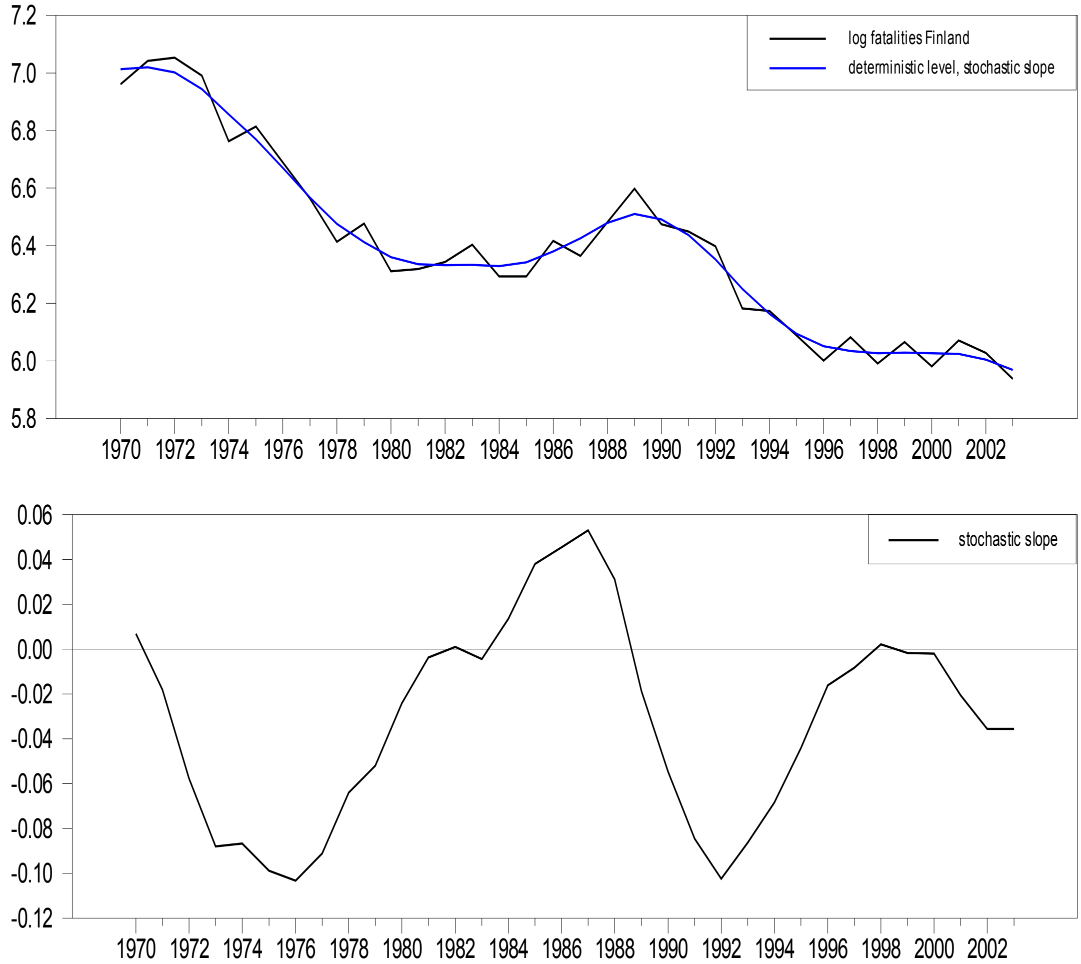


Figure 3.5 Deterministic level/stochastic slope model

Chapter 3 UK data

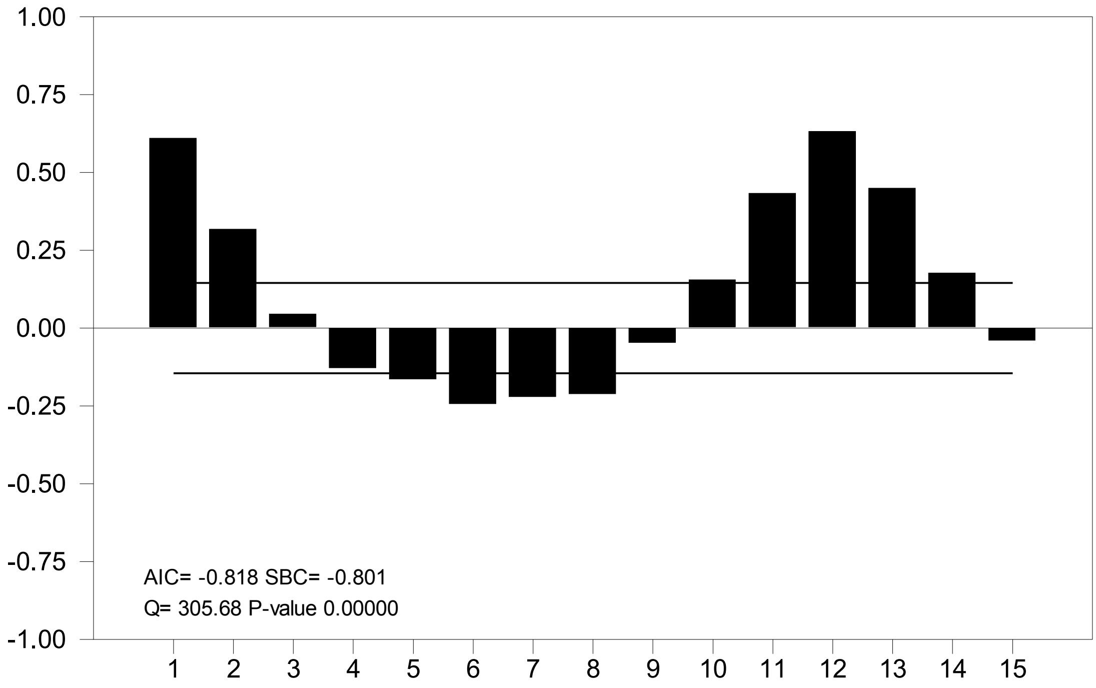
```
open data ukdriversksi.txt

calendar(m) 1969

data(format=free,org=columns,skips=1) 1969:01 1984:12 ksi

set logksi = log(ksi)


@LocalDLM(type=trend,shocks=both,a=at,c=ct,f=ft)
```

```
@LocalDLMInit(irreg=sigsqeps) logksi
```

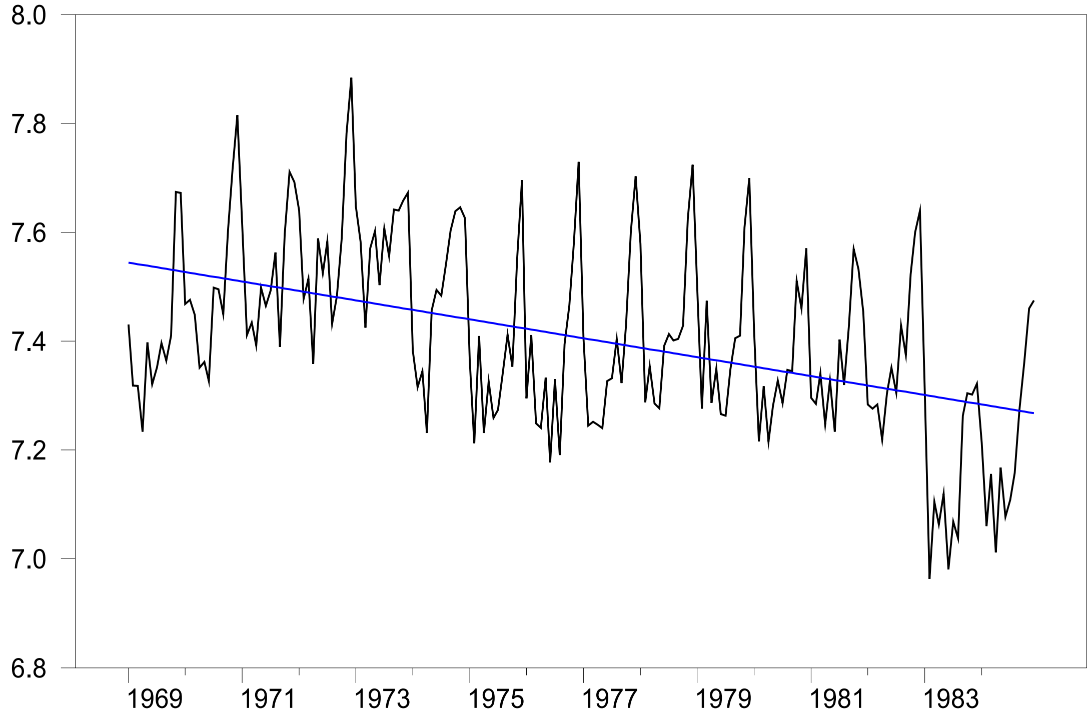
Estimation with sigsqxi and sigsqzeta fixed at zero

```
nonlin sigsqeps sigsqxi=0.0 sigsqzeta=0.0
dlm(a=at,c=ct,sv=sigsqeps,f=ft,sw=%diag(||sigsqxi,sigsqzeta||),exact,y=logksi,$
  method=bfgs,vhat=vhat,svhat=svhat)
```

```
DLM - Estimation by BFGS
Convergence in     6 Iterations. Final criterion was  0.0000052 <=  0.0000100
Monthly Data From 1969:01 To 1984:12
Usable Observations                 192
Rank of Observables                 190
Log Likelihood                  79.5020

    Variable                     Coeff      Std Error      T-Stat      Signif
*******************************************************************************
1.  SIGSQEPS                  0.0229979987 0.0023486524      9.79200  0.00000000
set resids = %scalar(vhat)/sqrt(%scalar(svhat))
@STAMPDiags(ncorrs=15) resids

State Space Model Diagnostics
          Statistic Sig. Level
Q(15-0)      305.68     0.0000
Normality      1.76     0.4156
H(63)          1.36     0.2252
```




```
dlm(a=at,c=ct,sv=sigsqeps,f=ft,sw=%diag(||sigsqxi,sigsqzeta||),exact,y=logksi,$
  type=smooth) / xstates
set level = %scalar(xstates)
set irreg = logksi-level


graph(footer="UK data with deterministic trend") 2
# logksi
# level
```



UK data with deterministic trend

Same model, freeing up variances

```
@LocalDLMInit(irreg=sigsqeps,trend=sigsqzeta) logksi

compute sigsqxi=sigsqeps*.01

nonlin sigsqeps sigsqxi sigsqzeta

dlm(a=at,c=ct,sv=sigsqeps,f=ft,sw=%diag(||sigsqxi,sigsqzeta||),exact,y=logksi,$

  method=bfgs,vhat=vhat,svhat=svhat)
```

DLM - Estimation by BFGS

NO CONVERGENCE IN 7 ITERATIONS

LAST CRITERION WAS 0.0000005

ESTIMATION POSSIBLY HAS STALLED OR MACHINE ROUNDOFF IS MAKING FURTHER PROGRESS DIFFICULT

TRY HIGHER SUBITERATIONS LIMIT, TIGHTER CVCRIT, DIFFERENT SETTING FOR EXACTLINE OR ALPHA ON NLPAR

RESTARTING ESTIMATION FROM LAST ESTIMATES OR DIFFERENT INITIAL GUESSES MIGHT ALSO WORK

```
Monthly Data From 1969:01 To 1984:12
Usable Observations                 192
Rank of Observables                 190
Log Likelihood                 121.7970

   Variable                  Coeff      Std Error      T-Stat      Signif
*******************************************************************************
1.  SIGSQEPS                 5.3406e-003  3.6750e-003     1.45322  0.14616254
2.  SIGSQXI                7.0548e-003  1.3218e-003     5.33742  0.00000009
3.  SIGSQZETA               -1.9292e-006  4.8007e-007    -4.01865  0.00005853
```

```
Unconstrained, sigsqzeta comes in negative, so we re-estimate with it
* fixed at 0. (The results in the text come from estimating the
* variances in log form, which prevents negative values. The 1.5e-11 is
* effectively zero). The results here will be identical to section 3.3
* in the book.

nonlin sigsqeps sigsqxi sigsqzeta=0.0
dlm(a=at,c=ct,sv=sigsqeps,f=ft,sw=%diag(||sigsqxi,sigsqzeta||),exact,y=logksi,$
  method=bfgs,vhat=vhat,svhat=svhat)
set resids = %scalar(vhat)/sqrt(%scalar(svhat))
@STAMPDiags(ncorrs=15) resids
```

```
DLM - Estimation by BFGS
Convergence in     7 Iterations. Final criterion was  0.0000091 <=  0.0000100
Monthly Data From 1969:01 To 1984:12
Usable Observations                 192
Rank of Observables                 190
Log Likelihood                 119.9604

   Variable                  Coeff      Std Error      T-Stat      Signif
```

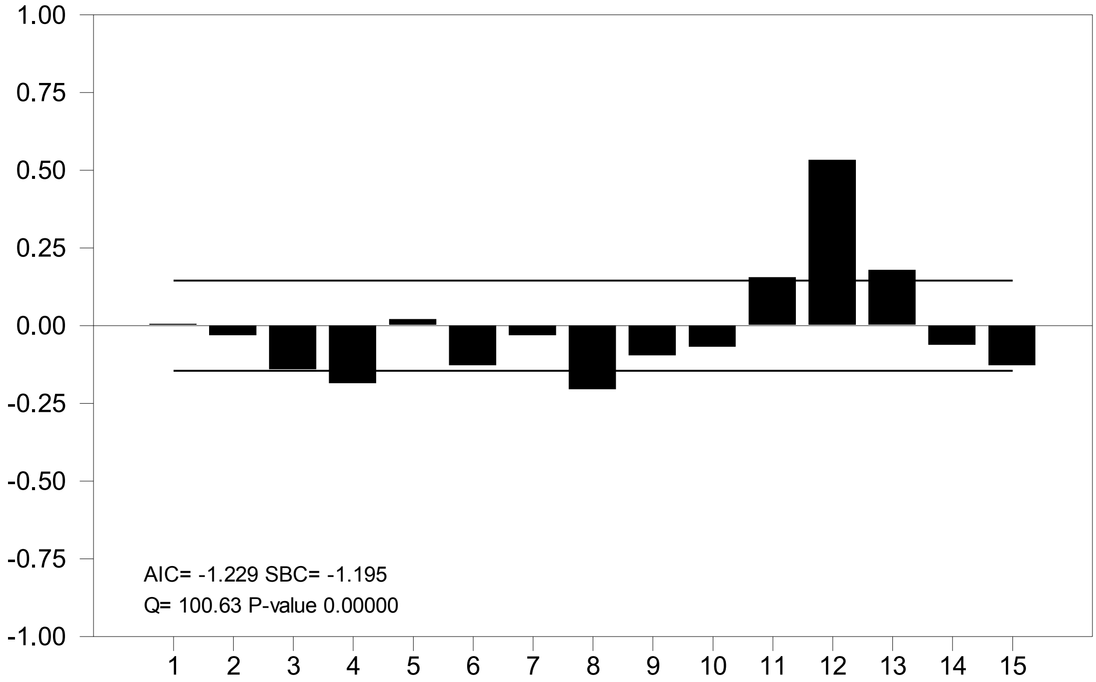
****

1. SIGSQEPS 0.0021194466 0.0011778270 1.79945 0.07194675

2. SIGSQXI 0.0121246062 0.0021399228 5.66591 0.00000001

State Space Model Diagnostics

	Statistic	Sig. Level
Q(15-1)	100.63	0.0000
Normality	15.34	0.0005
H(63)	1.06	0.8241




```
dlm(a=at,c=ct,sv=sigsqeps,f=ft,sw=%diag(||sigsqxi,sigsqzeta||),exact,y=logksi,$
  type=smooth) / xstates
set level = %scalar(xstates)
```

```
set irreg = logksi-level
graph(footer="Figure 3.1 Stochastic linear trend model",$
 key=upright,klabels=||"Log UK drivers KSI","Stochastic level and slope"||) 2
# logksi
# level
set irreg = logksi-level
graph(footer="Figure 3.3 Irregular component for stochastic linear trend")
# irreg
```

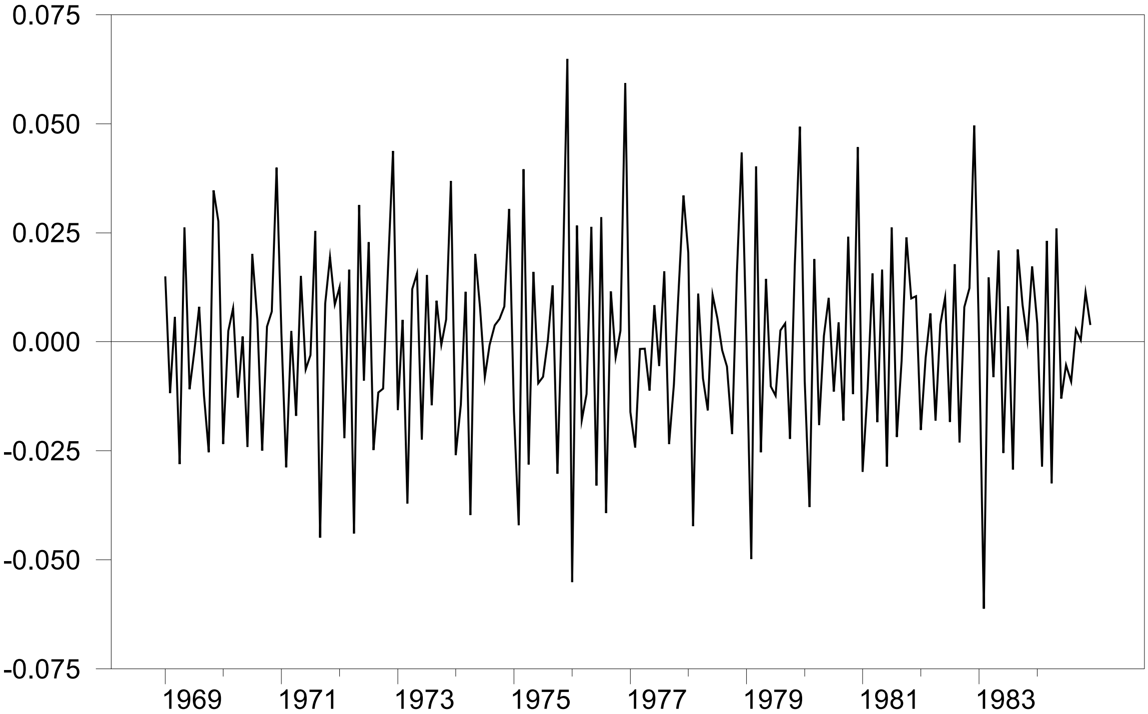


Figure 3.3 Irregular component for stochastic linear trend

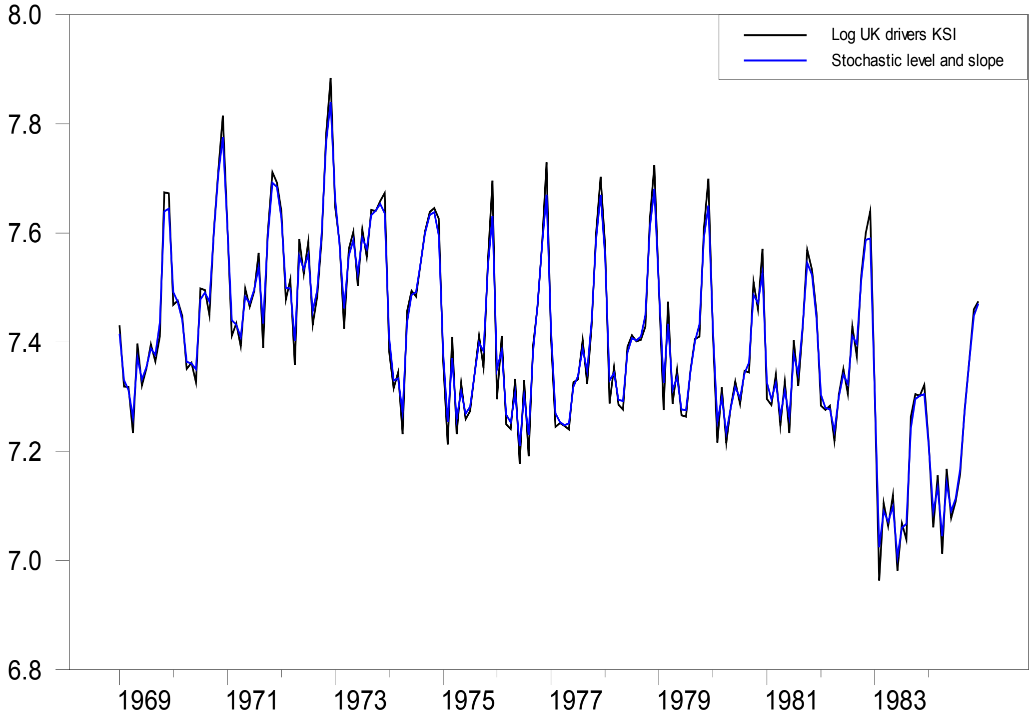


Figure 3.1 Stochastic linear trend model

CHAPTER 4

open data ukinflation.txt

calendar(q) 1950

data(format=free,org=columns,skips=1) 1950:01 2001:04 ukinflation

ENTRY	UKINFLATION
1950:01	0.008449
1950:02	-0.005049
1950:03	0.003846
1950:04	0.021429
1951:01	0.023284
1951:02	0.029912
1951:03	0.037929
1951:04	0.021277
1952:01	0.027001

1952:02	0.014035
1952:03	0.011258
1952:04	0.010929
1953:01	0.008854
1953:02	0.003497
1953:03	0.002363
1953:04	0.000973
1954:01	0.003884
1954:02	-0.000453
1954:03	0.019647
1954:04	0.009461
1955:01	0.011236
1955:02	0.001171
1955:03	0.018193
1955:04	0.026139
1956:01	0.007975
1956:02	0.010381
1956:03	0.001028
1956:04	0.012142
1957:01	0.013699
1957:02	-0.003702
1957:03	0.018055
1957:04	0.015801
1958:01	0.004938
1958:02	0.005179
1958:03	-0.007645
1958:04	0.016327
1959:01	0.007261
1959:02	-0.019195
1959:03	0.001352
1959:04	0.010582

1960:01	0.001618
1960:02	-0.002216
1960:03	0.005445
1960:04	0.012810
1961:01	0.007924
1961:02	0.003177
1961:03	0.017137
1961:04	0.013825
1962:01	0.012131
1962:02	0.010934
1962:03	0.001051
1962:04	0.001488
1963:01	0.016956
1963:02	-0.003330
1963:03	-0.001800
1963:04	0.009506
1964:01	0.010138
1964:02	0.009476
1964:03	0.014021
1964:04	0.009804
1965:01	0.011088
1965:02	0.016238
1965:03	0.009614
1965:04	0.008027
1966:01	0.009284
1966:02	0.010117
1966:03	0.008844
1966:04	0.009668
1967:01	0.006394
1967:02	0.000103
1967:03	0.000534

1967:04	0.013287
1968:01	0.015591
1968:02	0.014571
1968:03	0.011087
1968:04	0.013182
1969:01	0.021202
1969:02	0.007064
1969:03	0.008548
1969:04	0.014241
1970:01	0.019048
1970:02	0.015162
1970:03	0.017055
1970:04	0.022843
1971:01	0.027456
1971:02	0.026424
1971:03	0.019515
1971:04	0.014535
1972:01	0.016695
1972:02	0.009240
1972:03	0.022420
1972:04	0.025787
1973:01	0.018585
1973:02	0.022274
1973:03	0.021472
1973:04	0.035858
1974:01	0.041631
1974:02	0.048532
1974:03	0.030943
1974:04	0.045917
1975:01	0.059516
1975:02	0.081165

1975:03	0.049376
1975:04	0.035619
1976:01	0.036768
1976:02	0.026667
1976:03	0.029437
1976:04	0.046010
1977:01	0.050567
1977:02	0.034310
1977:03	0.022623
1977:04	0.015478
1978:01	0.018345
1978:02	0.017833
1978:03	0.024434
1978:04	0.017276
1979:01	0.032174
1979:02	0.026747
1979:03	0.072053
1979:04	0.028612
1980:01	0.047312
1980:02	0.047659
1980:03	0.028346
1980:04	0.019032
1981:01	0.024450
1981:02	0.038782
1981:03	0.024870
1981:04	0.024342
1982:01	0.017339
1982:02	0.023265
1982:03	0.012001
1982:04	0.007657
1983:01	0.004952

1983:02	0.012725
1983:03	0.019637
1983:04	0.011482
1984:01	0.005864
1984:02	0.012826
1984:03	0.015765
1984:04	0.012401
1985:01	0.012575
1985:02	0.026880
1985:03	0.009189
1985:04	0.004914
1986:01	0.006860
1986:02	0.006615
1986:03	0.007272
1986:04	0.012689
1987:01	0.011633
1987:02	0.009576
1987:03	0.008211
1987:04	0.010716
1988:01	0.004833
1988:02	0.017572
1988:03	0.020275
1988:04	0.020221
1989:01	0.016246
1989:02	0.021995
1989:03	0.015778
1989:04	0.019634
1990:01	0.017596
1990:02	0.039212
1990:03	0.022779
1990:04	0.015492

1991:01	0.005366
1991:02	0.014931
1991:03	0.010731
1991:04	0.009640
1992:01	0.005153
1992:02	0.014819
1992:03	0.005531
1992:04	0.004307
1993:01	-0.006468
1993:02	0.009487
1993:03	0.009085
1993:04	0.003532
1994:01	0.001409
1994:02	0.011202
1994:03	0.006942
1994:04	0.006205
1995:01	0.008895
1995:02	0.011975
1995:03	0.008922
1995:04	0.001333
1996:01	0.005316
1996:02	0.006263
1996:03	0.008211
1996:04	0.005861
1997:01	0.005827
1997:02	0.006579
1997:03	0.015765
1997:04	0.008174
1998:01	0.003126
1998:02	0.012303
1998:03	0.009309

1998:04	0.004267
1999:01	-0.004267
1999:02	0.004686
1999:03	0.006854
1999:04	0.007220
2000:01	0.004188
2000:02	0.012088
2000:03	0.008007
2000:04	0.006416
2001:01	-0.001163
2001:02	0.005899
2001:03	0.006825
2001:04	-0.001150

```
Rescaling data to percentages helps quite a bit by increasing the
* variances by a factor of 10^4.

set ukinflation = ukinflation*100.0

reate the component models for the level and seasonal.
*
@LocalDLM(type=level,a=al,c=cl,f=fl)
@SeasonalDLM(type=additive,a=as,c=cs,f=fs)
* Glue them together to make the full system matrices
compute a=al~\as,f=fl~\fs,c=cl~~cs
@LocalDLMInit(deseasonalize,irreg=sigsqeps) ukinflation
nonlin sigsqeps sigsqxi sigsqomega
compute sigsqxi=sigsqeps*.01,sigsqomega=sigsqeps*.01
@LocalDLMInit(deseasonalize,irreg=sigsqeps) ukinflation
nonlin sigsqeps sigsqxi sigsqomega
compute sigsqxi=sigsqeps*.01,sigsqomega=sigsqeps*.01
```

```
dlm(a=a,c=c,sv=sigsqeps,f=f,sw=%diag(||sigsqxi,sigsqomega||),exact,y=ukinflation,$
 method=bfgs,vhat=vhat,svhat=svhat)
set resids = %scalar(vhat)/sqrt(%scalar(svhat))
@STAMPDiags(ncorrs=15) resids
```

DLM - Estimation by BFGS

Convergence in 24 Iterations. Final criterion was 0.0000006 <= 0.0000100

Quarterly Data From 1950:01 To 2001:04

Usable Observations 208

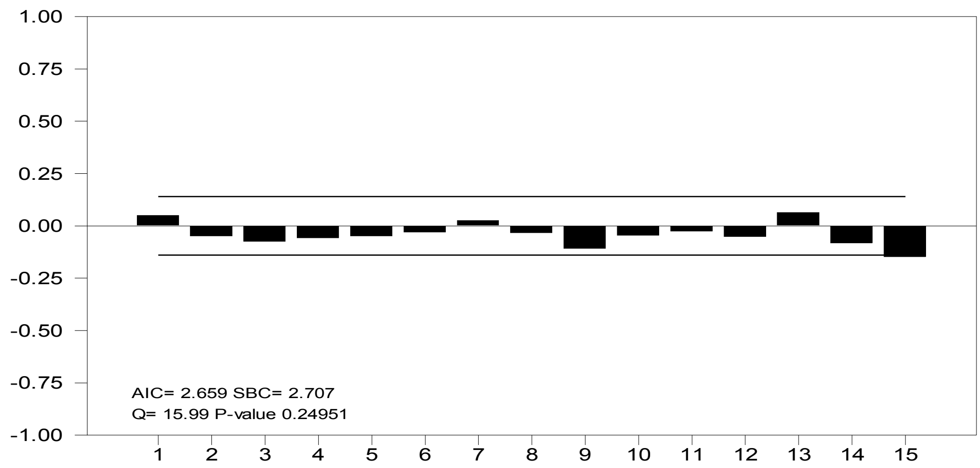
Rank of Observables 204

Log Likelihood -273.5674

Variable	Coeff	Std Error	T-Stat	Signif
1. SIGSQEPS	0.3371295758	0.0680574501	4.95360	0.00000073
2. SIGSQXI	0.2124071587	0.0612535888	3.46767	0.00052499
3. SIGSQOMEGA	0.0043455183	0.0026332014	1.65028	0.09888578

State Space Model Diagnostics

	Statistic	Sig. Level
Q(15-2)	15.99	0.2495
Normality	182.27	0.0000
H(68)	0.37	0.0001




```
dlm(a=a,c=c,sv=sigsqeps,f=f,sw=%diag(||sigsqxi,sigsqomega||),exact,y=ukinflation,$
```

```
 type=smooth) / xstates
set level    = xstates(t)(1)
set irreg    = ukinflation-level
set seasonal = xstates(t)(2)
set fitted   = %dot(c,xstates)
spgraph(vfields=3,footer="Figure 4.10 UK inflation series",samesize)
graph(key=upleft,klabels=||"quarterly price changes in UK","stochastic level"||) 2
# ukinflation
# level
graph(key=upleft,klabels=||"stochastic seasonal"||)
# seasonal
graph(key=upleft,klabels=||"irregular"||)
# irreg
spgraph(done)
```

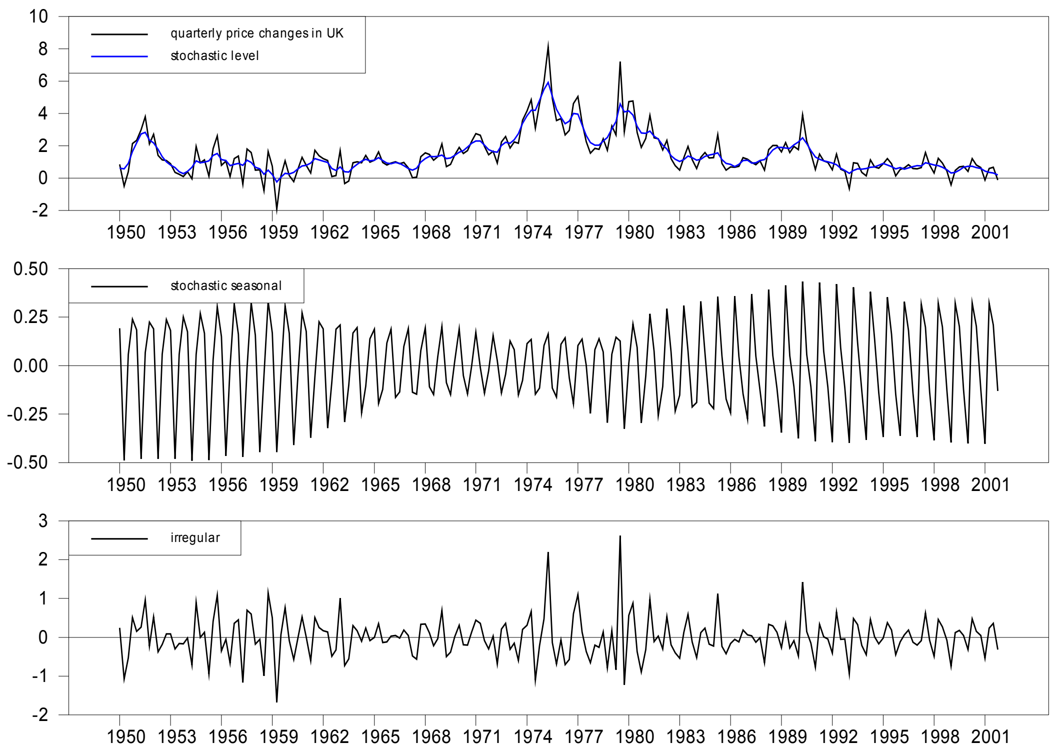


Figure 4.10 UK inflation series

Chapter 4. UK data

```
open data ukdriversksi.txt
calendar(m) 1969
data(format=free,org=columns,skips=1) 1969:01 1984:12 ksi
set logksi = log(ksi)



set january = %period(t)==1
graph(footer="Figure 4.1 Log UK drivers KSI with time lines for years",$
  grid=january)
# logksi
```

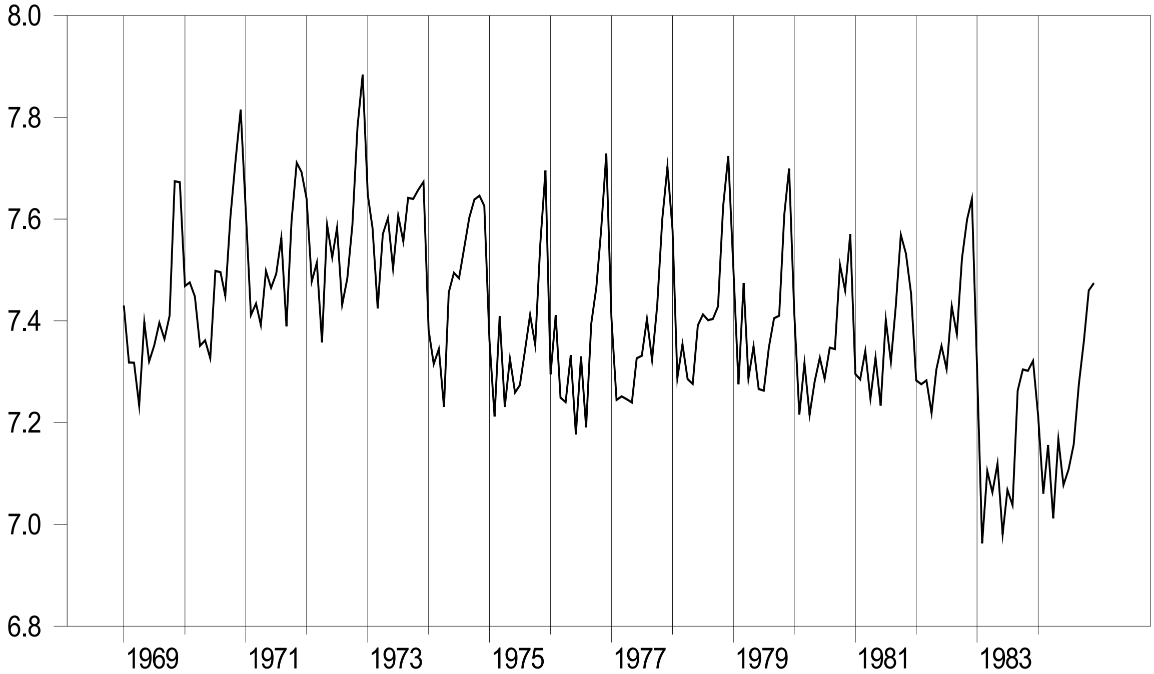


Figure 4.1 Log UK drivers KSI with time lines for years

Create the component models for the level and seasonal.

```
@LocalDLM(type=level,a=al,c=cl,f=fl)
@SeasonalDLM(type=additive,a=as,c=cs,f=fs)
```

Glue them together to make the full system matrices

compute a=al~\as,f=fl~\fs,c=cl~~cs

@LocalDLMInit(deseasonalize,irreg=sigsqeps) logksi

First model, deterministic level and seasonal pegs the variances for

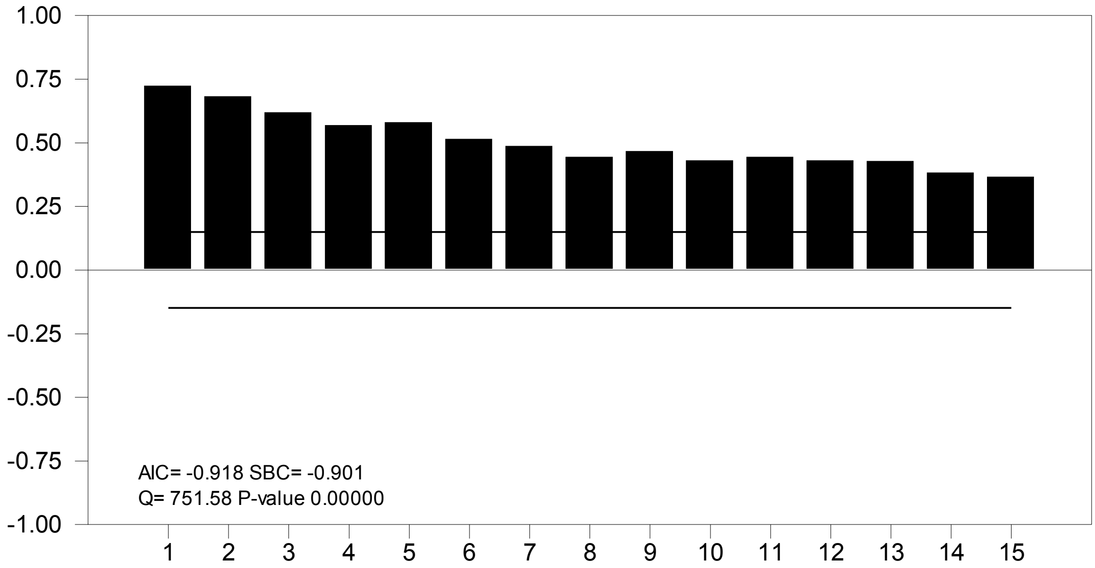
nonlin sigsqeps sigsqxi=0.0 sigsqomega=0.0

```
dlm(a=a,c=c,sv=sigsqeps,f=f,sw=%diag(||sigsqxi,sigsqomega||),exact,y=logksi,$
  method=bfgs,vhat=vhat,svhat=svhat)
set resids = %scalar(vhat)/sqrt(%scalar(svhat))
@STAMPDiags(ncorrs=15) resids
```

```
DLM - Estimation by BFGS
Convergence in    11 Iterations. Final criterion was  0.0000017 <=  0.0000100
Monthly Data From 1969:01 To 1984:12
Usable Observations                   192
Rank of Observables                   180
Log Likelihood                   89.1164

   Variable                    Coeff      Std Error      T-Stat      Signif
*********************************************************************************
**
1.  SIGSQEPS                 0.0175885151 0.0018490137      9.51238  0.00000000
```

State Space Model Diagnostics

	Statistic	Sig. Level
Q(15-0)	751.58	0.0000
Normality	1.89	0.3878
H(60)	3.40	0.0000




```
dlm(a=a,c=c,sv=sigsqeps,f=f,sw=%diag(||sigsqxi,sigsqomega||),exact,y=logksi,$
 type=smoothed) / xstates
set level    = xstates(t)(1)
set irreg    = logksi-level
set seasonal = xstates(t)(2)
set fitted   = %dot(c,xstates)


graph(footer="Figure 4.2 Combined deterministic level and seasonal",$
 key=upright,klabels=||"log UK drivers KSI","deterministic level plus seasonal"||) 2
# logksi
# fitted
```

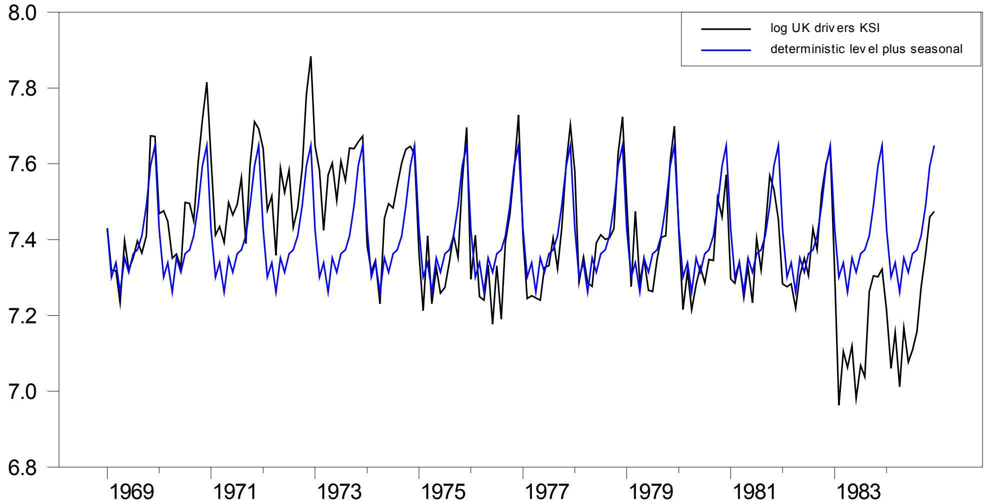


Figure 4.2 Combined deterministic level and seasonal

```
graph(footer="Figure 4.3 Deterministic level and seasonal",$
 key=upright,klabels=||"log UK drivers KSI","deterministic level"||) 2
# logksi
# level
```

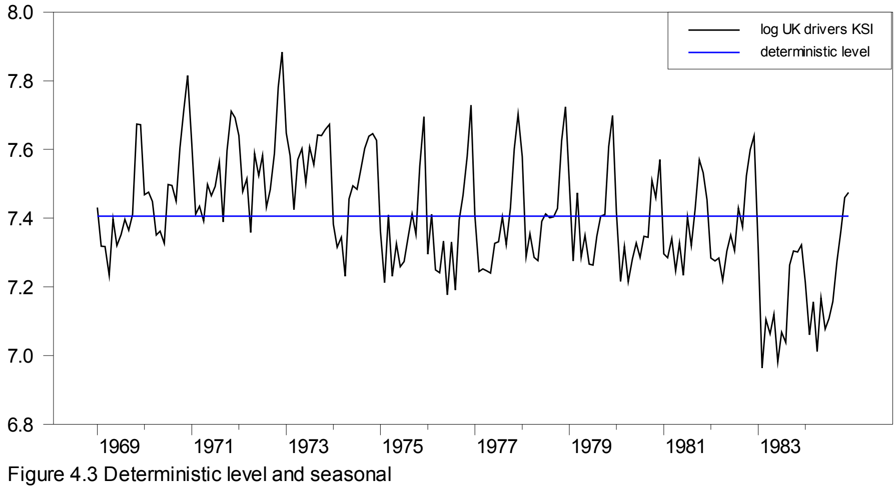


Figure 4.3 Deterministic level and seasonal

```
graph(footer="Figure 4.4 Deterministic seasonal",$
 key=upright,klabels=||"deterministic seasonal"||)
# seasonal
```

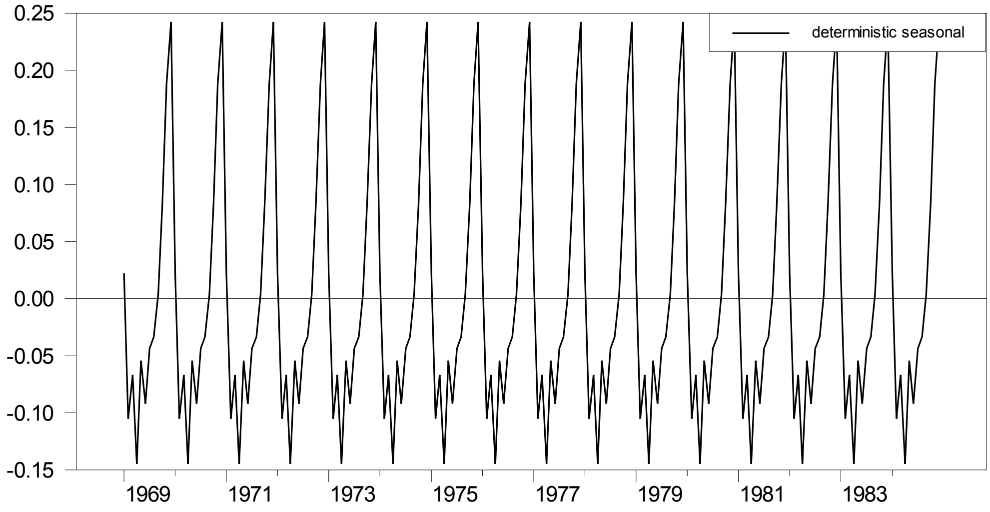


Figure 4.4 Deterministic seasonal

```
graph(footer="Figure 4.5 Irregular component",$
 key=upright,klabels=||"irregular"||)
# irreg
```

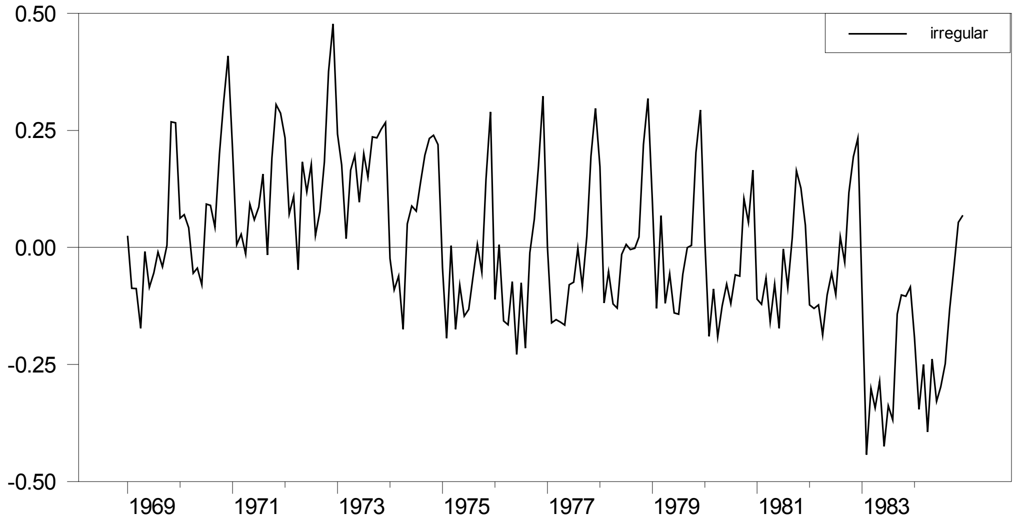


Figure 4.5 Irregular component

```
nonlin sigsqeps sigsqxi sigsqomega
```

```
dlm(a=a,c=c,sv=sigsqeps,f=f,sw=%diag(||sigsqxi,sigsqomega||),exact,y=logksi,$
  method=bfgs,vhat=vhat,svhat=svhat)
```

```
DLM - Estimation by BFGS
Convergence in    26 Iterations. Final criterion was  0.0000020 <=  0.0000100
Monthly Data From 1969:01 To 1984:12
Usable Observations                  192
Rank of Observables                  180
Log Likelihood                 188.7465

    Variable                     Coeff      Std Error      T-Stat      Signif
****************************************************************************************
**
1.  SIGSQEPS                   0.003541644  0.000675752      5.24104  0.00000016
2.  SIGSQXI                    0.000952443  0.000286032      3.32985  0.00086893
3.  SIGSQOMEGA                -0.000003796  0.000025577     -0.14842  0.88201415
```

The variance of the seasonal comes in negative, so we re-estimate with

```
* that set to zero. This is the same as the model in section 4.3
nonlin sigsqeps sigsqxi sigsqomega=0.00
dlm(a=a,c=c,sv=sigsqeps,f=f,sw=%diag(||sigsqxi,sigsqomega||),exact,y=logksi,$
  method=bfgs,vhat=vhat,svhat=svhat)
set resids = %scalar(vhat)/sqrt(%scalar(svhat))
@STAMPDiags(ncorrs=15) resids
```

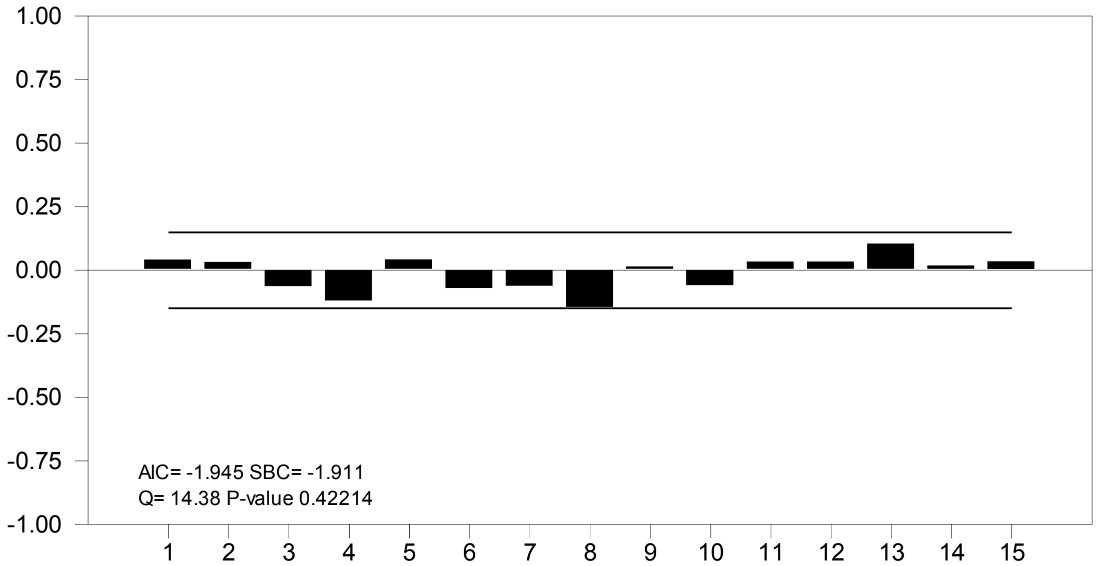
```
DLM - Estimation by BFGS
Convergence in     3 Iterations. Final criterion was  0.0000014 <=  0.0000100
Monthly Data From 1969:01 To 1984:12
Usable Observations                  192
Rank of Observables                  180
```

Log Likelihood 188.7353

Variable	Coeff	Std Error	T-Stat	Signif
1. SIGSQEPS	0.0035156481	0.0004306518	8.16355	0.00000000
2. SIGSQXI	0.0009446740	0.0002808774	3.36330	0.00077018

State Space Model Diagnostics

	Statistic	Sig. Level
Q(15-1)	14.38	0.4221
Normality	5.44	0.0658
H(60)	1.09	0.7323




```
dlm(a=a,c=c,sv=sigsqeps,f=f,sw=%diag(||sigsqxi,sigsqomega||),exact,y=logksi,$
  type=smooth) / xstates
set level   = xstates(t)(1)
```

```
set irreg    = logksi-level

set seasonal = xstates(t)(2)

set fitted   = %dot(c,xstates)


graph(footer="Figure 4.6 Stochastic level",$
 key=upright,klabels=||"log UK drivers KSI","stochastic level"||) 2
# logksi
# level
```

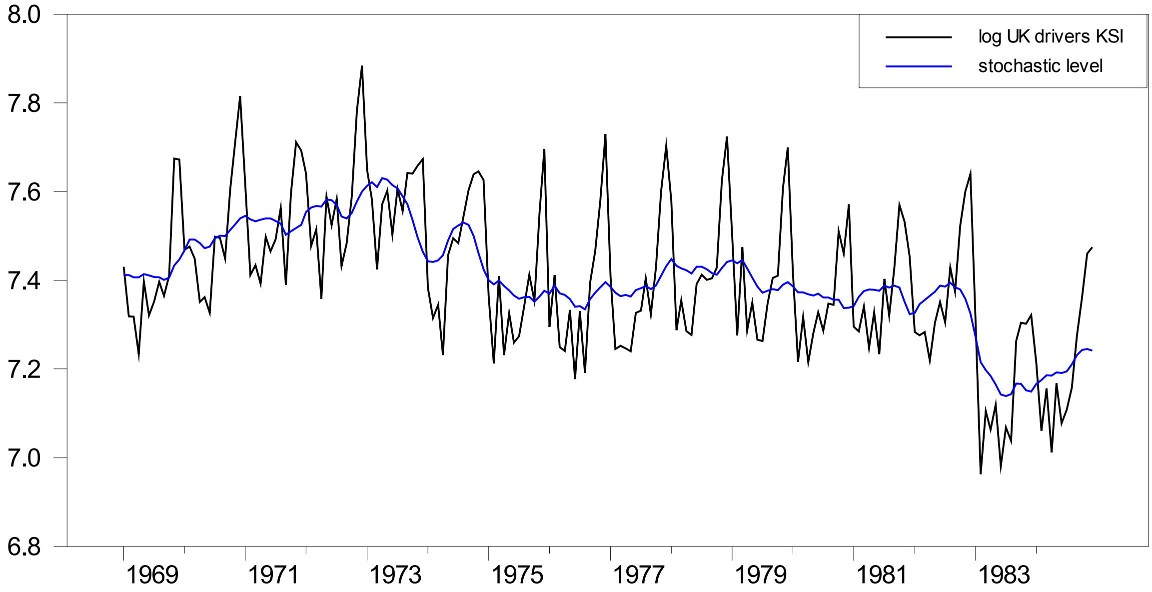


Figure 4.6 Stochastic level

```
graph(footer="Figure 4.7 Stochastic seasonal",$
 key=upright,klabels=||"stochastic seasonal"||)
# seasonal
```

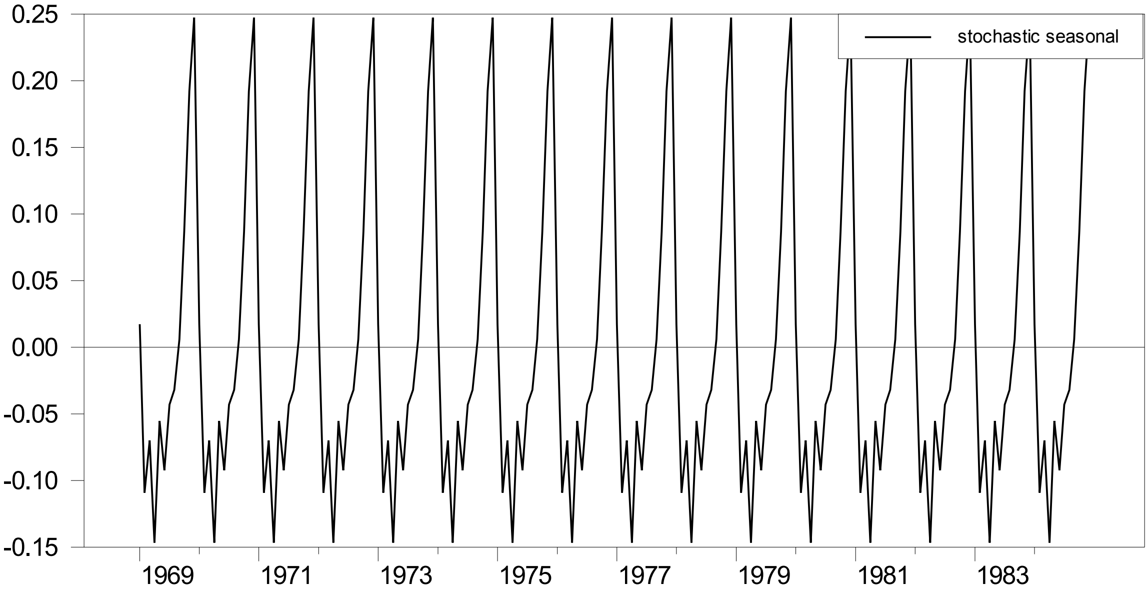


Figure 4.7 Stochastic seasonal

graph(footer="Figure 4.8 Stochastic seasonal for the year 1969",$

key=upleft,klabels=||"seasonal 1969"||)

seasonal 1969:1 1969:12

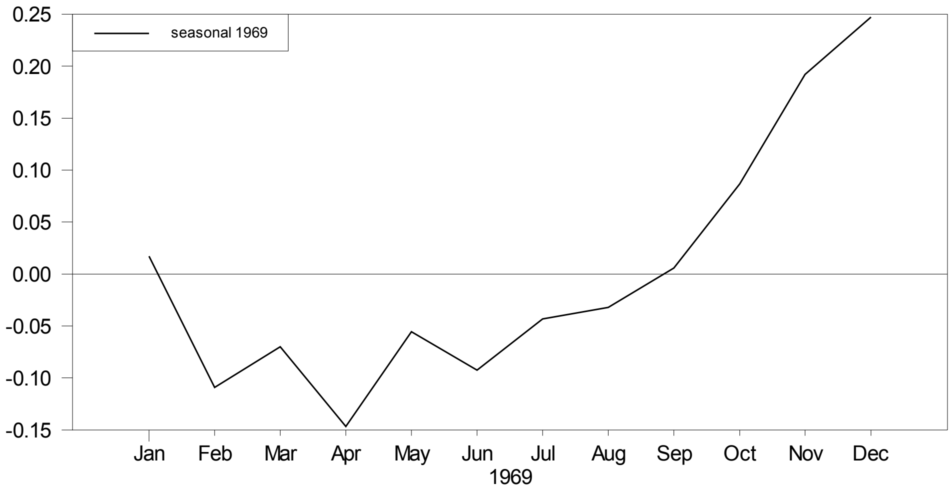


Figure 4.8 Stochastic seasonal for the year 1969

graph(footer="Figure 4.9 Irregular component",$

key=upright,klabels=||"irregular"||)

irreg

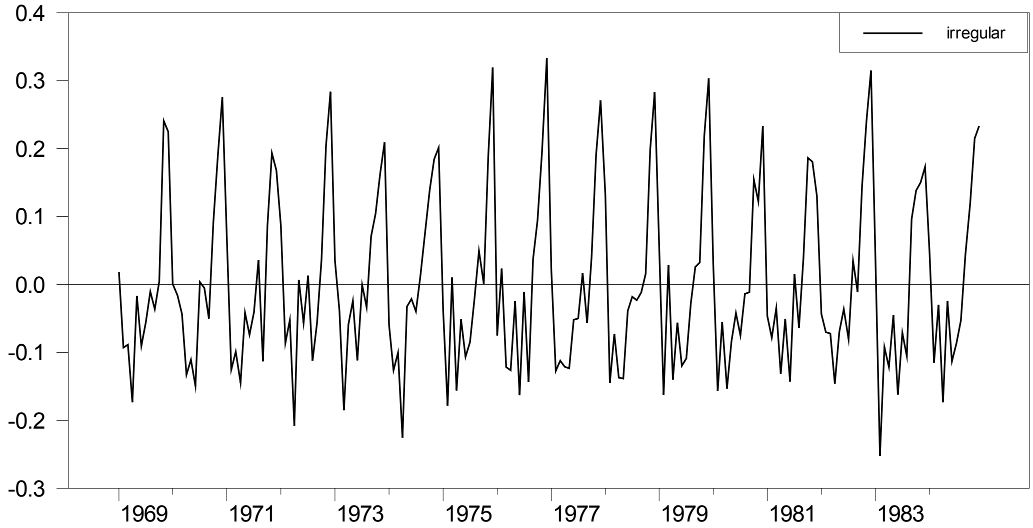


Figure 4.9 Irregular component

CHAPTER 5

open data ukdriversksi.txt

calendar(m) 1969

data(format=free,org=columns,skips=1) 1969:01 1984:12 ksi

set logksi = log(ksi)

open data logukpetrolprice.txt

data(format=free,org=columns,skips=1) 1969:01 1984:12 logukpetrol

Fixed coefficients regression done with linreg

inreg logksi

constant logukpetrol

```
Linear Regression - Estimation by Least Squares
Dependent Variable LOGKSI
Monthly Data From 1969:01 To 1984:12
Usable Observations                  192
Degrees of Freedom                   190
Centered R^2                   0.2200618
R-Bar^2                        0.2159569
Uncentered R^2                 0.9995850
Mean of Dependent Variable       7.4061076031
Std Error of Dependent Variable  0.1713258861
Standard Error of Estimate       0.1517025795
Sum of Squared Residuals         4.3725977964
Regression F(1,190)              53.6090
Significance Level of F          0.0000000
Log Likelihood                   90.6491
Durbin-Watson Statistic          0.7179

   Variable                  Coeff      Std Error      T-Stat      Signif
************************************************************************
1.  Constant                 5.878730822  0.208893266    28.14227  0.00000000
2.  LOGUKPETROL             -0.671664418  0.091734628    -7.32182  0.00000000
```

```
compute sigsqeps=%sigmasq,beta=%beta(2)
```

Model with explanatory variable and deterministic level

```
nonlin sigsqeps sigsqxi=0.0 beta
```

```
dlm(a=1.0,c=1.0,sv=sigsqeps,sw=sigsqxi,exact,y=logksi-beta*logukpetrol,$
  method=bfgs,vhat=vhat,svhat=svhat)
```

DLM - Estimation by BFGS

Convergence in 2 Iterations. Final criterion was 0.0000017 <= 0.0000100

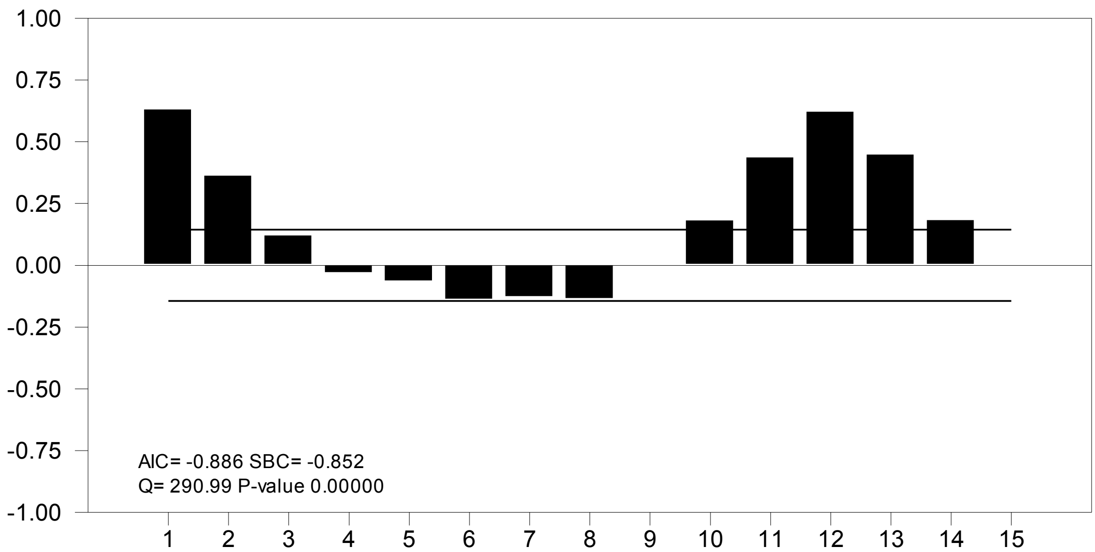
Monthly Data From 1969:01 To 1984:12

Usable Observations 192

Rank of Observables 191

Log Likelihood 87.0495

Variable	Coeff	Std Error	T-Stat	Signif
1. SIGSQEPS	0.022893160	0.002335167	9.80365	0.00000000
2. BETA	-0.671664873	0.091051523	-7.37676	0.00000000




```
set resids = %scalar(vhat)/sqrt(%scalar(svhat))
@STAMPDiags(ncorrs=15) resids
```

```
State Space Model Diagnostics
        Statistic Sig. Level
Q(15-1)     290.99     0.0000
Normality     2.57     0.2765
H(64)         1.90     0.0111
dlm(a=1.0,c=1.0,sv=sigsqeps,sw=sigsqxi,exact,y=logksi-beta*logukpetrol,$
  type=smooth) / xstates
set level     = xstates(t)(1)
set levelplus = level+beta*logukpetrol
set irreg     = logksi-levelplus


graph(footer="Figure 5.1 Deterministic level and explanatory variable",$
  key=upright,klabels=||"log UK drivers KSI","deterministic level + beta*log(petrol)"||) 2
# logksi
# levelplus
graph(footer="Figure 5.2 Irregular component for deterministic level + beta * log(petrol)")
# irreg
```

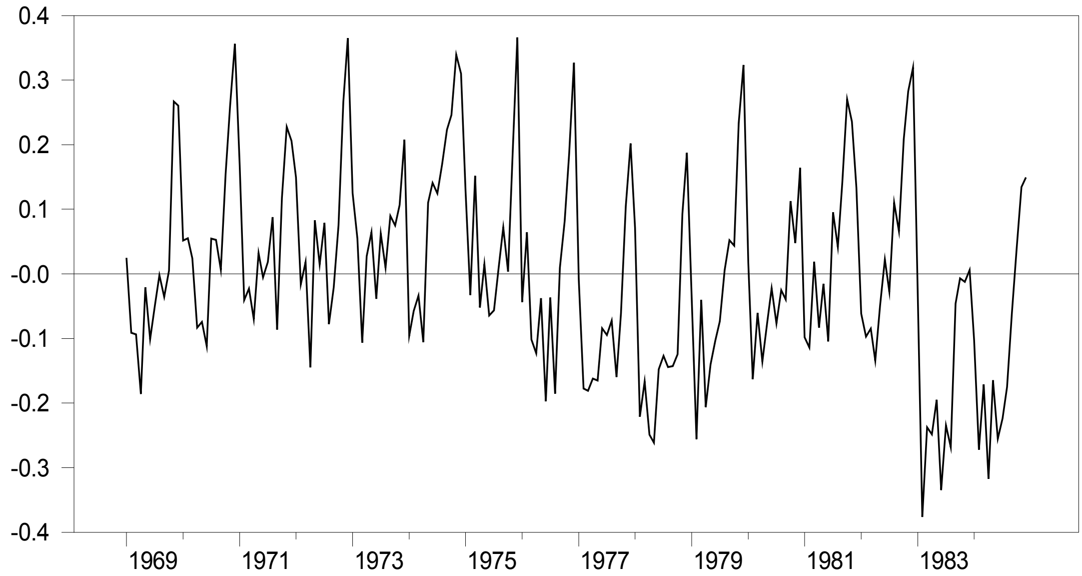


Figure 5.2 Irregular component for deterministic level + beta * log(petrol)

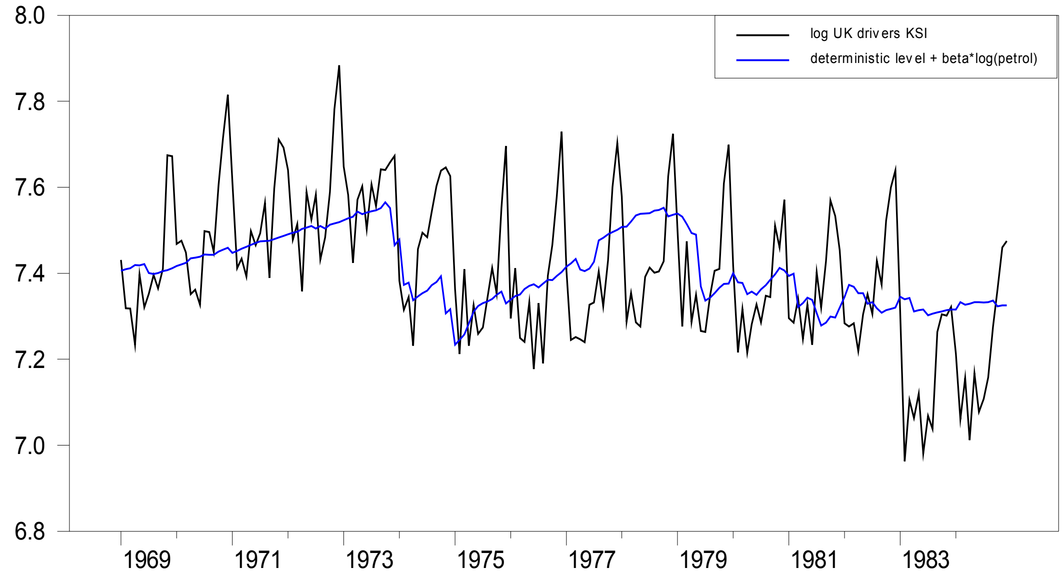


Figure 5.1 Deterministic level and explanatory variable

```
nonlin sigsqeps sigsqxi beta
dlm(a=1.0,c=1.0,sv=sigsqeps,sw=sigsqxi,exact,y=logksi-beta*logukpetrol,$
  method=bfgs,vhat=vhat,svhat=svhat)
```

DLM - Estimation by BFGS

Convergence in 29 Iterations. Final criterion was 0.0000056 <= 0.0000100

```
Monthly Data From 1969:01 To 1984:12
Usable Observations                   192
Rank of Observables                   191
Log Likelihood                   124.2672

   Variable                   Coeff      Std Error      T-Stat      Signif
*******************************************************************************
1.  SIGSQEPS                0.002363224  0.001261545     1.87328  0.06103010
2.  SIGSQXI                 0.011559264  0.002452609     4.71305  0.00000244
3.  BETA                   -0.261791606  0.289983621    -0.90278  0.36664232
```

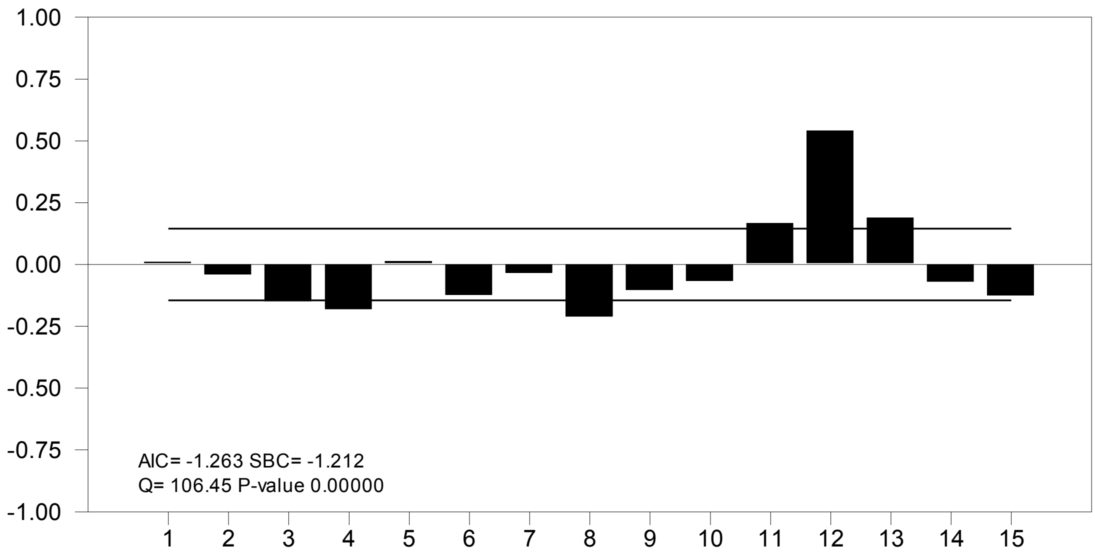
```
nonlin sigsqeps sigsqxi beta
dlm(a=1.0,c=1.0,sv=sigsqeps,sw=sigsqxi,exact,y=logksi-beta*logukpetrol,$
  method=bfgs,vhat=vhat,svhat=svhat)
```

```
DLM - Estimation by BFGS
Convergence in    29 Iterations. Final criterion was  0.0000056 <=  0.0000100
Monthly Data From 1969:01 To 1984:12
Usable Observations                   192
Rank of Observables                   191
Log Likelihood                   124.2672

   Variable                   Coeff      Std Error      T-Stat      Signif
*********************************************************************************
1.  SIGSQEPS                0.002363224  0.001261545     1.87328  0.06103010
2.  SIGSQXI                 0.011559264  0.002452609     4.71305  0.00000244
3.  BETA                   -0.261791606  0.289983621    -0.90278  0.36664232
```

```
set resids = %scalar(vhat)/sqrt(%scalar(svhat))
@STAMPDiags(ncorrs=15) resids
```

State Space Model Diagnostics

	Statistic	Sig. Level
Q(15-2)	106.45	0.0000
Normality	14.57	0.0007
H(64)	1.09	0.7272




```
dlm(a=1.0,c=1.0,sv=sigsqeps,sw=sigsqxi,exact,y=logksi-beta*logukpetrol,$
  type=smooth) / xstates
set level     = xstates(t)(1)
set levelplus = level+beta*logukpetrol
set irreg     = logksi-levelplus
```

```
graph(footer="Figure 5.4 Stochastic level and explanatory variable",$
  key=upright,klabels=||"log UK drivers KSI","deterministic level + beta*log(petrol)"||) 2
# logksi
# levelplus
```

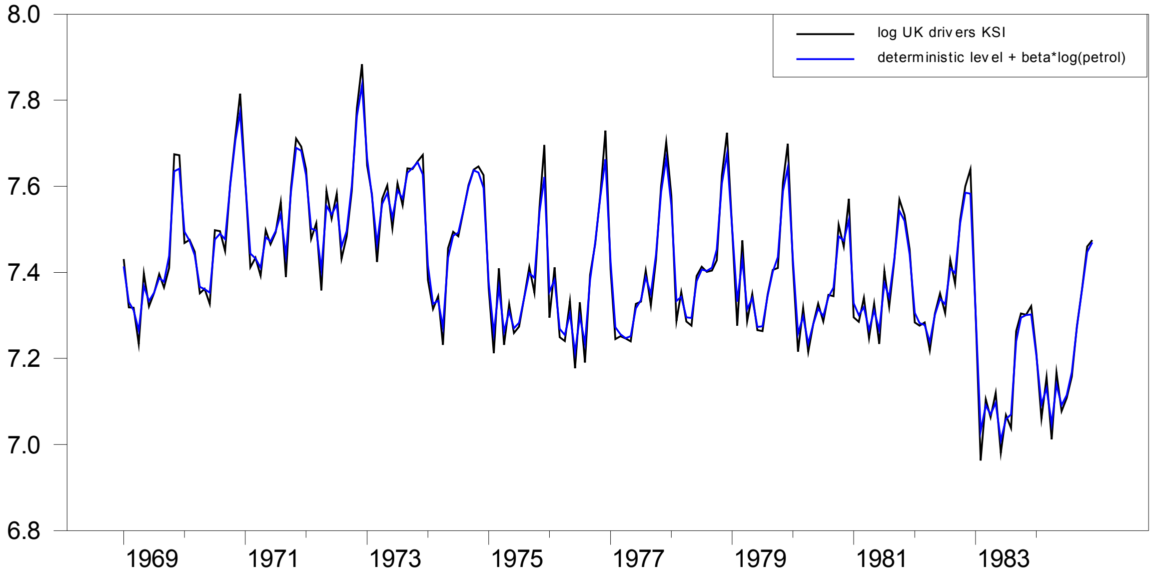


Figure 5.4 Stochastic level and explanatory variable

```
graph(footer="Figure 5.5 Irregular component for stochastic level + beta * log(petrol)")
# irreg
```

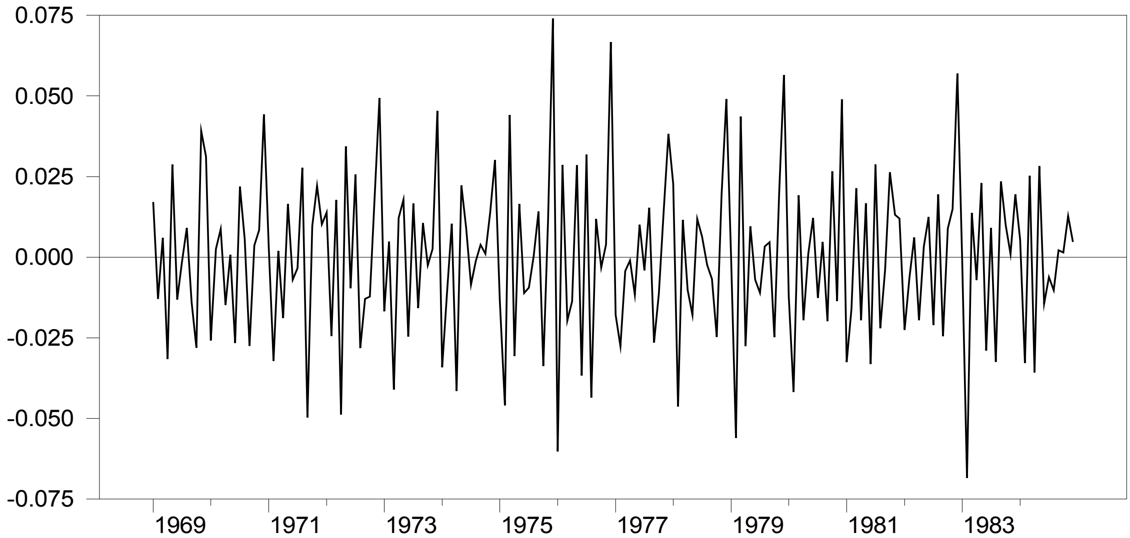


Figure 5.5 Irregular component for stochastic level + beta * log(petrol)

```
* Commandeur & Koopman, An Introduction to State Space Time Series Analysis.
* Chapter 6. UK data.
*
open data ukdriversksi.txt
calendar(m) 1969
data(format=free,org=columns,skips=1) 1969:01 1984:12 ksi
set logksi = log(ksi)
set seatbelt = t>=1983:2
```

Fixed coefficients regression done with linreg

```
linreg logksi
# constant seatbelt
```

```
Linear Regression - Estimation by Least Squares
Dependent Variable LOGKSI
Monthly Data From 1969:01 To 1984:12
Usable Observations                  192
Degrees of Freedom                   190
Centered R^2                   0.2461923
R-Bar^2                        0.2422249
Uncentered R^2                 0.9995989
Mean of Dependent Variable      7.4061076031
Std Error of Dependent Variable 0.1713258861
Standard Error of Estimate      0.1491396641
Sum of Squared Residuals        4.2261014859
Regression F(1,190)              62.0537
Significance Level of F         0.0000000
Log Likelihood                  93.9205
```

Durbin-Watson Statistic 0.7088

```
   Variable                     Coeff      Std Error      T-Stat      Signif
*****************************************************************************
1.  Constant                  7.437386169  0.011472282    648.29179  0.00000000
2.  SEATBELT                 -0.261108030  0.033146411     -7.87741  0.00000000
```

```
compute sigsqeps=%sigmasq,lambda=%beta(2)
```

Model with explanatory variable and deterministic level

```
nonlin sigsqeps sigsqxi=0.0 lambda
dlm(a=1.0,c=1.0,sv=sigsqeps,sw=sigsqxi,exact,y=logksi-lambda*seatbelt,$
  method=bfgs,vhat=vhat,svhat=svhat)
```

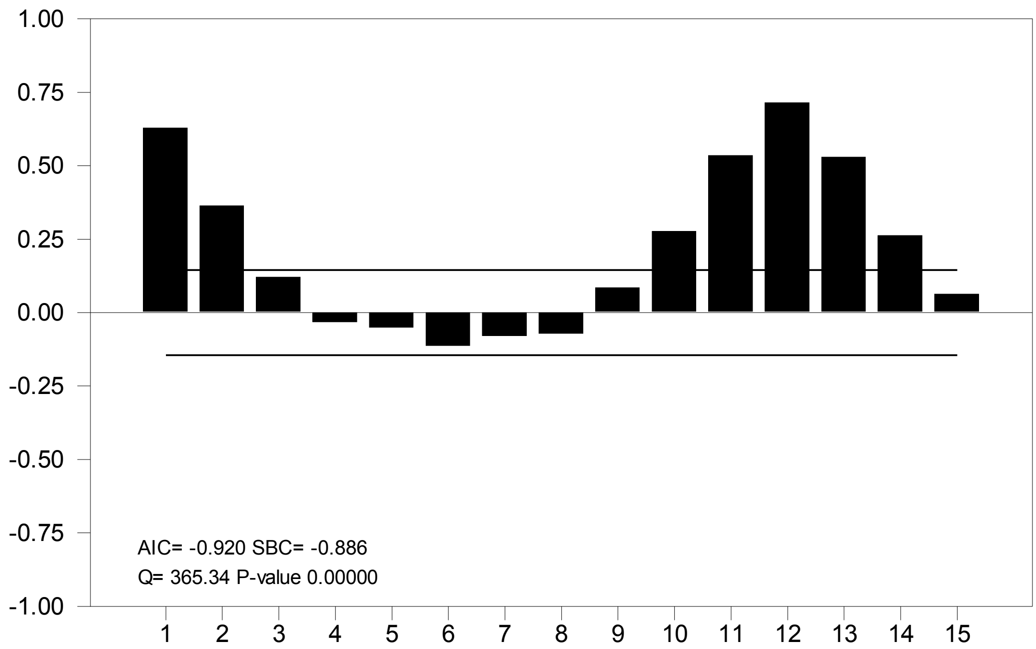
```
DLM - Estimation by BFGS
Convergence in     2 Iterations. Final criterion was  0.0000017 <=  0.0000100
Monthly Data From 1969:01 To 1984:12
Usable Observations                    192
Rank of Observables                    191
Log Likelihood                    90.3039

   Variable                     Coeff      Std Error      T-Stat      Signif
******************************************************************************
1.  SIGSQEPS                  0.022126164  0.002257100      9.80292  0.00000000
2.  LAMBDA                   -0.261108192  0.032973923     -7.91863  0.00000000
```

```
set resids = %scalar(vhat)/sqrt(%scalar(svhat))
```

```
@STAMPDiags(ncorrs=15) resids
```

State Space Model Diagnostics

	Statistic	Sig. Level
Q(15-1)	365.34	0.0000
Normality	6.37	0.0414
H(64)	0.98	0.9426




```
dlm(a=1.0,c=1.0,sv=sigsqeps,sw=sigsqxi,exact,y=logksi-lambda*seatbelt,$
  type=smooth) / xstates
set level     = xstates(t)(1)
set levelplus = level+lambda*seatbelt
set irreg     = logksi-levelplus
```

graph(footer="Figure 6.1 Deterministic level and intervention variable",$

key=upright,klabels=||"log UK drivers KSI","deterministic level + lambda*seatbelt"||) 2

logksi

levelplus

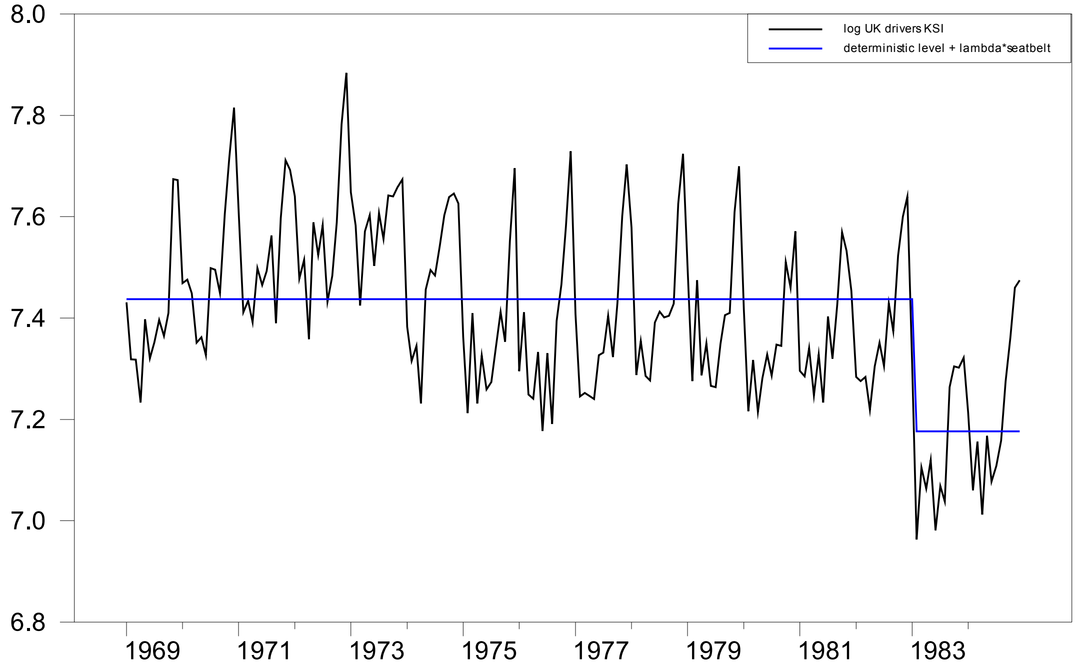


Figure 6.1 Deterministic level and intervention variable

graph(footer="Figure 6.3 Irregular component for deterministic level + lambda*seatbelt")

irreg

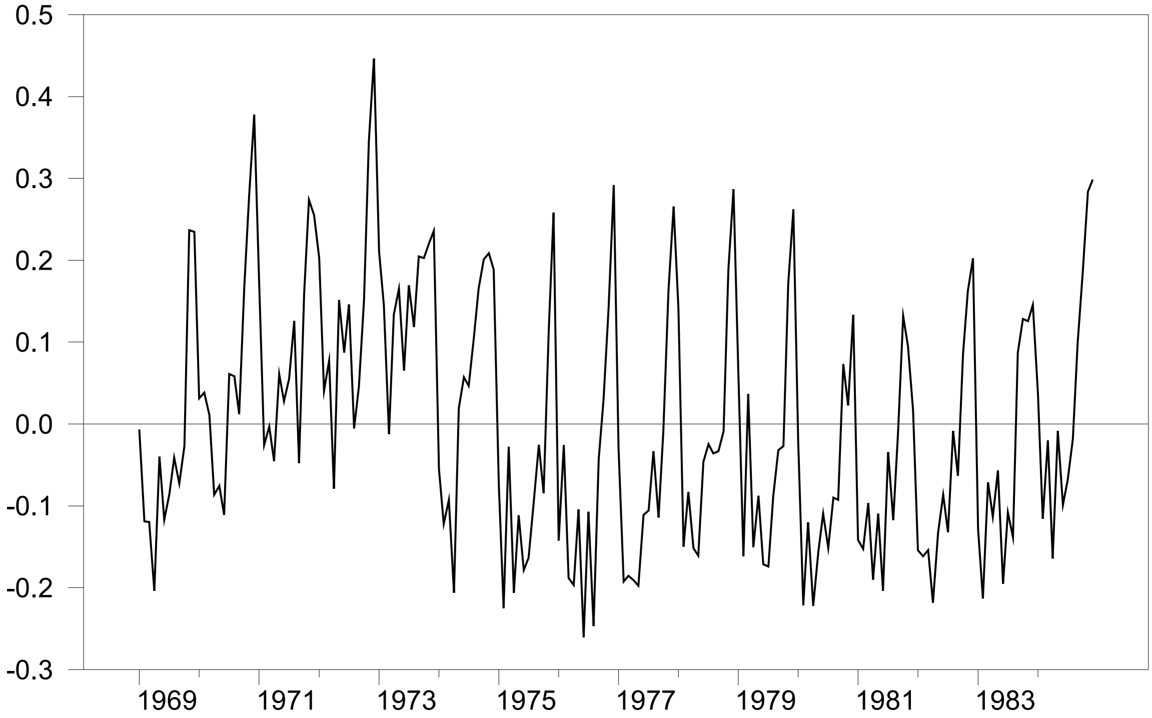


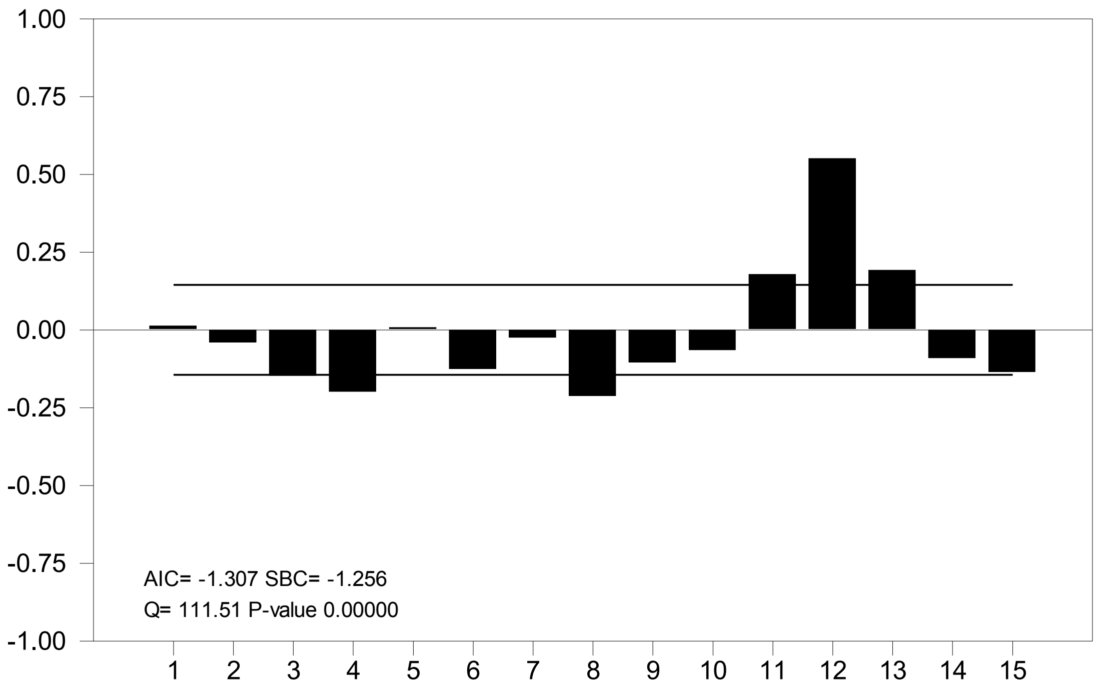
Figure 6.3 Irregular component for deterministic level + lambda*seatbelt

Same with stochastic level

```
nonlin sigsqeps sigsqxi lambda
dlm(a=1.0,c=1.0,sv=sigsqeps,sw=sigsqxi,exact,y=logksi-lambda*seatbelt,$
  method=bfgs,vhat=vhat,svhat=svhat)
```

```
DLM - Estimation by BFGS
Convergence in    27 Iterations. Final criterion was  0.0000010 <=  0.0000100
Monthly Data From 1969:01 To 1984:12
Usable Observations                    192
Rank of Observables                    191
Log Likelihood                  128.4997

   Variable                    Coeff      Std Error      T-Stat      Signif
*************************************************************************
```

```
1.  SIGSQEPS                  0.002697110  0.001209117      2.23064  0.02570471
2.  SIGSQXI                 0.010326662  0.002223671      4.64397  0.00000342
3.  LAMBDA                   -0.378710958  0.121709888     -3.11159  0.00186084


set resids = %scalar(vhat)/sqrt(%scalar(svhat))
@STAMPDiags(ncorrs=15) resids


State Space Model Diagnostics
        Statistic Sig. Level
Q(15-2)      111.51     0.0000
Normality     10.15     0.0063
H(64)         0.91     0.7096
```



```
dlm(a=1.0,c=1.0,sv=sigsqeps,sw=sigsqxi,exact,y=logksi-lambda*seatbelt,$
  type=smooth) / xstates
set level     = xstates(t)(1)
set levelplus = level+lambda*seatbelt
set irreg     = logksi-levelplus

graph(footer="Figure 6.4 Stochastic level and explanatory variable",$
  key=upright,klabels=||"log UK drivers KSI","deterministic level +
lambda*seatbelt"||) 2
# logksi
# levelplus
```

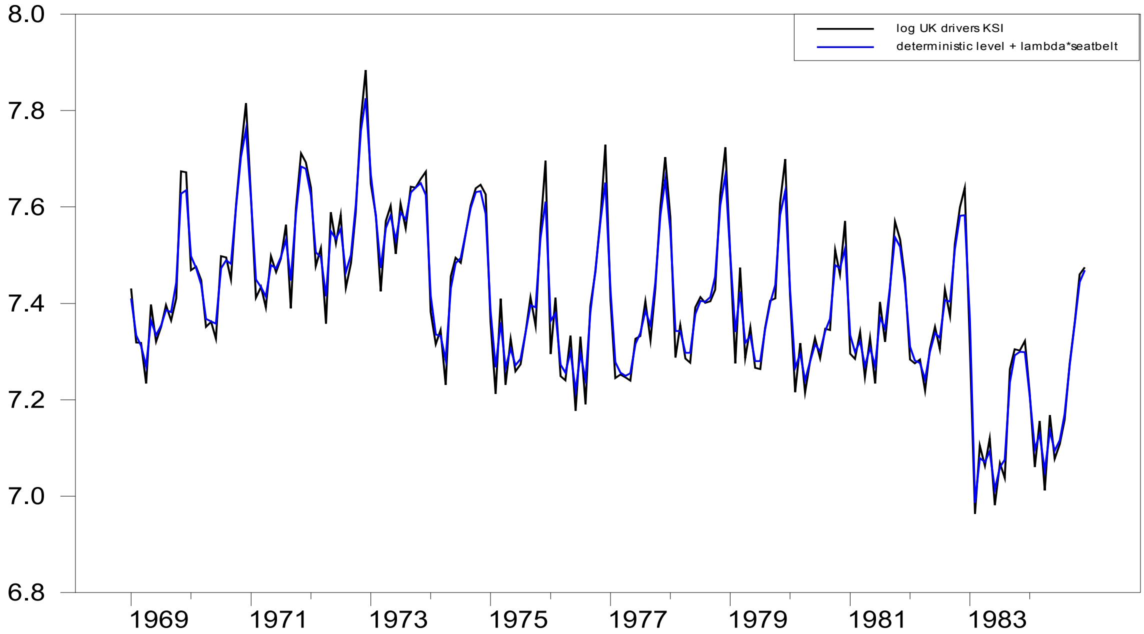


Figure 6.4 Stochastic level and explanatory variable

```
graph(footer="Figure 6.5 Irregular component for stochastic level + lambda*seatbelt")
# irreg
```

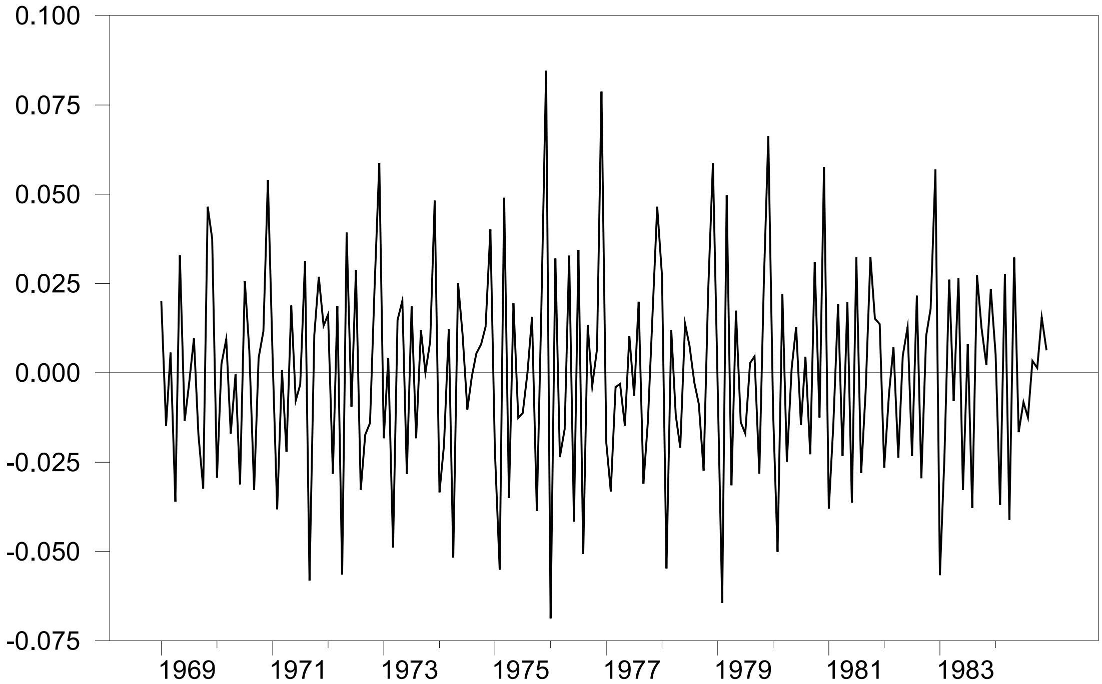


Figure 6.5 Irregular component for stochastic level + lambda*seatbelt

CHAPTER 7

open data ukinflation.txt

calendar(q) 1950

data(format=free,org=columns,skips=1) 1950:01 2001:04 ukinflation

Rescaling data to percentages helps quite a bit by increasing the

* variances by a factor of 10^4.

set ukinflation = ukinflation*100.0

* Create pulse dummies

*

set d1975q2 = (t==1975:2)

set d1979q3 = (t==1979:3)

Create the standard level + seasonal model

@LocalDLM(type=level,a=al,c=cl,f=fl)

```
@SeasonalDLM(type=additive,a=as,c=cs,f=fs)
compute a=al~\as,f=fl~\fs,c=cl~~cs
```

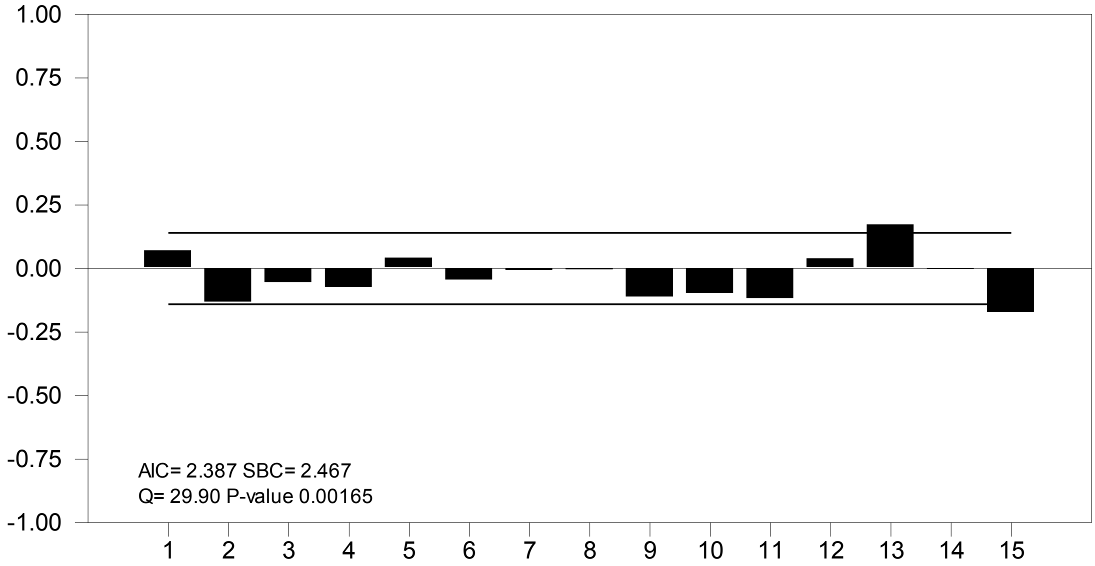
```
linreg ukinflation
# constant d1975q2 D1979q3 ; seasons{0 to -2}
```

```
Linear Regression - Estimation by Least Squares
Dependent Variable UKINFLATION
Quarterly Data From 1950:01 To 2001:04
Usable Observations                208
Degrees of Freedom                 205
Centered R^2                 0.2099825
R-Bar^2                      0.2022751
Uncentered R^2               0.6414254
Mean of Dependent Variable      1.4652365445
Std Error of Dependent Variable 1.3390054717
Standard Error of Estimate      1.1959387523
Sum of Squared Residuals        293.20524734
Regression F(2,205)             27.2440
Significance Level of F         0.0000000
Log Likelihood                  -330.8460
Durbin-Watson Statistic         0.6628

   Variable              Coeff      Std Error      T-Stat     Signif
************************************************************************
1.  Constant          1.4050846919 0.0833250012    16.86270  0.00000000
2.  D1975Q2           6.7113934812 1.1988380020     5.59825  0.00000007
3.  D1979Q3           5.8001918488 1.1988380020     4.83818  0.00000257
```

```
compute del1=%beta(2),del2=%beta(3)
compute sigsqeps=%sigmasq

nonlin sigsqeps sigsqxi sigsqomega del1 del2
compute sigsqxi=sigsqeps*.01,sigsqomega=sigsqeps*.01

frml explan = del1*d1975q2+del2*d1979q3
dlm(a=a,c=c,sv=sigsqeps,f=f,sw=%diag(||sigsqxi,sigsqomega||),exact,y=ukinflation-explan,$
  method=bfgs,vhat=vhat,svhat=svhat)

DLM - Estimation by BFGS
Convergence in    19 Iterations. Final criterion was  0.0000015 <=  0.0000100
Quarterly Data From 1950:01 To 2001:04
Usable Observations                    208
Rank of Observables                    204
Log Likelihood                   -243.2272

    Variable                     Coeff      Std Error      T-Stat      Signif
*****************************************************************************
1.  SIGSQEPS                  0.2153799686 0.0521346139      4.13123  0.00003608
2.  SIGSQXI                   0.1873890860 0.0535143017      3.50166  0.00046236
3.  SIGSQOMEGA                0.0043218203 0.0021912390      1.97232  0.04857331
4.  DEL1                      3.3253145680 0.6903164260      4.81709  0.00000146
5.  DEL2                      4.2370529538 0.6479206037      6.53946  0.00000000


set resids = %scalar(vhat)/sqrt(%scalar(svhat))
@STAMPDiags(ncorrs=15) resids
```

State Space Model Diagnostics

	Statistic	Sig. Level
Q(15-4)	29.90	0.0016
Normality	0.06	0.9717
H(68)	0.36	0.0000

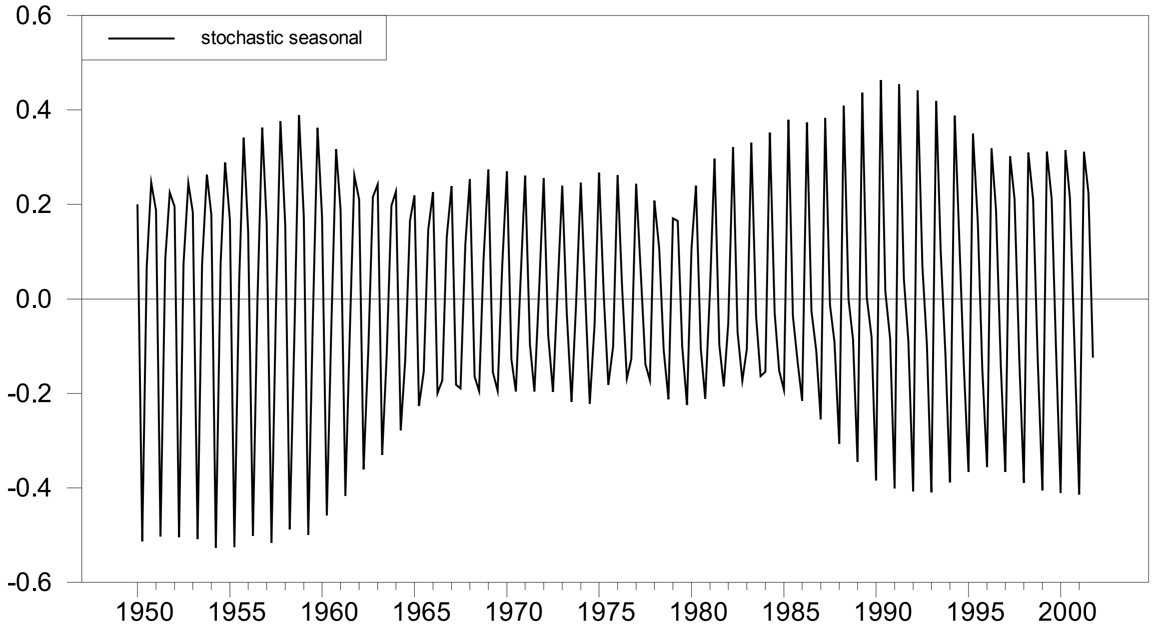


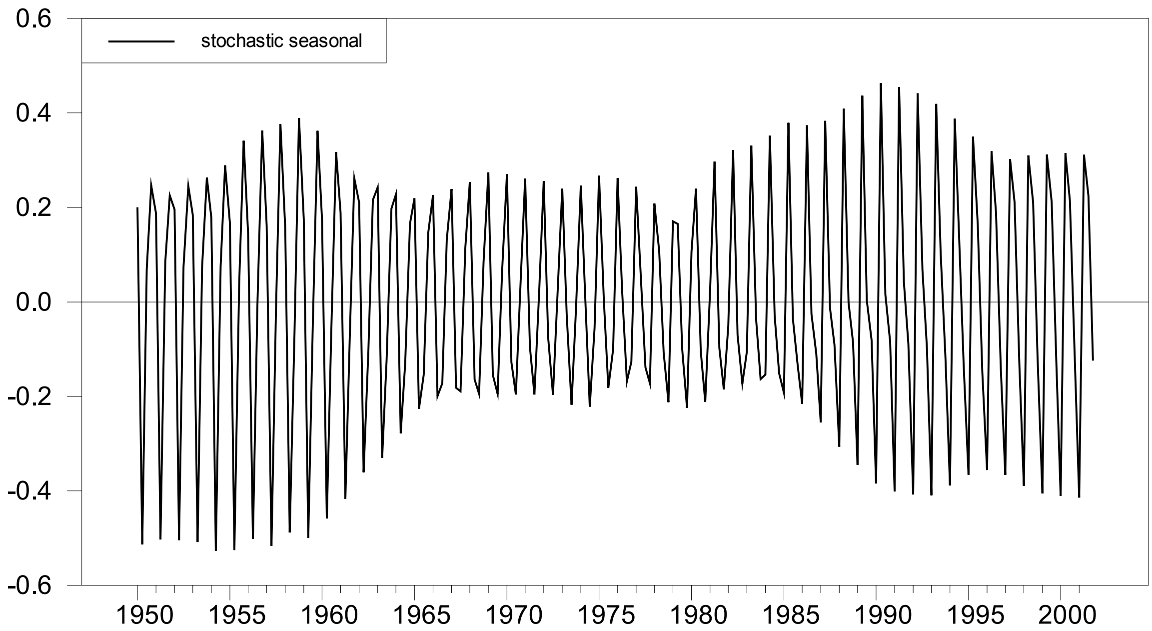

```
dlm(a=a,c=c,sv=sigsqeps,f=f,sw=%diag(||sigsqxi,sigsqomega||),exact,y=ukinflation-explan,$
  type=smooth) / xstates
set fitted    = %dot(c,xstates)
set seasonal  = xstates(t)(2)
set fitplus   = fitted+explan
set irreg     = ukinflation-fitplus

spgraph(vfields=3,footer="Figure 7.7 UK inflation series",samesize)
```

graph(key=upleft,klabels=||"quarterly price changes in UK","stochastic level+intervention variables"||) 2

ukinflation

fitplus





spgraph(vfields=3,footer="Figure 7.7 UK inflation series",samesize)

graph(key=upleft,klabels=||"quarterly price changes in UK","stochastic level+intervention variables"||) 2

ukinflation

fitplus

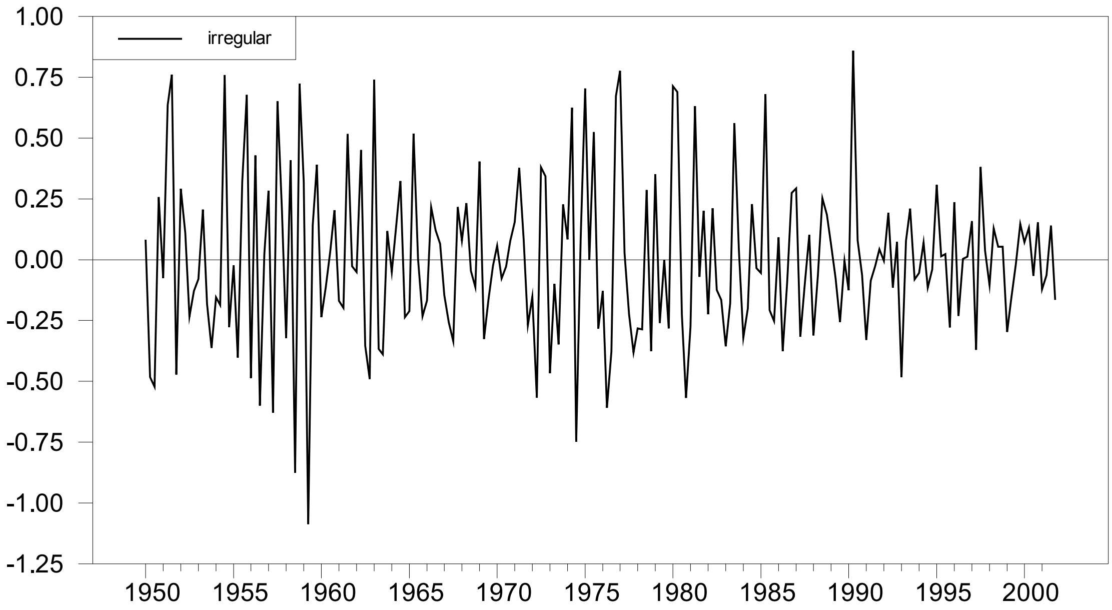
graph(key=upleft,klabels=||"stochastic seasonal"||)

seasonal

graph(key=upleft,klabels=||"irregular"||)

irreg

spgraph(done)



Chapter 8 - Norway & Finland data, forecasts

open data norwayfinland.txt

calendar(a) 1970

data(format=free,org=columns,skips=1) 1970:01 2003:01 year norway finland

set logfinland = log(finland)

set lognorway = log(norway)

@LocalDLMInit(irreg=sigsqeps) lognorway

```
nonlin sigsqeps sigsqxi
compute sigsqxi=sigsqeps*.01
dlm(a=1.0,c=1.0,sv=sigsqeps,sw=sigsqxi,exact,y=lognorway,$
  method=bfgs,yhat=yhat,svhat=svhat) * 2008:1 xstates vstates
```

```
DLM - Estimation by BFGS
Convergence in    20 Iterations. Final criterion was  0.0000068 <=  0.0000100
Annual Data From 1970:01 To 2008:01
Usable Observations                    39
Rank of Observables                    33
Log Likelihood                   28.7933

    Variable                     Coeff      Std Error      T-Stat      Signif
********************************************************************************
1.  SIGSQEPS                  0.0032675682 0.0017139951      1.90640  0.05659772
2.  SIGSQXI                   0.0047076220 0.0020504609      2.29588  0.02168247
```

```
Because RATS dates the "filtered" state differently from the book, the
* in-sample forecasts are computing using the yhat option.

set forecast  1970:2 2008:1 = %if(t<=2003:1,%scalar(yhat),%scalar(xstates(t)))
set fvariance 1970:2 2008:1 = %if(t<=2003:1,%scalar(svhat),%scalar(vstates(t)))

set upper * 2008:1 = forecast+1.64*sqrt(fvariance)
set lower * 2008:1 = forecast-1.64*sqrt(fvariance)

graph(footer="Figure 8.13 In-sample one step forecasts and \\"+$
  "five year out-of-sample forecasts for Norway") 4
# lognorway
```

forecast * 2008:1 2

upper   * 2008:1 3

lower   * 2008:1 3

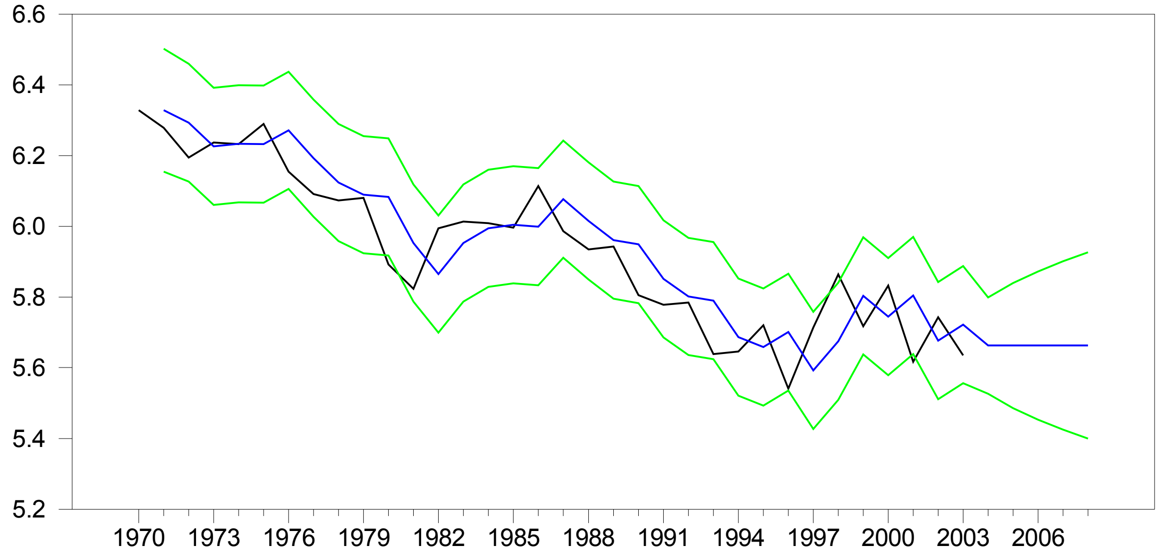


Figure 8.13 In-sample one step forecasts and five year out-of-sample forecasts for Norway

@LocalDLM(type=trend,shocks=both,a=at,c=ct,f=ft)

@LocalDLMInit(irreg=sigsqeps,trend=sigsqzeta) logfinland

compute sigsqxi=sigsqeps*.01

nonlin sigsqeps sigsqxi=0.0 sigsqzeta

dlm(a=at,c=ct,sv=sigsqeps,f=ft,sw=%diag(||sigsqxi,sigsqzeta||),exact,y=logfinland,$

 method=bfgs,yhat=vhat,svhat=svhat) * 2008:1 xstates vstates

DLM - Estimation by BFGS

Convergence in 7 Iterations. Final criterion was 0.0000053 <= 0.0000100

Annual Data From 1970:01 To 2008:01

Usable Observations 39

Rank of Observables 32

Log Likelihood 26.7401

Variable	Coeff	Std Error	T-Stat	Signif
1. SIGSQEPS	0.0032009939	0.0010490489	3.05133	0.00227830
2. SIGSQZETA	0.0015331338	0.0008965330	1.71007	0.08725299

```
set forecast  1970:3 2008:1 = %if(t<=2003:1,%scalar(yhat),%scalar(xstates(t)))
set fvariance 1970:3 2008:1 = %if(t<=2003:1,%scalar(svhat),%scalar(vstates(t)))
set upper * 2008:1 = forecast+1.64*sqrt(fvariance)
set lower * 2008:1 = forecast-1.64*sqrt(fvariance)
graph(footer="Figure 8.14 In-sample one step forecasts and \\"+$
  "five year out-of-sample forecasts for Finland") 4
# lognorway
# forecast   * 2008:1 2
# upper      * 2008:1 3
# lower      * 2008:1 3
```

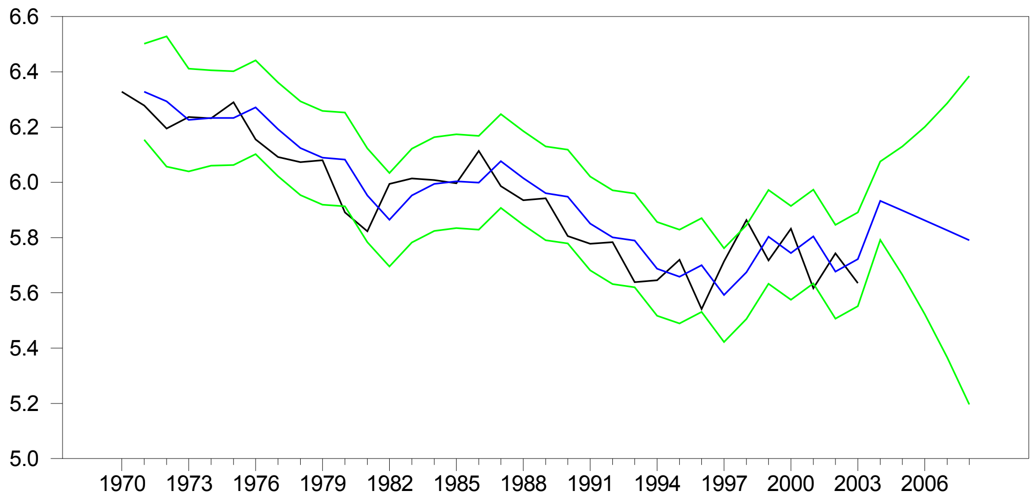


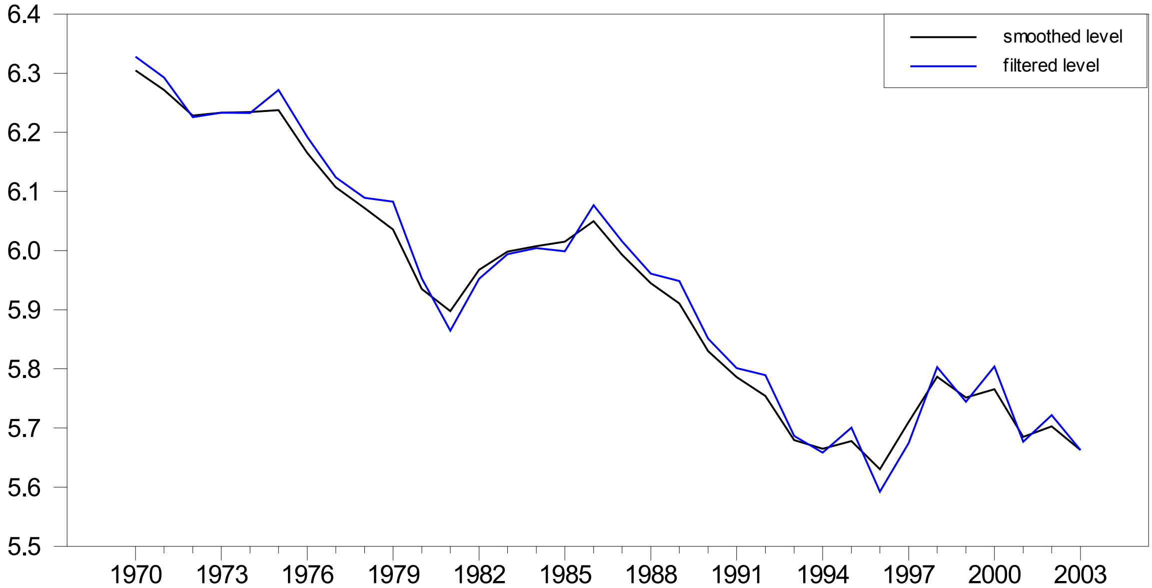
Figure 8.14 In-sample one step forecasts and
five year out-of-sample forecasts for Finland

CHAPTER 8

```
open data norwayfinland.txt

calendar(a) 1970

data(format=free,org=columns,skips=1) 1970:01 2003:01 year norway finland



set lognorway = log(norway)


@LocalDLMInit(irreg=sigsqeps) lognorway

nonlin sigsqeps sigsqxi

compute sigsqxi=sigsqeps*.01

dlm(a=1.0,c=1.0,sv=sigsqeps,sw=sigsqxi,exact,y=lognorway,$
  method=bfgs,vhat=vhat,svhat=svhat) / fstates



DLM - Estimation by BFGS

Convergence in    20 Iterations. Final criterion was  0.0000068 <=  0.0000100

Annual Data From 1970:01 To 2003:01

Usable Observations                   34

Rank of Observables                   33

Log Likelihood                  28.7933


   Variable                   Coeff      Std Error      T-Stat      Signif
******************************************************************************

1.  SIGSQEPS                  0.0032675682 0.0017139951      1.90640  0.05659772

2.  SIGSQXI                   0.0047076220 0.0020504609      2.29588  0.02168247


dlm(a=1.0,c=1.0,sv=sigsqeps,sw=sigsqxi,exact,y=lognorway,$
  type=smooth) / sstates
```

The graph doesn't quite match because of a different definition of "filtered" state. For the RATS DLM instruction, the filtered state is the expectation of X(t) given information through t. In the text, the filtered state is the expectation of X(t) given information through t-1. "Smoothed" means the same regardless.

```
set filtered = %scalar(fstates)

set smoothed = %scalar(sstates)



graph(footer="Smoothed and filtered state of the local level model",$

  key=upright,klabels=||"smoothed level","filtered level"||) 2

# smoothed

# filtered
```



Smoothed and filtered state of the local level model

```
set perror = %scalar(vhat)

set pevar  = %scalar(svhat)
```

The prediction error and prediction error variance really only make sense for entries 2 and above (or, in general, beyond the number of unit roots in the state-space model).

```
spgraph(vfields=2,samesize,$
 footer="Figure 8.7 One-step ahead prediction errors and their variances")
graph(key=upleft,klabels=||"prediction errors"||)
# perror 2 *

graph(key=upleft,klabels=||"prediction errors"||)
# perror 2 *
graph(key=upright,klabels=||"prediction error variance"||)
# pevar  2 *
spgraph(done)
```

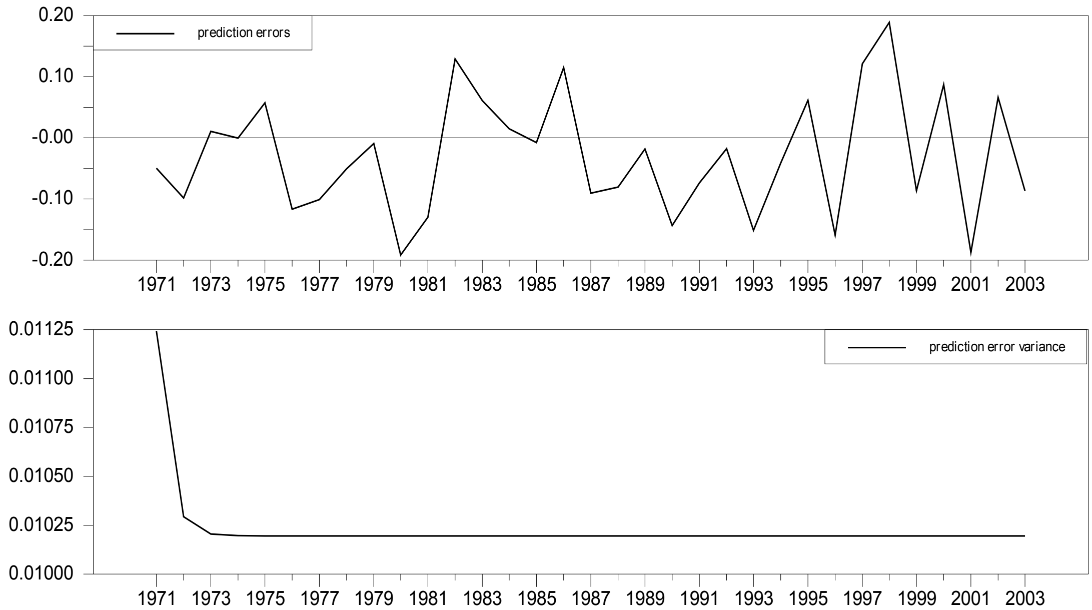


Figure 8.7 One-step ahead prediction errors and their variances

Chapter 8. UK data

```
open data ukdriversksi.txt
calendar(m) 1969
data(format=free,org=columns,skips=1) 1969:01 1984:12 ksi
```

```
set logksi = log(ksi)
set january = %period(t)==1

@LocalDLM(type=level,a=al,c=cl,f=fl)
@SeasonalDLM(type=additive,a=as,c=cs,f=fs)
compute a=al~\as,f=fl~\fs,c=cl~~cs

@LocalDLMInit(deseasonalize,irreg=sigsqeps) logksi
compute sigsqxi=sigsqeps*.01

* Settings for stochastic level/deterministic seasonal
nonlin sigsqeps sigsqxi sigsqomega=0.0
* If you don't need the filtered information, you can just do
* type=smooth on the DLM that does the estimation. The estimation is
* done using Kalman filtering passes, then a smoothing is done at the
* final values (only).

dlm(a=a,c=c,sv=sigsqeps,f=f,sw=%diag(||sigsqxi,sigsqomega||),exact,y=logksi,$
  method=bfgs,type=smooth) / xstates vstates

DLM - Estimation by BFGS
Convergence in    14 Iterations. Final criterion was  0.0000023 <=  0.0000100
Monthly Data From 1969:01 To 1984:12
Usable Observations                   192
Rank of Observables                   180
Log Likelihood                   188.7353

    Variable                     Coeff      Std Error      T-Stat      Signif
********************************************************************************
1.  SIGSQEPS                 0.0035139218 0.0005308840      6.61900  0.00000000
2.  SIGSQXI                  0.0009455771 0.0003476733      2.71973  0.00653354
```

```
set levelvar = vstates(t)(1,1)

graph(footer="Figure 8.1 Level estimation error variance for stochastic level\\"+$
  "and deterministic seasonal model")
# levelvar
```

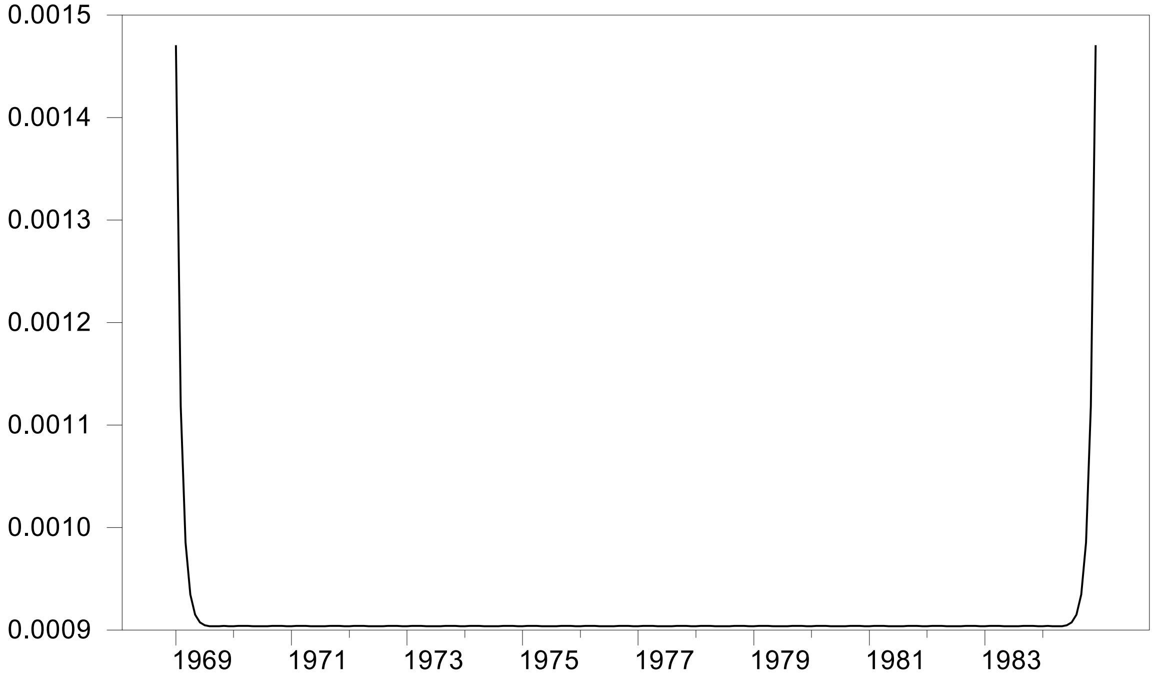


Figure 8.1 Level estimation error variance for stochastic level
and deterministic seasonal model

```
set level = xstates(t)(1)
set upper = level+1.64*sqrt(levelvar)
set lower = level-1.64*sqrt(levelvar)

graph(footer="Figure 8.2 Stochastic level and 90% confidence interval") 4
# level
# upper  / 2
# lower  / 2
```

logksi / 3

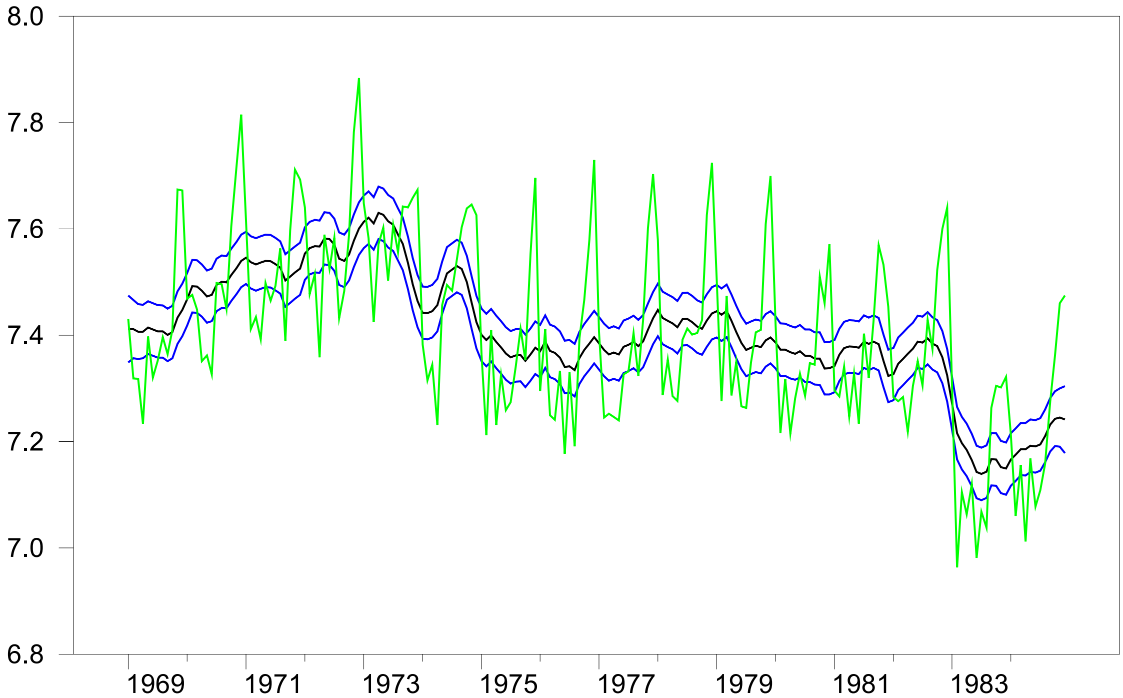


Figure 8.2 Stochastic level and 90% confidence interval

```
* The current seasonal is state 2

set seasonal = xstates(t)(2)
set upper    = seasonal+1.64*sqrt(vstates(t)(2,2))
set lower    = seasonal-1.64*sqrt(vstates(t)(2,2))
* This is graphed under a shorter range, since it repeats exactly, and
* over the full range, the lines run together because there's so much
* rapid vertical movement.
The sum of the level and seasonal is the c vector dotted with the
* state vector. So the variance is the quadratic form of the variance
* matrix with c.
set combined = %dot(c,xstates)
set upper    = combined+1.64*sqrt(%qform(vstates,c))
set lower    = combined-1.64*sqrt(%qform(vstates,c))
```

```
graph(footer="Figure 8.4 Stochastic level + deterministic seasonal") 3
# combined 1981:1 1984:12
# upper    1981:1 1984:12  2
# lower    1981:1 1984:12  2
```

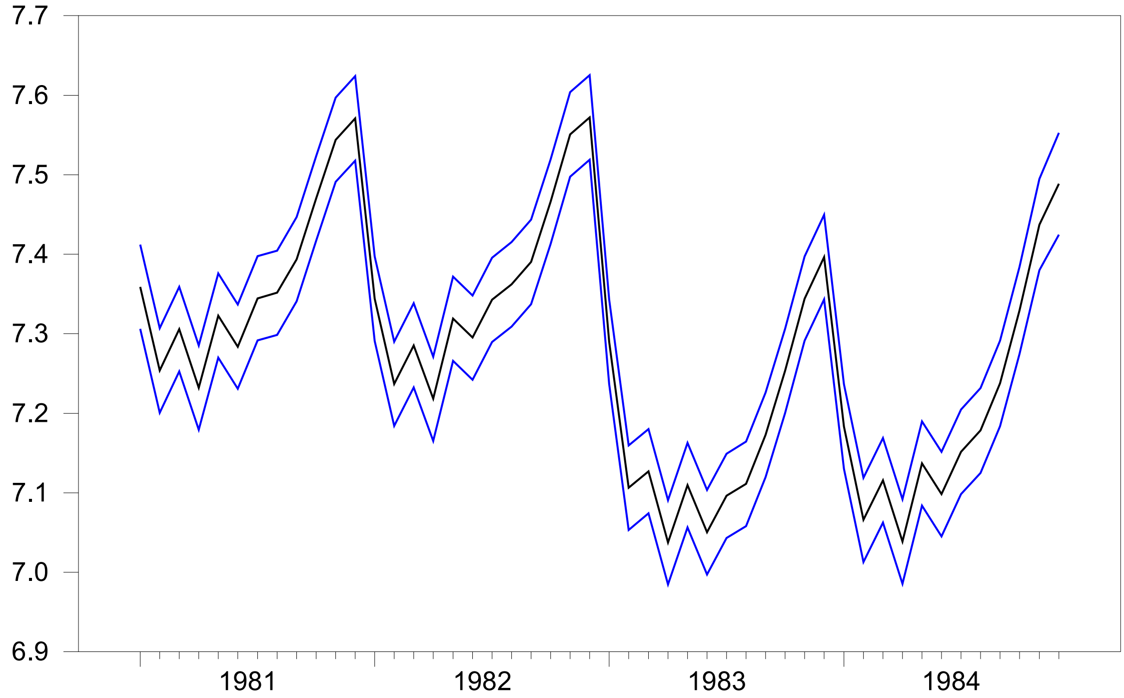


Figure 8.4 Stochastic level + deterministic seasonal

```
* Commandeur & Koopman, An Introduction to State Space Time Series Analysis.
* Chapter 8. UK data. Diagnostics.
*
open data ukdriversksi.txt
calendar(m) 1969
data(format=free,org=columns,skips=1) 1969:01 1984:12 ksi
set logksi = log(ksi)
open data logukpetrolprice.txt
data(format=free,org=columns,skips=1) 1969:01 1984:12 logukpetrol
set seatbelt = t>=1983:2
   seasonal seasons
```

```
linreg logksi
# constant logukpetrol seatbelt seasons{0 to -10}

Linear Regression - Estimation by Least Squares
Dependent Variable LOGKSI
Monthly Data From 1969:01 To 1984:12
Usable Observations                192
Degrees of Freedom                 178
Centered R^2                 0.7649810
R-Bar^2                    0.7478167
Uncentered R^2               0.9998750
Mean of Dependent Variable      7.4061076031
Std Error of Dependent Variable  0.1713258861
Standard Error of Estimate      0.0860361905
Sum of Squared Residuals        1.3175962408
Regression F(13,178)             44.5681
Significance Level of F          0.0000000
Log Likelihood                 205.8057
Durbin-Watson Statistic            1.0271

   Variable                  Coeff      Std Error      T-Stat      Signif
*******************************************************************
1.  Constant                   6.408271488  0.131043387    48.90191  0.00000000
2.  LOGUKPETROL               -0.452130127  0.056396100    -8.01705  0.00000000
3.  SEATBELT                  -0.197139472  0.020727560    -9.51098  0.00000000
4.  SEASONS{-10}              -0.113298463  0.030443139    -3.72164  0.00026527
5.  SEASONS{-9}               -0.073250058  0.030441978    -2.40622  0.01714199
6.  SEASONS{-8}               -0.148612311  0.030442789    -4.88169  0.00000233
7.  SEASONS{-7}               -0.061018712  0.030442201    -2.00441  0.04654189
8.  SEASONS{-6}               -0.094322520  0.030445215    -3.09811  0.00226380
9.  SEASONS{-5}               -0.043678566  0.030450539    -1.43441  0.15320973
```

```
10. SEASONS{-4}            -0.036163911  0.030444339    -1.18787  0.23646732
11. SEASONS{-3}            -0.001580202  0.030442029    -0.05191  0.95865976
12. SEASONS{-2}             0.073900896  0.030445849     2.42729  0.01620850
13. SEASONS{-1}             0.180678532  0.030442576     5.93506  0.00000002
14. SEASONS                 0.236943712  0.030441972     7.78345  0.00000000
```

```
compute sigsqeps=%sigmasq,beta=%beta(2),lambda=%beta(3)

@LocalDLM(type=level,a=al,c=cl,f=fl)
@SeasonalDLM(type=additive,a=as,c=cs,f=fs)
compute a=al~\as,f=fl~\fs,c=cl~~cs
frml explan = beta*logukpetrol+lambda*seatbelt
compute sigsqxi=sigsqeps*.01
nonlin sigsqeps sigsqxi sigsqomega=0.00 lambda beta
dlm(a=a,c=c,sv=sigsqeps,f=f,sw=%diag(||sigsqxi,sigsqomega||),exact,y=logksi-explan,$
  method=bfgs,vhat=vhat,svhat=svhat)
```

```
DLM - Estimation by BFGS
Convergence in    12 Iterations. Final criterion was  0.0000015 <=  0.0000100
Monthly Data From 1969:01 To 1984:12
Usable Observations              192
Rank of Observables              180
Log Likelihood              200.6874

   Variable                Coeff      Std Error      T-Stat      Signif
*******************************************************************************
1.  SIGSQEPS              0.004083894  0.000521384     7.83279  0.00000000
2.  SIGSQXI               0.000223718  0.000131729     1.69833  0.08944633
3.  LAMBDA               -0.235925437  0.040434059    -5.83482  0.00000001
4.  BETA                 -0.281653592  0.088015228    -3.20006  0.00137401
```

set resids = %scalar(vhat)/sqrt(%scalar(svhat))

graph(footer="Figure 8.8 Standardized one-step prediction errors")

resids

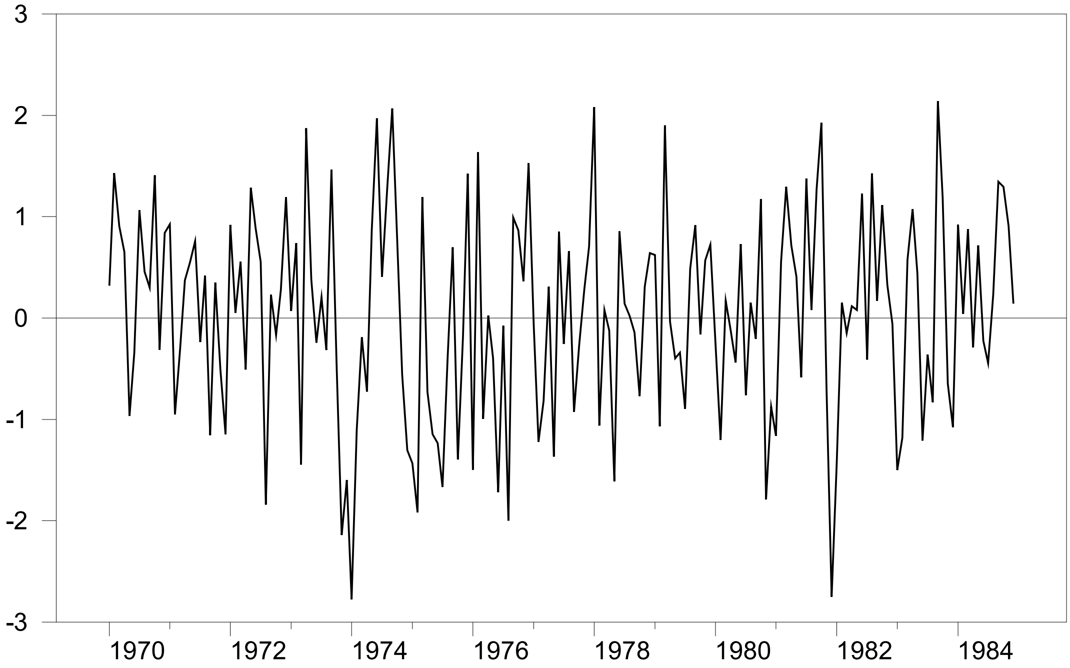


Figure 8.8 Standardized one-step prediction errors

RATS uses slightly different (bias-corrected) formulas for the skewness and kurtosis, hence the normality statistic is a bit different.

set resids = %scalar(vhat)/sqrt(%scalar(svhat))

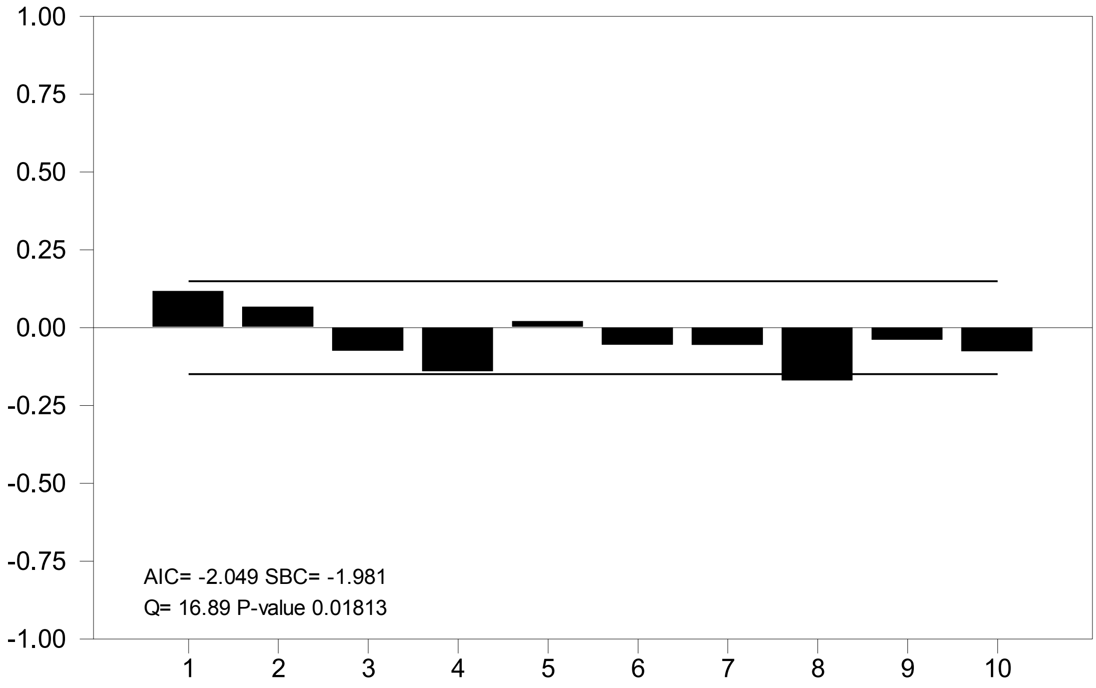
graph(footer="Figure 8.8 Standardized one-step prediction errors")

resids

@STAMPDiags(ncorrs=10) resids

State Space Model Diagnostics

	Statistic	Sig. Level
Q(10-3)	16.89	0.0181
Normality	2.50	0.2861
H(60)	0.91	0.7159




```
@histogram(maxgrid=20,distrib=normal,$
 footer="Figure 8.10 Histogram of standardized one-step prediction errors") resids
```

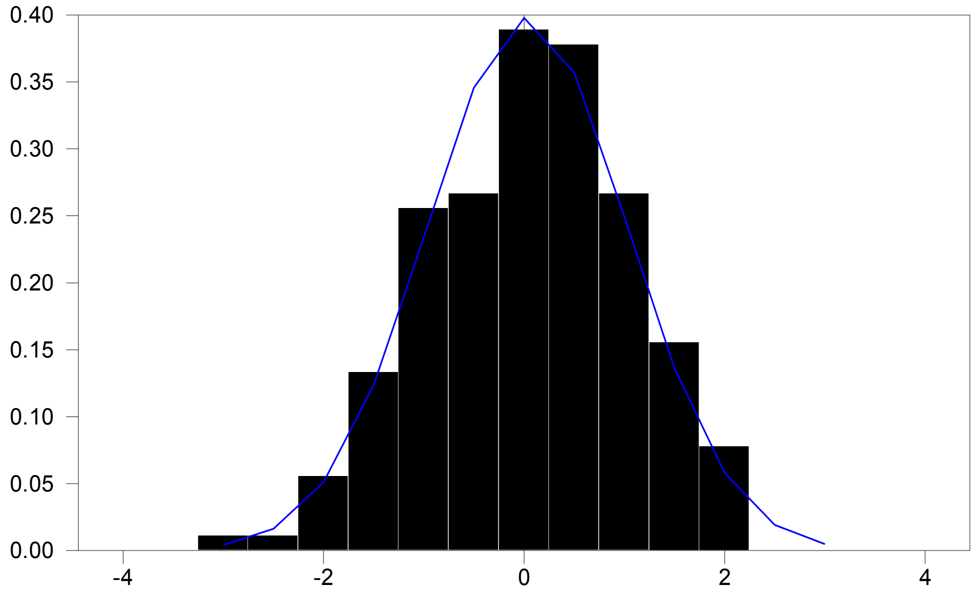


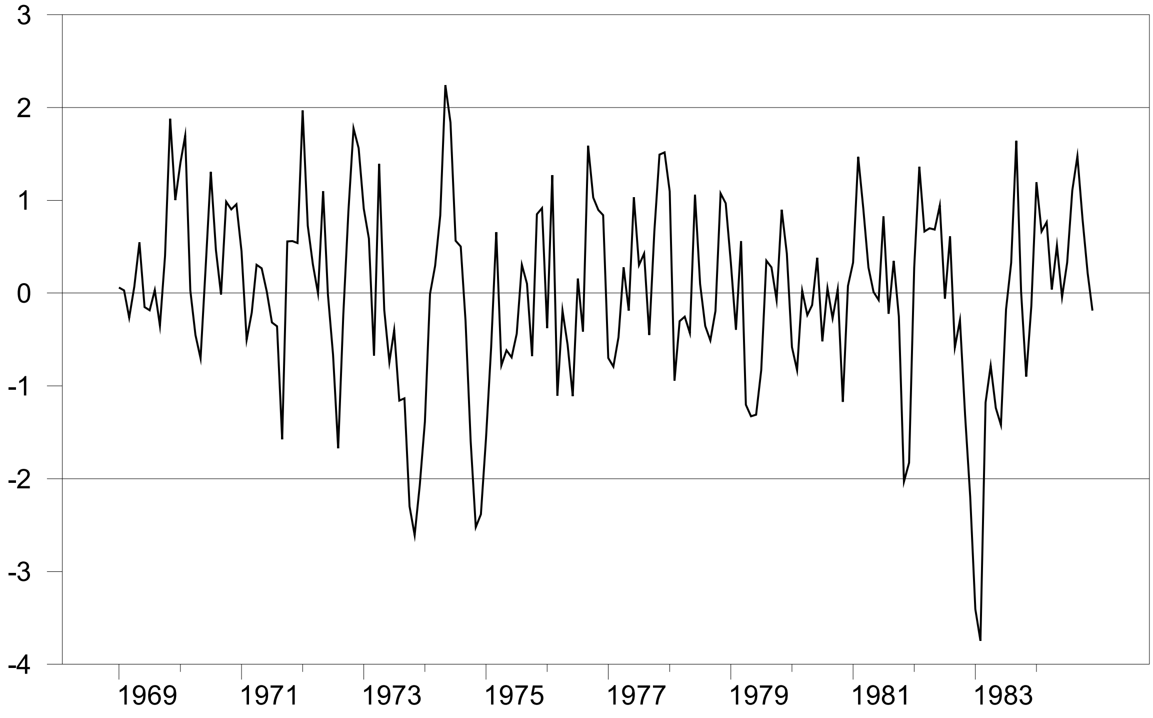
Figure 8.10 Histogram of standardized one-step prediction errors

Section 4.3 does the stochastic level, deterministic seasonal, but without the explanatory variables. The smoothed disturbances are computed using Kalman smoothing.

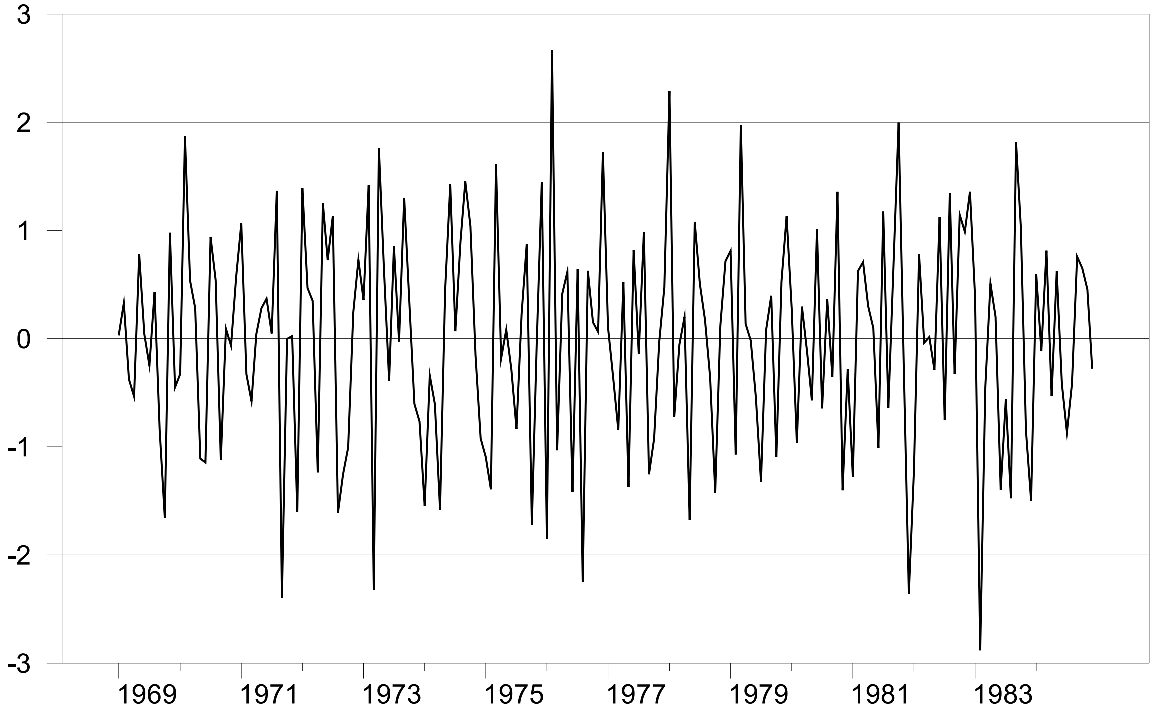
```
nonlin sigsqeps sigsqxi sigsqomega=0.00

dlm(a=a,c=c,sv=sigsqeps,f=f,sw=%diag(||sigsqxi,sigsqomega||),exact,y=logksi,$

  method=bfgs,type=smooth,vhat=vhat,what=what)
```

```
DLM - Estimation by BFGS

Convergence in    8 Iterations. Final criterion was  0.0000058 <=  0.0000100

Monthly Data From 1969:01 To 1984:12

Usable Observations                   192

Rank of Observables                   180

Log Likelihood                188.7353

   Variable                    Coeff      Std Error      T-Stat      Signif

*******************************************************************************

1.  SIGSQEPS                  0.0035148488 0.0004996804      7.03419  0.00000000

2.  SIGSQXI                   0.0009451475 0.0003364325      2.80932  0.00496458
```

```
set outlier = %scalar(vhat)
diff(standardize) outlier
set breaks  = %scalar(what)
diff(standardize) breaks
spgraph(vfields=2,samesize,$
 footer="Figure 8.11 Standardized smoothed level and observation disturbances\\"+$
```



Structural level break t-tests



Outlier t-tests

* Same thing, but with the model with the explanatory variables

```
nonlin sigsqeps sigsqxi sigsqomega=0.00 lambda beta
dlm(a=a,c=c,sv=sigsqeps,f=f,sw=%diag(||sigsqxi,sigsqomega||),exact,y=logksi-explan,$
```

```
 method=bfgs,type=smooth,vhat=vhat,what=what)


DLM - Estimation by BFGS
Convergence in     9 Iterations. Final criterion was  0.0000098 <=  0.0000100
Monthly Data From 1969:01 To 1984:12
Usable Observations                  192
Rank of Observables                  180
Log Likelihood                  200.6874

   Variable                  Coeff      Std Error      T-Stat      Signif
************************************************************************************
1.  SIGSQEPS                 0.004083925  0.000632110      6.46078  0.00000000
2.  SIGSQXI                  0.000223710  0.000161989      1.38102  0.16727302
3.  LAMBDA                  -0.235925369  0.044843679     -5.26106  0.00000014
4.  BETA                    -0.281654065  0.095778020     -2.94070  0.00327475


spgraph(vfields=2,samesize,$
 footer="Figure 8.12 Standardized smoothed level and observation disturbances\\"+$
 "for model with explanatory variables")
graph(hlabel="Structural level break t-tests",vgrid=||-2.0,2.0||)
# breaks
graph(hlabel="Outlier t-tests",vgrid=||-2.0,2.0||)
# outlier
spgraph(done)
```

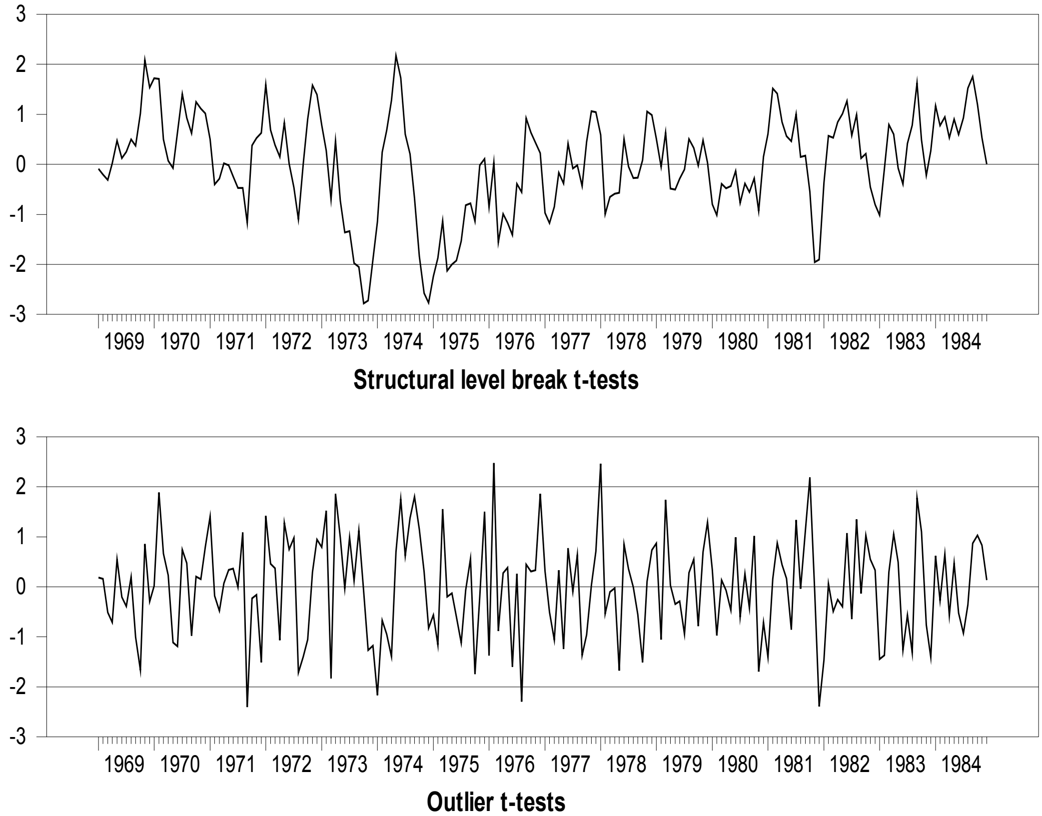


Figure 8.12 Standardized smoothed level and observation disturbances for model with explanatory variables

```
* Commandeur & Koopman, An Introduction to State Space Time Series Analysis.
* Chapter 8. UK data.
*
open data ukdriversksi.txt
calendar(m) 1969
data(format=free,org=columns,skips=1) 1969:01 1984:12 ksi
set logksi = log(ksi)
open data logukpetrolprice.txt
data(format=free,org=columns,skips=1) 1969:01 1984:12 logukpetrol
set seatbelt = t>=1983:2
ENTRY       KSI      LOGKSI        LOGUKPETROL    SEATBELT
 1969:01    1687     7.43070708255   -2.27330         0
```

1969:02	1508	7.31853954857	-2.27923	0
1969:03	1507	7.31787619863	-2.28217	0
1969:04	1385	7.23345541862	-2.29389	0
1969:05	1632	7.39756153552	-2.29244	0
1969:06	1511	7.32052696227	-2.29679	0
1969:07	1559	7.35179986906	-2.26554	0
1969:08	1630	7.39633529380	-2.26263	0
1969:09	1579	7.36454701426	-2.26554	0
1969:10	1653	7.41034709782	-2.27277	0
1969:11	2152	7.67415292128	-2.27565	0
1969:12	2148	7.67229245563	-2.28281	0
1970:01	1752	7.46851327150	-2.28992	0
1970:02	1765	7.47590596937	-2.29557	0
1970:03	1717	7.44833386090	-2.30119	0
1970:04	1558	7.35115822643	-2.31647	0
1970:05	1575	7.36201055126	-2.31923	0
1970:06	1520	7.32646561384	-2.32197	0
1970:07	1805	7.49831587077	-2.33017	0
1970:08	1800	7.49554194388	-2.32882	0
1970:09	1719	7.44949800538	-2.32867	0
1970:10	2008	7.60489448081	-2.33945	0
1970:11	2242	7.71512360363	-2.34613	0
1970:12	2478	7.81520706219	-2.35276	0
1971:01	2030	7.61579107204	-2.33577	0
1971:02	1655	7.41155628781	-2.34227	0
1971:03	1693	7.43425738213	-2.35002	0
1971:04	1623	7.39203156751	-2.35694	0
1971:05	1805	7.49831587077	-2.36321	0
1971:06	1746	7.46508273640	-2.36945	0
1971:07	1795	7.49276030092	-2.37565	0
1971:08	1926	7.56320059236	-2.37688	0

1971:09	1619	7.38956395368	-2.37812	0
1971:10	1992	7.59689443814	-2.38304	0
1971:11	2233	7.71110125184	-2.38916	0
1971:12	2192	7.69256964807	-2.39402	0
1972:01	2080	7.64012317270	-2.40007	0
1972:02	1768	7.47760424320	-2.40488	0
1972:03	1835	7.51479976049	-2.40848	0
1972:04	1569	7.35819375273	-2.41800	0
1972:05	1976	7.58882987831	-2.42273	0
1972:06	1853	7.52456122629	-2.42861	0
1972:07	1965	7.58324752430	-2.42022	0
1972:08	1689	7.43189191681	-2.42836	0
1972:09	1778	7.48324441607	-2.41979	0
1972:10	1976	7.58882987831	-2.43353	0
1972:11	2397	7.78197323443	-2.43693	0
1972:12	2654	7.88382321489	-2.44144	0
1973:01	2097	7.64826303090	-2.44819	0
1973:02	1963	7.58222919428	-2.45489	0
1973:03	1677	7.42476176182	-2.46043	0
1973:04	1941	7.57095858317	-2.47906	0
1973:05	2003	7.60240133567	-2.46993	0
1973:06	1813	7.50273821075	-2.47531	0
1973:07	2012	7.60688453122	-2.47958	0
1973:08	1912	7.55590509361	-2.48278	0
1973:09	2084	7.64204440287	-2.49125	0
1973:10	2080	7.64012317270	-2.51110	0
1973:11	2118	7.65822752616	-2.49068	0
1973:12	2150	7.67322312112	-2.36244	0
1974:01	1608	7.38274644974	-2.38163	0
1974:02	1503	7.31521838975	-2.22413	0
1974:03	1548	7.34471905415	-2.23295	0

1974:04	1382	7.23128700433	-2.17118	0
1974:05	1731	7.45645455518	-2.18521	0
1974:06	1798	7.49443021503	-2.19538	0
1974:07	1779	7.48380668767	-2.20454	0
1974:08	1887	7.54274354537	-2.22380	0
1974:09	2004	7.60290046220	-2.23467	0
1974:10	2077	7.63867982388	-2.25430	0
1974:11	2092	7.64587582518	-2.12563	0
1974:12	2051	7.62608275807	-2.14028	0
1975:01	1577	7.36327958696	-2.01720	0
1975:02	1356	7.21229446850	-2.03374	0
1975:03	1652	7.40974195408	-2.05324	0
1975:04	1382	7.23128700433	-2.09113	0
1975:05	1519	7.32580750260	-2.13211	0
1975:06	1421	7.25911612810	-2.15126	0
1975:07	1442	7.27378631784	-2.16142	0
1975:08	1543	7.34148385236	-2.16717	0
1975:09	1656	7.41216033495	-2.17575	0
1975:10	1561	7.35308192052	-2.18988	0
1975:11	1905	7.55223728756	-2.20174	0
1975:12	2199	7.69575799055	-2.16044	0
1976:01	1473	7.29505641646	-2.17337	0
1976:02	1655	7.41155628781	-2.18614	0
1976:03	1407	7.24921505711	-2.19146	0
1976:04	1395	7.24064969426	-2.21053	0
1976:05	1530	7.33302301439	-2.22155	0
1976:06	1309	7.17701876591	-2.22669	0
1976:07	1526	7.33040521184	-2.21563	0
1976:08	1327	7.19067603433	-2.22960	0
1976:09	1627	7.39449310722	-2.24277	0
1976:10	1748	7.46622755622	-2.24149	0

1976:11	1958	7.57967882309	-2.25546	0
1976:12	2274	7.72929567431	-2.26865	0
1977:01	1648	7.40731771047	-2.28819	0
1977:02	1401	7.24494154634	-2.29857	0
1977:03	1411	7.25205395185	-2.31403	0
1977:04	1403	7.24636808010	-2.27793	0
1977:05	1394	7.23993259132	-2.27276	0
1977:06	1520	7.32646561384	-2.28103	0
1977:07	1528	7.33171496973	-2.30422	0
1977:08	1643	7.40427911804	-2.37907	0
1977:09	1515	7.32317071794	-2.38798	0
1977:10	1685	7.42952084279	-2.39993	0
1977:11	2000	7.60090245954	-2.40771	0
1977:12	2215	7.70300768248	-2.41541	0
1978:01	1956	7.57865685059	-2.42540	0
1978:02	1462	7.28756064031	-2.42642	0
1978:03	1563	7.35436233042	-2.44464	0
1978:04	1459	7.28550654852	-2.46516	0
1978:05	1446	7.27655640272	-2.47020	0
1978:06	1622	7.39141523468	-2.47181	0
1978:07	1657	7.41276401743	-2.47277	0
1978:08	1638	7.40123126441	-2.48170	0
1978:09	1643	7.40427911804	-2.48390	0
1978:10	1683	7.42833319419	-2.49199	0
1978:11	2050	7.62559507213	-2.46234	0
1978:12	2262	7.72400465668	-2.46781	0
1979:01	1813	7.50273821075	-2.47149	0
1979:02	1445	7.27586460055	-2.46097	0
1979:03	1762	7.47420480650	-2.43544	0
1979:04	1461	7.28687641175	-2.40370	0
1979:05	1556	7.34987370474	-2.39928	0

1979:06	1431	7.26612877956	-2.21877	0
1979:07	1427	7.26332961748	-2.17031	0
1979:08	1554	7.34858753093	-2.18043	0
1979:09	1645	7.40549566320	-2.19534	0
1979:10	1653	7.41034709782	-2.21525	0
1979:11	2016	7.60887062919	-2.22842	0
1979:12	2207	7.69938940626	-2.22932	0
1980:01	1665	7.41758040241	-2.26553	0
1980:02	1361	7.21597500265	-2.23386	0
1980:03	1506	7.31721240836	-2.23143	0
1980:04	1360	7.21523997873	-2.19198	0
1980:05	1453	7.28138566357	-2.20149	0
1980:06	1522	7.32778053842	-2.19055	0
1980:07	1460	7.28619171470	-2.20962	0
1980:08	1552	7.34729970074	-2.22383	0
1980:09	1548	7.34471905415	-2.24191	0
1980:10	1827	7.51043055638	-2.26151	0
1980:11	1737	7.45991476624	-2.28343	0
1980:12	1941	7.57095858317	-2.27503	0
1981:01	1474	7.29573507275	-2.25608	0
1981:02	1458	7.28482091257	-2.26334	0
1981:03	1542	7.34083555412	-2.14853	0
1981:04	1404	7.24708058459	-2.16142	0
1981:05	1522	7.32778053842	-2.18046	0
1981:06	1385	7.23345541862	-2.17278	0
1981:07	1641	7.40306109109	-2.12764	0
1981:08	1510	7.31986492981	-2.08353	0
1981:09	1681	7.42714413341	-2.09376	0
1981:10	1938	7.56941179245	-2.11463	0
1981:11	1868	7.53262361879	-2.11156	0
1981:12	1726	7.45356187164	-2.14585	0

1982:01	1456	7.28344822876	-2.18258	0
1982:02	1445	7.27586460055	-2.22489	0
1982:03	1456	7.28344822876	-2.21789	0
1982:04	1365	7.21890970762	-2.19560	0
1982:05	1487	7.30451594646	-2.19549	0
1982:06	1558	7.35115822643	-2.15888	0
1982:07	1488	7.30518821539	-2.16484	0
1982:08	1684	7.42892719480	-2.14381	0
1982:09	1594	7.37400185935	-2.12799	0
1982:10	1850	7.52294091807	-2.13736	0
1982:11	1998	7.59990195921	-2.14175	0
1982:12	2079	7.63964228786	-2.14568	0
1983:01	1494	7.30921236569	-2.18382	0
1983:02	1057	6.96318998587	-2.17457	1
1983:03	1218	7.10496544827	-2.17909	1
1983:04	1168	7.06304816339	-2.13288	1
1983:05	1236	7.11963563802	-2.13733	1
1983:06	1076	6.98100574072	-2.13973	1
1983:07	1174	7.06817200039	-2.11977	1
1983:08	1139	7.03790596345	-2.12496	1
1983:09	1427	7.26332961748	-2.12963	1
1983:10	1487	7.30451594646	-2.13316	1
1983:11	1483	7.30182234214	-2.13693	1
1983:12	1513	7.32184971379	-2.13956	1
1984:01	1357	7.21303165983	-2.13897	1
1984:02	1165	7.06047636600	-2.16459	1
1984:03	1282	7.15617663748	-2.15645	1
1984:04	1110	7.01211529431	-2.15973	1
1984:05	1297	7.16780918432	-2.16443	1
1984:06	1185	7.07749805357	-2.16476	1
1984:07	1222	7.10824413973	-2.16338	1

1984:08	1284	7.15773548425	-2.16459	1
1984:09	1444	7.27517231945	-2.17074	1
1984:10	1575	7.36201055126	-2.15016	1
1984:11	1737	7.45991476624	-2.15394	1
1984:12	1763	7.47477218240	-2.15359	1

```
seasonal seasons
linreg logksi * 1983:1
# constant logukpetrol seasons{0 to -10}
```

Linear Regression - Estimation by Least Squares

Dependent Variable LOGKSI

Monthly Data From 1969:01 To 1983:01

Usable Observations 169

Degrees of Freedom 156

Centered R^2 0.6780685

R-Bar^2 0.6533045

Uncentered R^2 0.9998706

Mean of Dependent Variable 7.4373861693

Std Error of Dependent Variable 0.1495807337

Standard Error of Estimate 0.0880744124

Sum of Squared Residuals 1.2101079314

Regression F(12,156) 27.3813

Significance Level of F 0.0000000

Log Likelihood 177.5609

Durbin-Watson Statistic 1.0049

Variable Coeff Std Error T-Stat Signif

****

1. Constant	6.403211361	0.134496533	47.60875	0.00000000
2. LOGUKPETROL	-0.453325009	0.057814902	-7.84097	0.00000000
3. SEASONS{-10}	-0.101418661	0.032729702	-3.09867	0.00230634
4. SEASONS{-9}	-0.072723650	0.032729681	-2.22195	0.02772597
5. SEASONS{-8}	-0.146950855	0.032730640	-4.48970	0.00001379
6. SEASONS{-7}	-0.061719286	0.032729661	-1.88573	0.06119041
7. SEASONS{-6}	-0.083325449	0.032734617	-2.54548	0.01188266
8. SEASONS{-5}	-0.034553254	0.032739646	-1.05539	0.29287653
9. SEASONS{-4}	-0.027139328	0.032732479	-0.82913	0.40830032
10. SEASONS{-3}	-0.011762096	0.032729751	-0.35937	0.71980417
11. SEASONS{-2}	0.064791515	0.032735073	1.97927	0.04954563
12. SEASONS{-1}	0.180273819	0.032730323	5.50785	0.00000015
13. SEASONS	0.242165115	0.032729562	7.39897	0.00000000

```
compute sigsqeps=%sigmasq,beta=%beta(2),lambda=%beta(3)
@LocalDLM(type=level,a=al,c=cl,f=fl)
@SeasonalDLM(type=additive,a=as,c=cs,f=fs)
compute a=al~\as,f=fl~\fs,c=cl~~cs
frml explan = beta*logukpetrol
Estimates through Jan 1983 (prior to seatbelt law) using stochastic
* level, deterministic seasonal and the log price of petrol as
* explanatory variable.
compute sigsqxi=.01*sigsqeps
nonlin sigsqeps sigsqxi sigsqomega=0.00 beta
dlm(a=a,c=c,sv=sigsqeps,f=f,sw=%diag(||sigsqxi,sigsqomega||),exact,y=logksi-explan,$
  method=bfgs) * 1983:1
```

DLM - Estimation by BFGS

Convergence in 13 Iterations. Final criterion was 0.0000021 <= 0.0000100

Monthly Data From 1969:01 To 1983:01

```
Usable Observations              169
Rank of Observables              157
Log Likelihood              171.8695

   Variable                  Coeff      Std Error      T-Stat      Signif
**********************************************************************************
1.  SIGSQEPS             0.004175386  0.000594170     7.02725  0.00000000
2.  SIGSQXI              0.000224946  0.000149255     1.50713  0.13177813
3.  BETA                -0.294450297  0.096086617    -3.06443  0.00218088
```

Using those estimates, forecast the last 23 periods of data, holding back the actual values of logksi, but using the petrol price.

```
dlm(a=a,c=c,sv=sigsqeps,f=f,sw=%diag(||sigsqxi,sigsqomega||),exact,$
  y=%if(t<=1983:1,logksi-explan,%na),yhat=yhat,svhat=svhat) / xstates vstates
set forecast  1970:1 * = explan+%if(t<=1983:1,%scalar(yhat),%dot(c,xstates))
set fvariance 1970:1 * = %if(t<=1983:1,%scalar(svhat),%qform(vstates,c))
set upper = forecast+1.64*sqrt(fvariance)
set lower = forecast-1.64*sqrt(fvariance)
```

```
graph(footer="Figure 8.15 Forecasts out of sample") 3
# forecast 1983:2 *
# upper    1983:2 * 2
# lower    1983:2 * 2
```

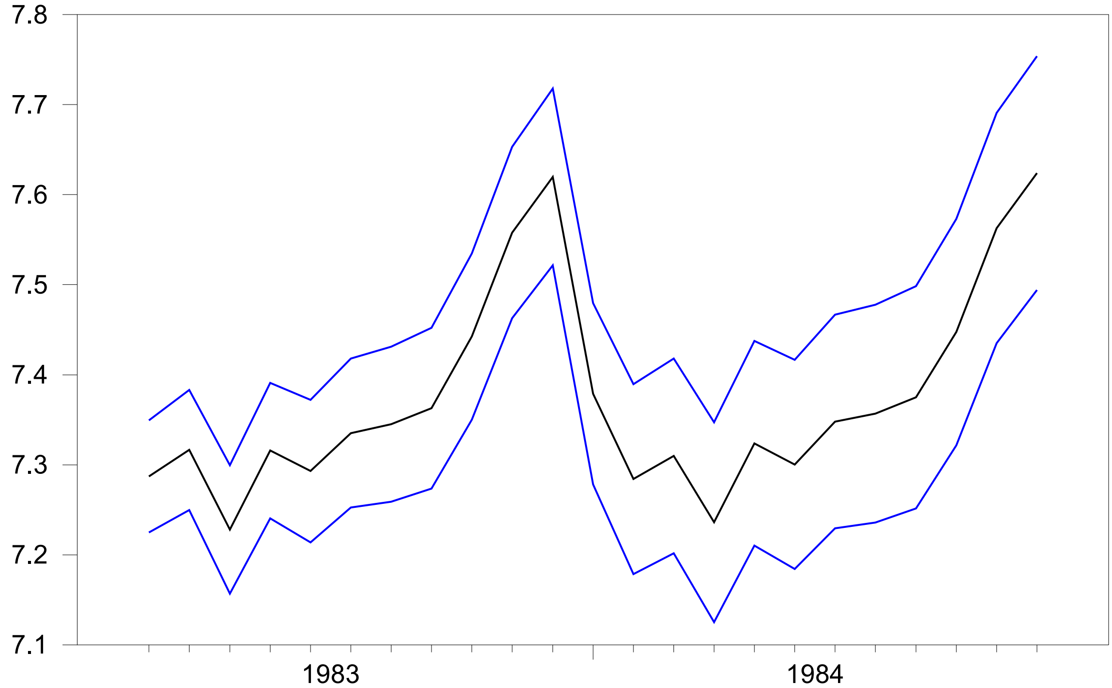


Figure 8.15 Forecasts out of sample

Redo estimation with all data, including the intervention variable

```
frml explan = beta*logukpetrol+lambda*seatbelt
nonlin sigsqeps sigsqxi sigsqomega=0.00 beta lambda
dlm(a=a,c=c,sv=sigsqeps,f=f,sw=%diag(||sigsqxi,sigsqomega||),exact,$
  method=bfgs,y=logksi-explan,yhat=yhat,svhat=svhat) / xstates vstates
```

DLM - Estimation by BFGS

Convergence in 8 Iterations. Final criterion was 0.0000007 <= 0.0000100

Monthly Data From 1969:01 To 1984:12

Usable Observations 192

Rank of Observables 180

Log Likelihood 200.6874

Variable	Coeff	Std Error	T-Stat	Signif
1. SIGSQEPS	0.004083895	0.000551713	7.40220	0.00000000
2. SIGSQXI	0.000223717	0.000143609	1.55782	0.11927512
3. BETA	-0.281653544	0.097181261	-2.89823	0.00375277
4. LAMBDA	-0.235925431	0.045010210	-5.24160	0.00000016

set cforecast 1970:1 * = %scalar(yhat)+explan

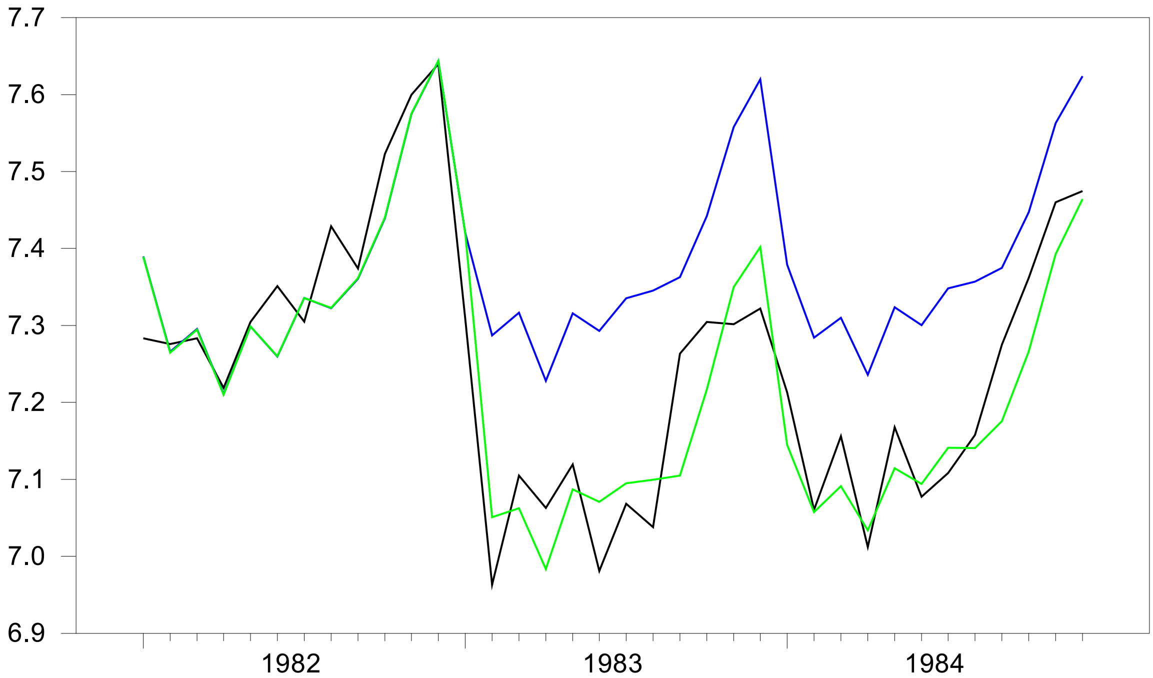


Figure 8.16 Last four years of data with forecasts obtained using data through Jan 1983 and with intervention

Chapter 8. UK data. Missing values.

open data ukdriversksi.txt

calendar(m) 1969

data(format=free,org=columns,skips=1) 1969:01 1984:12 ksi

set logksi = log(ksi)

@LocalDLM(type=level,a=al,c=cl,f=fl) r

@SeasonalDLM(type=additive,a=as,c=cs,f=fs)

```
compute a=al~\as,f=fl~\fs,c=cl~~cs
@LocalDLMInit(deseasonalize,irreg=sigsqeps) logksi
compute sigsqxi=sigsqeps*.01
```

Stochastic level, deterministic seasonal.

Patch over series with the range that we want to treat as missing

```
set withmiss = %if(t>=48.and.t<=62.or.t>=120.and.t<=140,%na,logksi)

nonlin sigsqeps sigsqxi sigsqomega=0.00
dlm(a=a,c=c,sv=sigsqeps,f=f,sw=%diag(||sigsqxi,sigsqomega||),exact,y=withmiss,$
  method=bfgs,type=smooth) / xstates vstates
```

```
DLM - Estimation by BFGS
Convergence in    13 Iterations. Final criterion was  0.0000046 <=  0.0000100
Monthly Data From 1969:01 To 1984:12
Usable Observations                 192
Rank of Observables                 144
Log Likelihood                 145.6626

    Variable                    Coeff      Std Error      T-Stat      Signif
********************************************************************************
1.  SIGSQEPS                  0.0038626869 0.0006286414      6.14450  0.00000000
2.  SIGSQXI                   0.0007509599 0.0003153380      2.38144  0.01724490
```

```
set levelvar = vstates(t)(1,1)

graph(footer="Figure 8.17 Stochastic level estimation error variance\\"+$
```

"with missing values")

levelvar

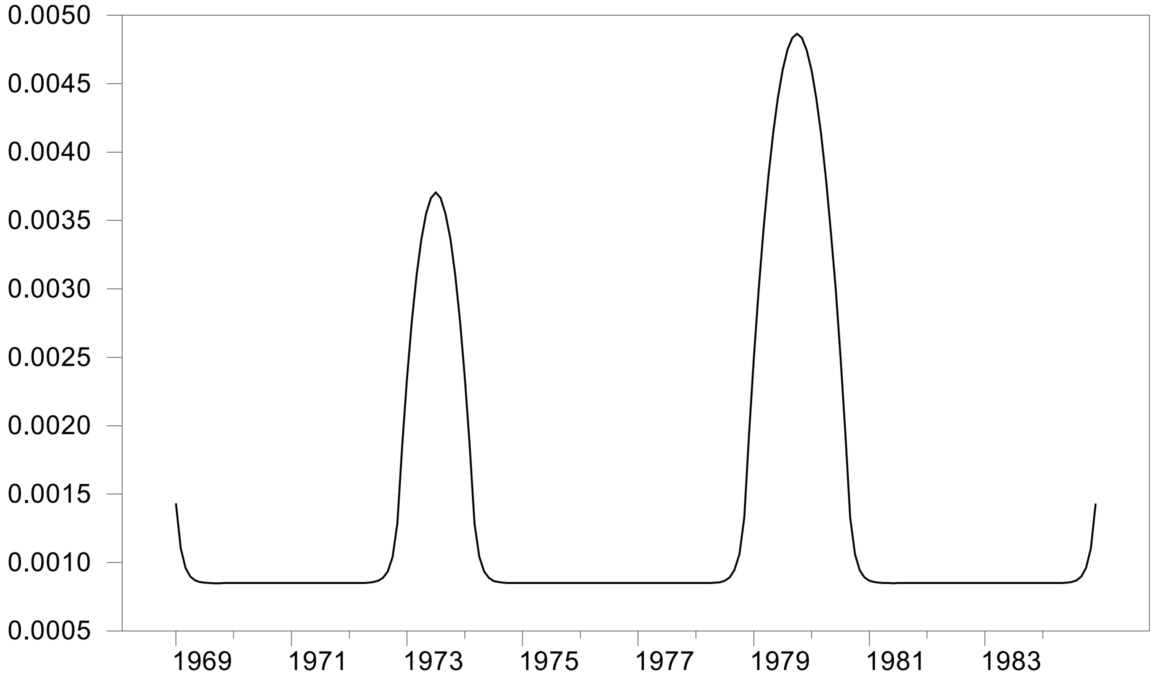


Figure 8.17 Stochastic level estimation error variance with missing values

set level = xstates(t)(1)

set upper = level+1.64*sqrt(levelvar)

set lower = level-1.64*sqrt(levelvar)

graph(footer="Figure 8.18 Stochastic level and 90% confidence interval") 4

level

upper / 2

lower / 2

logksi / 3

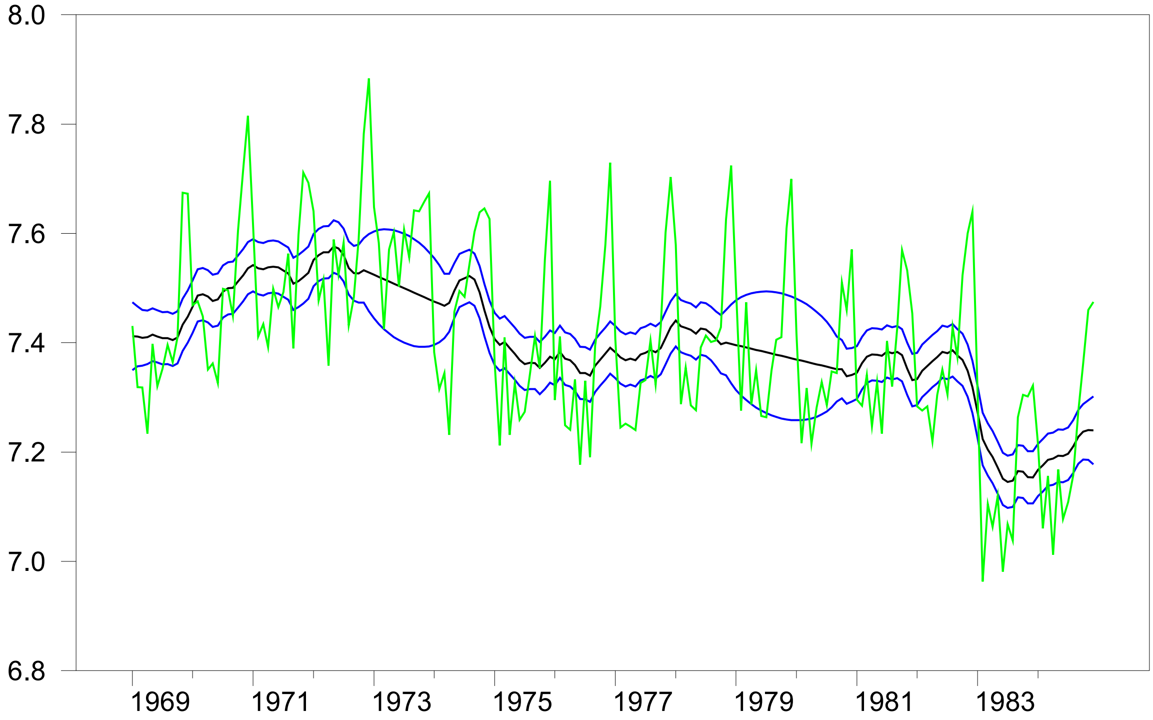


Figure 8.18 Stochastic level and 90% confidence interval

set seasonal = xstates(t)(2)

set upper = seasonal+1.64*sqrt(vstates(t)(2,2))

set lower = seasonal-1.64*sqrt(vstates(t)(2,2))

This is graphed under a shorter range, since it repeats exactly, and over the full range, the lines run together because there's so much rapid vertical movement.

graph(footer="Figure 8.20 Deterministic seasonal and 90% confidence interval") 3

seasonal 1971:1 1975:12

upper 1971:1 1975:12 2

lower 1971:1 1975:12 2

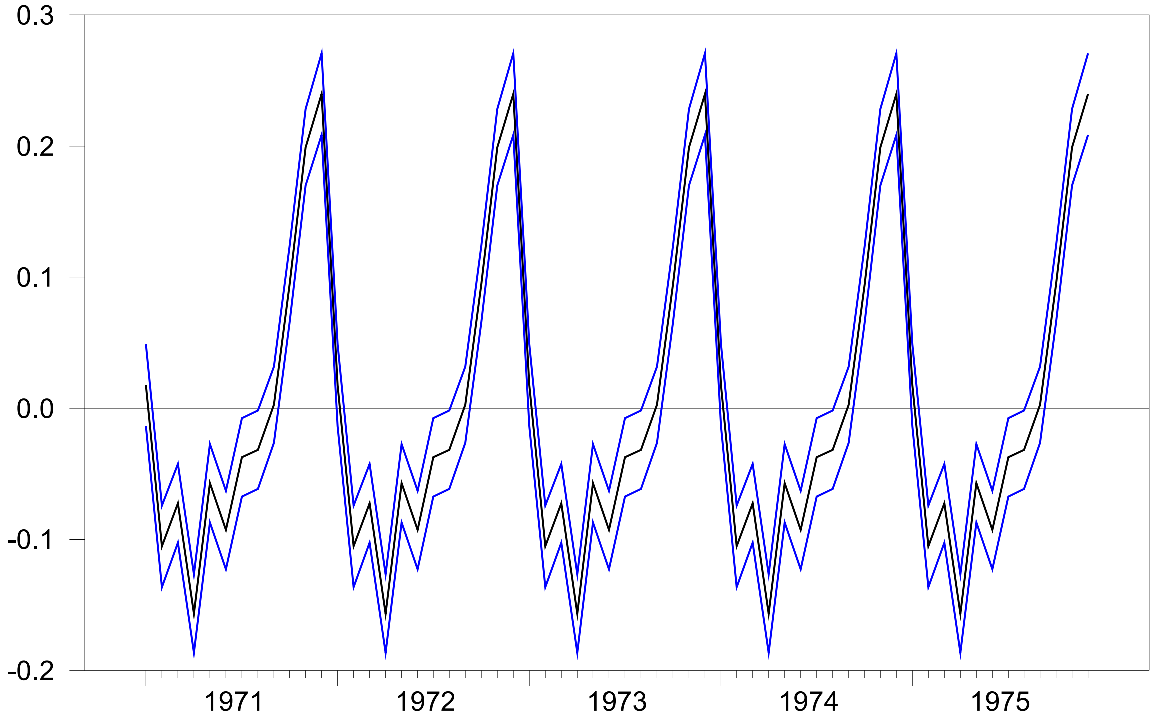


Figure 8.20 Deterministic seasonal and 90% confidence interval

The sum of the level and seasonal is the c vector dotted with the state vector. The irregular will be the difference between the data and that value. Since the data are missing in certain ranges, the irregular will be NA there as well.

```
set combined = %dot(c,xstates)
set irreg    = withmiss-combined
```

```
graph(footer="Figure 8.21 Irregular component")
# irreg
```

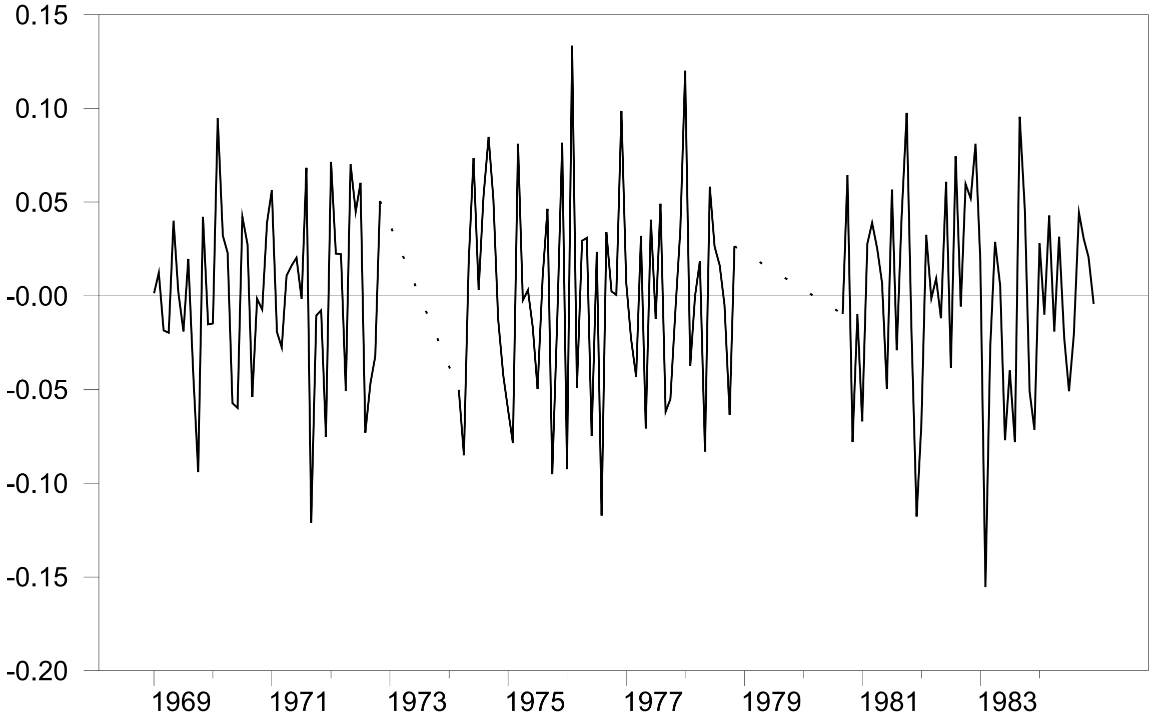


Figure 8.21 Irregular component

Chapter 9

```
open data ukfrontrearseatksi.txt
calendar(m) 1969
data(format=free,org=columns,skips=1) 1969:01 1984:12 driver front rear kilos petrol
set seatbelt = t>=1983:2
 print
```

ENTRY	DRIVER	FRONT	REAR	KILOS	PETROL	SEATBELT
1969:01	7.43071	6.76504	5.59471	9.11151	-2.27330	0
1969:02	7.31854	6.71538	5.57973	8.94703	-2.27923	0
1969:03	7.31788	6.69208	5.76519	9.20663	-2.28217	0
1969:04	7.23346	6.70196	6.00881	9.30155	-2.29389	0

1969:05	7.39756	6.89871	6.11810	9.37780	-2.29244	0
1969:06	7.32053	6.85118	6.05678	9.42473	-2.29679	0
1969:07	7.35180	6.91175	6.25767	9.50748	-2.26554	0
1969:08	7.39634	6.99485	6.28413	9.55073	-2.26263	0
1969:09	7.36455	6.86485	6.00389	9.40146	-2.26554	0
1969:10	7.41035	6.74524	6.07993	9.33891	-2.27277	0
1969:11	7.67415	7.01121	6.07304	9.19360	-2.27565	0
1969:12	7.67229	7.01481	6.07993	9.13422	-2.28281	0
1970:01	7.46851	6.82979	5.75574	9.11932	-2.28992	0
1970:02	7.47591	6.80572	5.73979	9.09751	-2.29557	0
1970:03	7.44833	6.91374	5.86079	9.30565	-2.30119	0
1970:04	7.35116	6.79347	5.89164	9.28108	-2.31647	0
1970:05	7.36201	6.89771	6.18621	9.46591	-2.31923	0
1970:06	7.32647	6.76389	6.06146	9.46700	-2.32197	0
1970:07	7.49832	6.99851	6.31173	9.54610	-2.33017	0
1970:08	7.49554	7.09340	6.47080	9.61086	-2.32882	0
1970:09	7.44950	6.93634	6.12249	9.46498	-2.32867	0
1970:10	7.60489	7.04491	6.16331	9.39549	-2.33945	0
1970:11	7.71512	7.06561	6.12249	9.27266	-2.34613	0
1970:12	7.81521	7.16935	6.14847	9.28192	-2.35276	0
1971:01	7.61579	6.85013	5.87493	9.23659	-2.33577	0
1971:02	7.41156	6.77308	5.60212	9.23805	-2.34227	0
1971:03	7.43426	6.73340	5.86930	9.35245	-2.35002	0
1971:04	7.39203	6.79459	6.05678	9.41581	-2.35694	0
1971:05	7.49832	6.91473	6.14204	9.51687	-2.36321	0
1971:06	7.46508	6.88038	6.08677	9.47647	-2.36945	0
1971:07	7.49276	7.00033	6.28972	9.68378	-2.37565	0
1971:08	7.56320	7.08506	6.47080	9.63037	-2.37688	0
1971:09	7.38956	6.89568	6.12468	9.53416	-2.37812	0
1971:10	7.59689	6.98193	6.10032	9.45164	-2.38304	0
1971:11	7.71110	6.95177	5.99645	9.34723	-2.38916	0

1971:12	7.69257	7.01661	6.08905	9.33706	-2.39402	0
1972:01	7.64012	6.91274	5.88332	9.28758	-2.40007	0
1972:02	7.47760	6.75344	5.81114	9.26369	-2.40488	0
1972:03	7.51480	6.77878	5.74300	9.42287	-2.40848	0
1972:04	7.35819	6.78785	6.05678	9.49635	-2.41800	0
1972:05	7.58883	6.98008	6.07304	9.53856	-2.42273	0
1972:06	7.52456	7.02198	6.18621	9.55308	-2.42861	0
1972:07	7.58325	7.08171	6.34388	9.73696	-2.42022	0
1972:08	7.43189	6.96414	6.25958	9.69054	-2.42836	0
1972:09	7.48324	6.84482	6.03548	9.60798	-2.41979	0
1972:10	7.58883	6.97915	6.11368	9.51281	-2.43353	0
1972:11	7.78197	6.99302	6.13556	9.41083	-2.43693	0
1972:12	7.88382	7.09672	6.20859	9.39474	-2.44144	0
1973:01	7.64826	6.80572	5.86930	9.36666	-2.44819	0
1973:02	7.58223	6.82002	5.84932	9.31299	-2.45489	0
1973:03	7.42476	6.66823	5.62040	9.52843	-2.46043	0
1973:04	7.57096	7.01571	6.15698	9.57373	-2.47906	0
1973:05	7.60240	6.92166	6.18826	9.57436	-2.46993	0
1973:06	7.50274	6.92952	6.22456	9.65483	-2.47531	0
1973:07	7.60688	7.01571	6.42811	9.73116	-2.47958	0
1973:08	7.55590	7.03174	6.46147	9.75742	-2.48278	0
1973:09	7.64204	7.01302	6.32615	9.66644	-2.49125	0
1973:10	7.64012	6.91572	6.11589	9.54295	-2.51110	0
1973:11	7.65823	6.82002	6.03548	9.44944	-2.49068	0
1973:12	7.67322	6.89972	6.03787	9.25254	-2.36244	0
1974:01	7.38275	6.59441	5.56834	9.36014	-2.38163	0
1974:02	7.31522	6.49979	5.70044	9.28804	-2.22413	0
1974:03	7.34472	6.58479	5.71373	9.42714	-2.23295	0
1974:04	7.23129	6.61204	5.99396	9.51819	-2.17118	0
1974:05	7.45645	6.81344	6.02345	9.57880	-2.18521	0
1974:06	7.49443	6.78333	6.05444	9.61707	-2.19538	0

1974:07	7.48381	6.80239	6.24611	9.65899	-2.20454	0
1974:08	7.54274	6.96319	6.39693	9.72585	-2.22380	0
1974:09	7.60290	6.98101	6.12905	9.59676	-2.23467	0
1974:10	7.63868	6.82329	6.09357	9.52923	-2.25430	0
1974:11	7.64588	6.82437	6.02102	9.43596	-2.12563	0
1974:12	7.62608	6.85961	5.99146	9.43891	-2.14028	0
1975:01	7.36328	6.49828	5.62762	9.32803	-2.01720	0
1975:02	7.21229	6.40853	5.71043	9.31434	-2.03374	0
1975:03	7.40974	6.65544	5.94280	9.44438	-2.05324	0
1975:04	7.23129	6.45047	5.63121	9.47409	-2.09113	0
1975:05	7.32581	6.67330	6.09131	9.61614	-2.13211	0
1975:06	7.25912	6.67203	6.01372	9.63135	-2.15126	0
1975:07	7.27379	6.68835	6.03069	9.65194	-2.16142	0
1975:08	7.34148	6.78446	6.23637	9.73536	-2.16717	0
1975:09	7.41216	6.64509	5.97381	9.60076	-2.17575	0
1975:10	7.35308	6.59578	5.84354	9.55421	-2.18988	0
1975:11	7.55224	6.75577	5.96871	9.46141	-2.20174	0
1975:12	7.69576	6.90174	6.15273	9.46931	-2.16044	0
1976:01	7.29506	6.55678	5.58350	9.40730	-2.17337	0
1976:02	7.41156	6.52796	5.74300	9.38581	-2.18614	0
1976:03	7.24922	6.50877	5.70378	9.51170	-2.19146	0
1976:04	7.24065	6.46614	5.92158	9.57616	-2.21053	0
1976:05	7.33302	6.64769	6.02102	9.67477	-2.22155	0
1976:06	7.17702	6.46770	5.77455	9.65432	-2.22669	0
1976:07	7.33041	6.71901	6.12687	9.71372	-2.21563	0
1976:08	7.19068	6.61740	6.05678	9.79395	-2.22960	0
1976:09	7.39449	6.64249	5.84644	9.64251	-2.24277	0
1976:10	7.46623	6.71538	6.04263	9.58885	-2.24149	0
1976:11	7.57968	6.69703	5.84064	9.48090	-2.25546	0
1976:12	7.72930	6.89366	5.91350	9.41475	-2.26865	0
1977:01	7.40732	6.57088	5.67332	9.39033	-2.28819	0

1977:02	7.24494	6.34036	5.41165	9.39499	-2.29857	0
1977:03	7.25205	6.42325	5.58350	9.54917	-2.31403	0
1977:04	7.24637	6.51915	5.82305	9.56409	-2.27793	0
1977:05	7.23993	6.60935	5.69709	9.63476	-2.27276	0
1977:06	7.32647	6.73340	5.95584	9.73826	-2.28103	0
1977:07	7.33172	6.78897	6.17170	9.76198	-2.30422	0
1977:08	7.40428	6.74759	6.15910	9.78098	-2.37907	0
1977:09	7.32317	6.65157	5.80513	9.69412	-2.38798	0
1977:10	7.42952	6.72263	5.96871	9.61374	-2.39993	0
1977:11	7.60090	6.79010	5.91350	9.51959	-2.40771	0
1977:12	7.70301	6.95273	6.06611	9.53546	-2.41541	0
1978:01	7.57866	6.79010	5.90263	9.42440	-2.42540	0
1978:02	7.28756	6.43935	5.52146	9.35945	-2.42642	0
1978:03	7.35436	6.69456	5.87212	9.61720	-2.44464	0
1978:04	7.28551	6.61473	5.71703	9.60468	-2.46516	0
1978:05	7.27656	6.62539	5.93754	9.71505	-2.47020	0
1978:06	7.39142	6.76273	6.08677	9.73400	-2.47181	0
1978:07	7.41276	6.88755	6.21461	9.79879	-2.47277	0
1978:08	7.40123	6.86589	6.23637	9.84453	-2.48170	0
1978:09	7.40428	6.75227	5.95064	9.75516	-2.48390	0
1978:10	7.42833	6.68211	5.90263	9.68315	-2.49199	0
1978:11	7.62560	6.84801	6.06843	9.59866	-2.46234	0
1978:12	7.72400	6.91771	5.96615	9.52705	-2.46781	0
1979:01	7.50274	6.67960	5.72359	9.32331	-2.47149	0
1979:02	7.27586	6.46614	5.44674	9.40137	-2.46097	0
1979:03	7.47421	6.67708	5.83481	9.59717	-2.43544	0
1979:04	7.28688	6.62007	5.79606	9.65387	-2.40370	0
1979:05	7.34987	6.69580	5.97635	9.73288	-2.39928	0
1979:06	7.26613	6.57368	5.87212	9.72663	-2.21877	0
1979:07	7.26333	6.74641	5.95324	9.76618	-2.17031	0
1979:08	7.34859	6.83626	6.13773	9.81787	-2.18043	0

1979:09	7.40550	6.72623	6.11589	9.75202	-2.19534	0
1979:10	7.41035	6.63595	5.92158	9.73560	-2.21525	0
1979:11	7.60887	6.77992	5.99396	9.64082	-2.22842	0
1979:12	7.69939	6.98193	6.14419	9.62648	-2.22932	0
1980:01	7.41758	6.61740	5.72359	9.54874	-2.26553	0
1980:02	7.21597	6.38519	5.57215	9.58039	-2.23386	0
1980:03	7.31721	6.57925	5.77765	9.68999	-2.23143	0
1980:04	7.21524	6.47080	5.73657	9.71625	-2.19198	0
1980:05	7.28139	6.63988	6.04973	9.80461	-2.20149	0
1980:06	7.32778	6.70930	5.99894	9.77292	-2.19055	0
1980:07	7.28619	6.69332	6.00635	9.81460	-2.20962	0
1980:08	7.34730	6.78559	6.14419	9.87102	-2.22383	0
1980:09	7.34472	6.68835	5.94280	9.79390	-2.24191	0
1980:10	7.51043	6.75693	5.91080	9.79099	-2.26151	0
1980:11	7.45991	6.71538	5.93489	9.68396	-2.28343	0
1980:12	7.57096	6.81454	5.97126	9.66434	-2.27503	0
1981:01	7.29573	6.55678	5.64897	9.63076	-2.25608	0
1981:02	7.28482	6.53814	5.75574	9.61126	-2.26334	0
1981:03	7.34084	6.53379	5.77144	9.73187	-2.14853	0
1981:04	7.24708	6.57088	5.88053	9.73234	-2.16142	0
1981:05	7.32778	6.70196	5.93489	9.80621	-2.18046	0
1981:06	7.23346	6.60123	5.94542	9.77332	-2.17278	0
1981:07	7.40306	6.77537	6.07074	9.83387	-2.12764	0
1981:08	7.31986	6.72022	6.22654	9.87576	-2.08353	0
1981:09	7.42714	6.70686	6.05912	9.79384	-2.09376	0
1981:10	7.56941	6.84801	6.17170	9.79339	-2.11463	0
1981:11	7.53262	6.66185	5.91350	9.71087	-2.11156	0
1981:12	7.45356	6.71296	5.85507	9.51370	-2.14585	0
1982:01	7.28345	6.38856	5.47227	9.51790	-2.18258	0
1982:02	7.27586	6.51175	5.65249	9.65931	-2.22489	0
1982:03	7.28345	6.49224	5.78074	9.76181	-2.21789	0

1982:04	7.21891	6.51619	5.84644	9.80433	-2.19560	0
1982:05	7.30452	6.62672	6.01616	9.82990	-2.19549	0
1982:06	7.35116	6.70319	6.01859	9.83943	-2.15888	0
1982:07	7.30519	6.76504	6.20658	9.93634	-2.16484	0
1982:08	7.42893	6.83841	6.28040	9.95418	-2.14381	0
1982:09	7.37400	6.68211	5.98141	9.85183	-2.12799	0
1982:10	7.52294	6.85646	6.15273	9.83457	-2.13736	0
1982:11	7.59990	6.71538	5.95324	9.72723	-2.14175	0
1982:12	7.63964	6.81454	6.01859	9.71420	-2.14568	0
1983:01	7.30921	6.42811	5.63835	9.69468	-2.18382	0
1983:02	6.96319	6.05444	5.70378	9.64930	-2.17457	1
1983:03	7.10497	6.16331	5.76205	9.81509	-2.17909	1
1983:04	7.06305	6.32077	5.96871	9.78656	-2.13288	1
1983:05	7.11964	6.32615	5.98645	9.86293	-2.13733	1
1983:06	6.98101	6.18002	5.82008	9.86068	-2.13973	1
1983:07	7.06817	6.37502	6.16752	9.95214	-2.11977	1
1983:08	7.03791	6.42162	6.04501	9.93813	-2.12496	1
1983:09	7.26333	6.42649	6.20456	9.83943	-2.12963	1
1983:10	7.30452	6.49527	6.15486	9.86475	-2.13316	1
1983:11	7.30182	6.25190	5.90808	9.77018	-2.13693	1
1983:12	7.32185	6.37161	5.84354	9.71662	-2.13956	1
1984:01	7.21303	6.18002	5.69036	9.69425	-2.13897	1
1984:02	7.06048	6.07304	5.76519	9.72137	-2.16459	1
1984:03	7.15618	6.24028	5.85507	9.82763	-2.15645	1
1984:04	7.01212	6.30628	5.92693	9.89136	-2.15973	1
1984:05	7.16781	6.37332	6.08905	9.88247	-2.16443	1
1984:06	7.07750	6.25767	6.14204	9.90229	-2.16476	1
1984:07	7.10824	6.39859	6.15698	9.97516	-2.16338	1
1984:08	7.15774	6.46770	6.25575	9.98165	-2.16459	1
1984:09	7.27517	6.46614	6.06146	9.91319	-2.17074	1
1984:10	7.36201	6.46303	6.01127	9.89988	-2.15016	1

1984:11	7.45991	6.56667	6.19441	9.82898	-2.15394	1
1984:12	7.47477	6.58064	6.19644	9.80637	-2.15359	1

```
graph(footer="Figure 9.1. Front and rear seat passengers killed and seriously injured\\"+$
 "in the UK in the period 1969-1984",key=attached) 2
# front
# rear
```

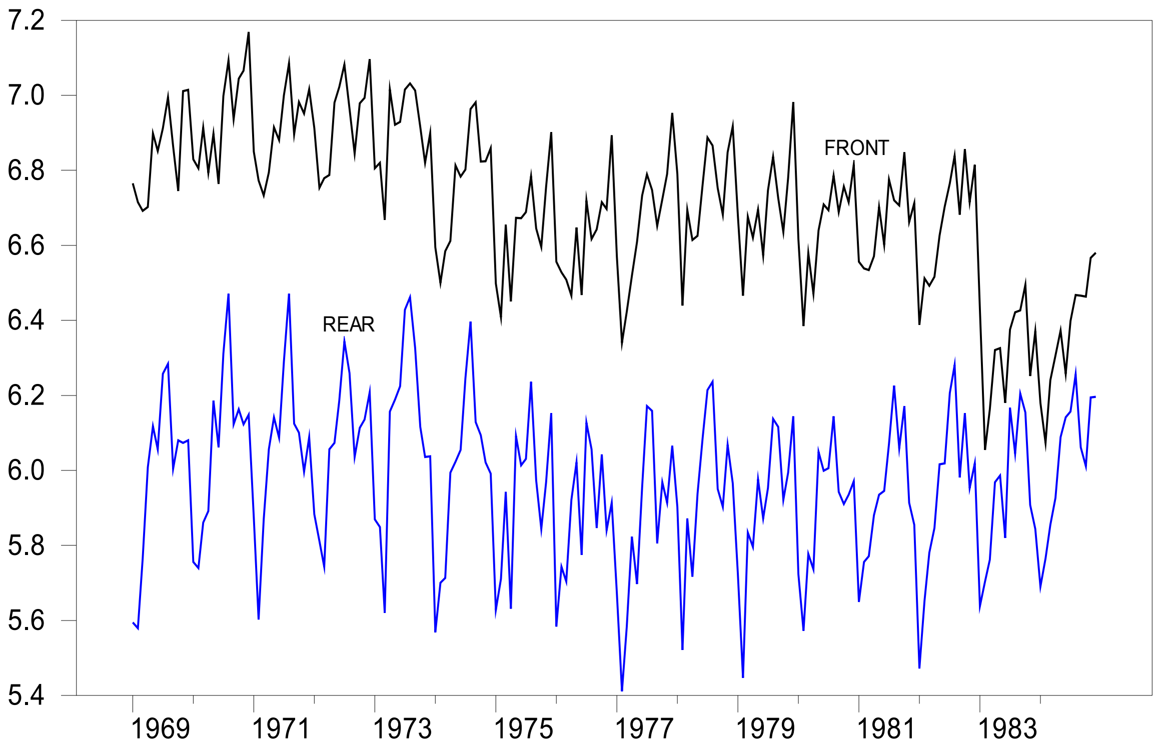


Figure 9.1. Front and rear seat passengers killed and seriously injured in the UK in the period 1969-1984

Generate the basic seasonal and local level component models.

```
@SeasonalDLM(type=additive,a=as,c=cs,f=fs)
@LocalDLM(a=al,c=cl,f=fl)
compute a1=(al~\as)
compute f1=(fl~\fs)
compute c1=(cl~~cs)
```

Because the two series will have separately estimated level and seasonal components, we have to "double" all the component matrices

up: the A matrix will be 2N x 2N, the F matrix will be 2N x 2M and the

C matrix will be 2N x 2. There are several ways to organize the

combined states. This one is most convenient, because it keeps the contemporaneously correlated shocks in consecutive positions. What

this does is to interleave the states and the shocks.

```
dec rect a(%rows(a1)*2,%rows(a1)*2)

ewise a(i,j)=%if(%clock(i,2)==%clock(j,2),a1((i+1)/2,(j+1)/2),0.0)

dec rect f(%rows(f1)*2,%cols(f1)*2)

ewise f(i,j)=%if(%clock(i,2)==%clock(j,2),f1((i+1)/2,(j+1)/2),0.0)

dec rect c(%rows(a1)*2,2)

ewise c(i,j)=%if(%clock(i,2)==j,c1((i+1)/2,1),0.0)
```

The component variances will now be 2 x 2 symmetric matrices

```
dec symm sigmaeps(2,2) sigmaxi(2,2) sigmaomega(2,2)

dec symm sw
```

sigmaxi and sigmaomega are modeled in packed lower triangular form

* since it's quite possible for one of them to go non-positive definite.

This function takes the current packed forms and converts them into

* standard covariance matrices, then concatenates them diagonally to

* form the overall covariance matrix for the shocks.

```
compute sigmaeps=%mscalar(.005),pxi=%mscalar(.0003),pomega=%mscalar(0.0)

dec vect bpetrol(2) bkilos(2) blaw(2)

dec vect[frml] explan(2)

frml explan(1) = bpetrol(1)*petrol+bkilos(1)*kilos+blaw(1)*seatbelt

frml explan(2) = bpetrol(2)*petrol+bkilos(2)*kilos+blaw(2)*seatbelt
```

Estimate the unconstrained model

```
nonlin sigmaeps pxi pomega bpetrol bkilos blaw

dlm(start=(sw=%%DLMSetupSW()),sw=sw,a=a,c=c,f=f,sv=sigmaeps,$

  y=||front-explan(1),rear-explan(2)||,exact,$

  method=bfgs) / xstates
```

NL6. NONLIN Parameter BPETROL(1) Has Not Been Initialized. Trying 0

NL6. NONLIN Parameter BPETROL(2) Has Not Been Initialized. Trying 0

NL6. NONLIN Parameter BKILOS(1) Has Not Been Initialized. Trying 0

NL6. NONLIN Parameter BKILOS(2) Has Not Been Initialized. Trying 0

NL6. NONLIN Parameter BLAW(1) Has Not Been Initialized. Trying 0

NL6. NONLIN Parameter BLAW(2) Has Not Been Initialized. Trying 0

DLM - Estimation by BFGS

Convergence in 74 Iterations. Final criterion was 0.0000025 <= 0.0000100

Monthly Data From 1969:01 To 1984:12

Usable Observations 192

Rank of Observables 360

Log Likelihood 388.4543

Variable	Coeff	Std Error	T-Stat	Signif
**				
1. SIGMAEPS(1,1)	0.005302612	0.000679341	7.80552	0.00000000
2. SIGMAEPS(2,1)	0.004470098	0.000677666	6.59631	0.00000000
3. SIGMAEPS(2,2)	0.008510631	0.001003434	8.48150	0.00000000
4. PXI(1,1)	0.014751922	0.003773862	3.90897	0.00009269
5. PXI(2,1)	0.013369416	0.003656099	3.65674	0.00025544
6. PXI(2,2)	0.004630952	0.002335905	1.98251	0.04742232
7. POMEGA(1,1)	0.004065081	0.004105123	0.99025	0.32205388
8. POMEGA(2,1)	-0.001798258	0.004634612	-0.38801	0.69801150
9. POMEGA(2,2)	-0.000000961	0.003212541	-2.99040e-004	0.99976140
10. BPETROL(1)	-0.320266000	0.104615070	-3.06138	0.00220323
11. BPETROL(2)	-0.087544832	0.109044021	-0.80284	0.42206759
12. BKILOS(1)	0.154337194	0.117943700	1.30857	0.19068118
13. BKILOS(2)	0.524693296	0.143747833	3.65010	0.00026214
14. BLAW(1)	-0.336651724	0.044861996	-7.50416	0.00000000
15. BLAW(2)	0.001493804	0.047909307	0.03118	0.97512612

Re-estimate with the seasonal variance zeroed out

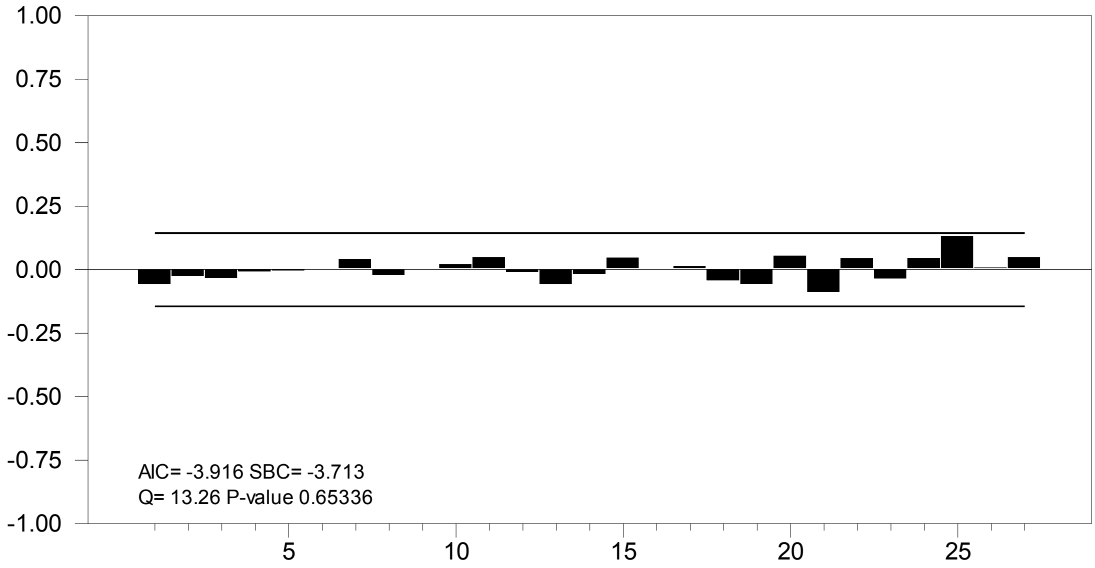
```
compute pomega=%zeros(2,2)
nonlin sigmaeps pxi bpetrol bkilos blaw
dlm(start=(sw=%%DLMSetupSW()),sw=sw,a=a,c=c,f=f,sv=sigmaeps,$
  y=||front-explan(1),rear-explan(2)||,exact,$
  method=bfgs,vhat=vhat,svhat=svhat)
```

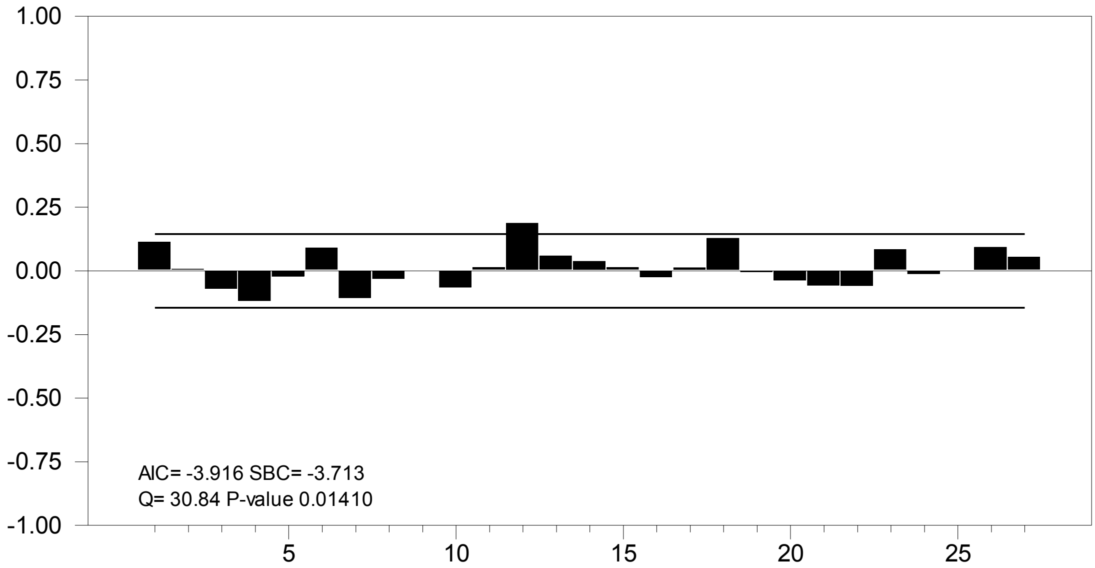
```
DLM - Estimation by BFGS
Convergence in    17 Iterations. Final criterion was  0.0000044 <=  0.0000100
Monthly Data From 1969:01 To 1984:12
Usable Observations                  192
Rank of Observables                  360
Log Likelihood                  387.9591

   Variable                     Coeff      Std Error      T-Stat      Signif
******************************************************************************
1.  SIGMAEPS(1,1)             0.005409167  0.000610272      8.86353  0.00000000
2.  SIGMAEPS(2,1)             0.004432537  0.000603621      7.34325  0.00000000
3.  SIGMAEPS(2,2)             0.008527973  0.000863138      9.88020  0.00000000
4.  PXI(1,1)                  0.014662508  0.003369986      4.35091  0.00001356
5.  PXI(2,1)                  0.013346312  0.003309292      4.03298  0.00005507
6.  PXI(2,2)                  0.004606584  0.001660310      2.77453  0.00552813
7.  BPETROL(1)               -0.318029915  0.067892935     -4.68429  0.00000281
8.  BPETROL(2)               -0.087513473  0.069510245     -1.25900  0.20802994
9.  BKILOS(1)                 0.152828801  0.085632800      1.78470  0.07431010
10. BKILOS(2)                 0.525829823  0.100774354      5.21789  0.00000018
11. BLAW(1)                  -0.337321602  0.042807396     -7.87998  0.00000000
12. BLAW(2)                   0.000852237  0.046492205      0.01833  0.98537500
```

This standardizes the residuals using the inverse Choleski factor (a

* matrix generalization of the reciprocal square root). We can apply

* standard diagnostics to each component of this.





```
dec vect stdres
set r1 = stdres=inv(%decomp(svhat))*vhat,stdres(1)
set r2 = stdres=inv(%decomp(svhat))*vhat,stdres(2)
@STAMPDiags r1
@STAMPDiags r2
```

```
State Space Model Diagnostics
          Statistic Sig. Level
Q(27-11)      30.84     0.0141
Normality      0.03     0.9828
H(64)          1.15     0.5749
```

```
State Space Model Diagnostics
          Statistic Sig. Level
Q(27-11)      13.26     0.6534
Normality      1.52     0.4669
H(64)          0.95     0.8292
```

```
disp "H=" #.####### sigmaeps
disp "Q=" #.####### sigmaxi
```

```
H=
0.0054092
0.0044325 0.0085280

Q=
0.0002150
0.0001957 0.0001993
dlm(start=(sw=%%DLMSetupSW()),sw=sw,a=a,c=c,f=f,sv=sigmaeps,$
```

```
  y=||front-explan(1),rear-explan(2)||,exact,$
  type=smoothed,what=what) / xstates

set lshock1 = what(t)(1)
set lshock2 = what(t)(2)
linreg lshock1
# constant lshock2

Linear Regression - Estimation by Least Squares
Dependent Variable LSHOCK1
Monthly Data From 1969:01 To 1984:12
Usable Observations                    192
Degrees of Freedom                     190
Centered R^2                    0.9682479
R-Bar^2                         0.9680808
Uncentered R^2                  0.9698180
Mean of Dependent Variable       -0.001003208
Std Error of Dependent Variable   0.004409872
Standard Error of Estimate       0.000787866
Sum of Squared Residuals         0.0001179392
Regression F(1,190)              5793.8513
Significance Level of F          0.0000000
Log Likelihood                   1100.6361
Durbin-Watson Statistic             0.1568

   Variable                     Coeff      Std Error      T-Stat      Signif
******************************************************************************
1.  Constant                 0.0003497169 0.0000595727      5.87042  0.00000002
2.  LSHOCK2                  1.0755086488 0.0141296120     76.11735  0.00000000
```

```
scatter(footer="Figure 9.2 Level disturbances for rear vs front seat",$
  line=%beta)
# lshock2 lshock1
```

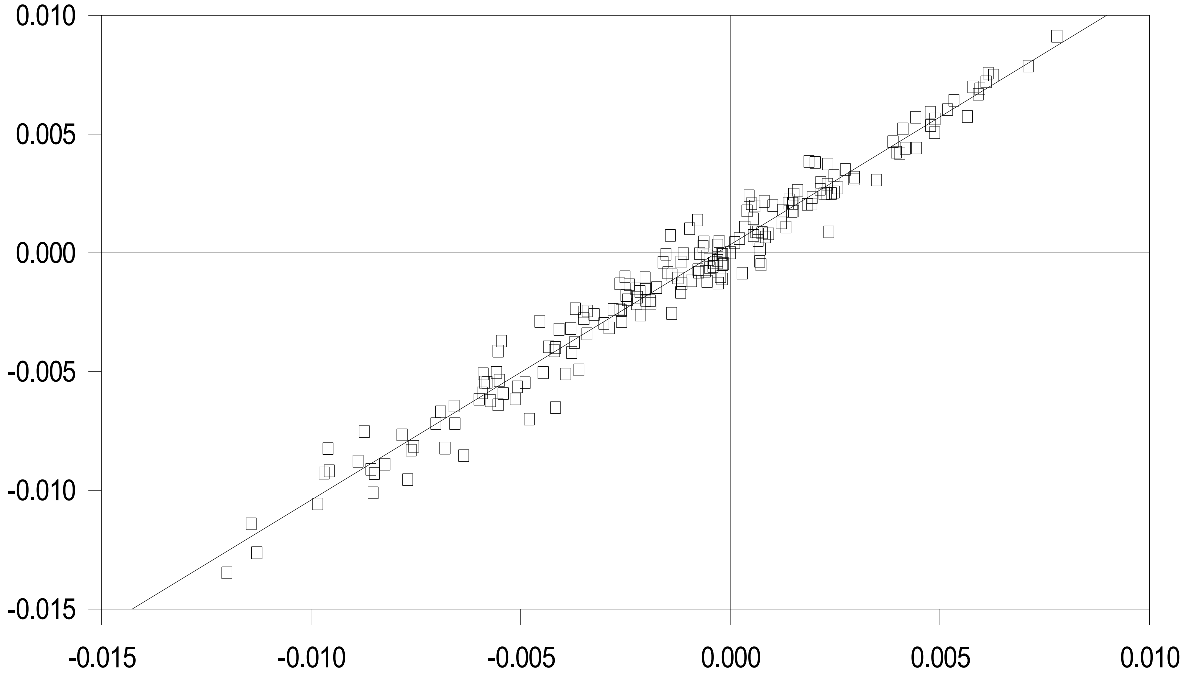


Figure 9.2 Level disturbances for rear vs front seat

```
set level1 = xstates(t)(1)
set level2 = xstates(t)(2)

spgraph(vfields=2,samesize,$
 footer="Figure 9.3 Levels of treatment and control series in the SUR model")
graph(key=upright,klabels=||"level front"||)
# level1

graph(key=upright,klabels=||"level rear"||)
# level2
spgraph(done)
```

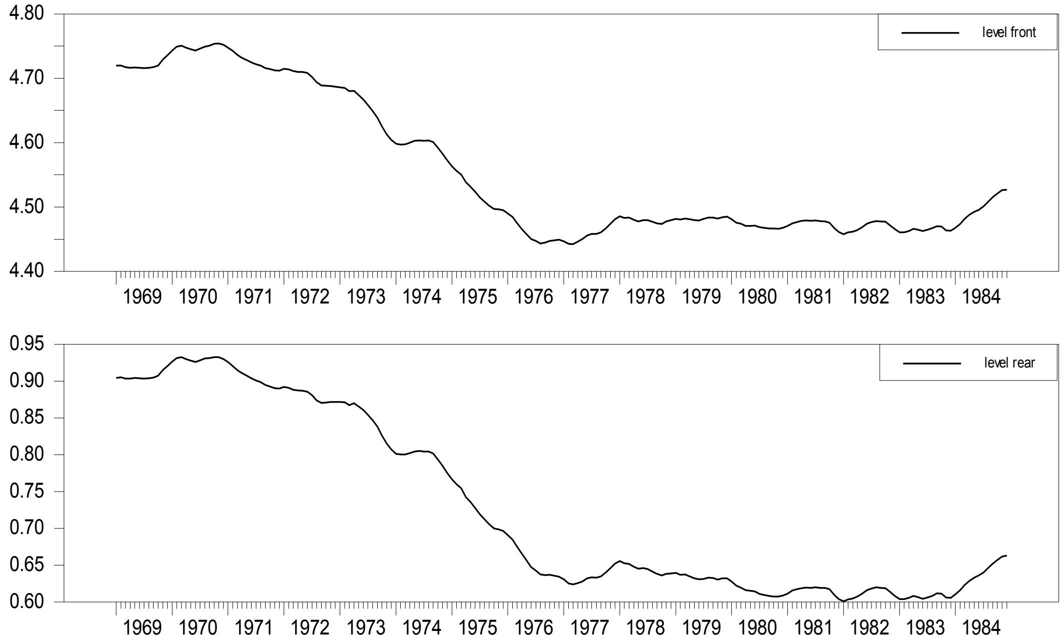


Figure 9.3 Levels of treatment and control series in the SUR model

scatter(footer="Figure 9.4 Level of treatment vs level of control")

level2 level1

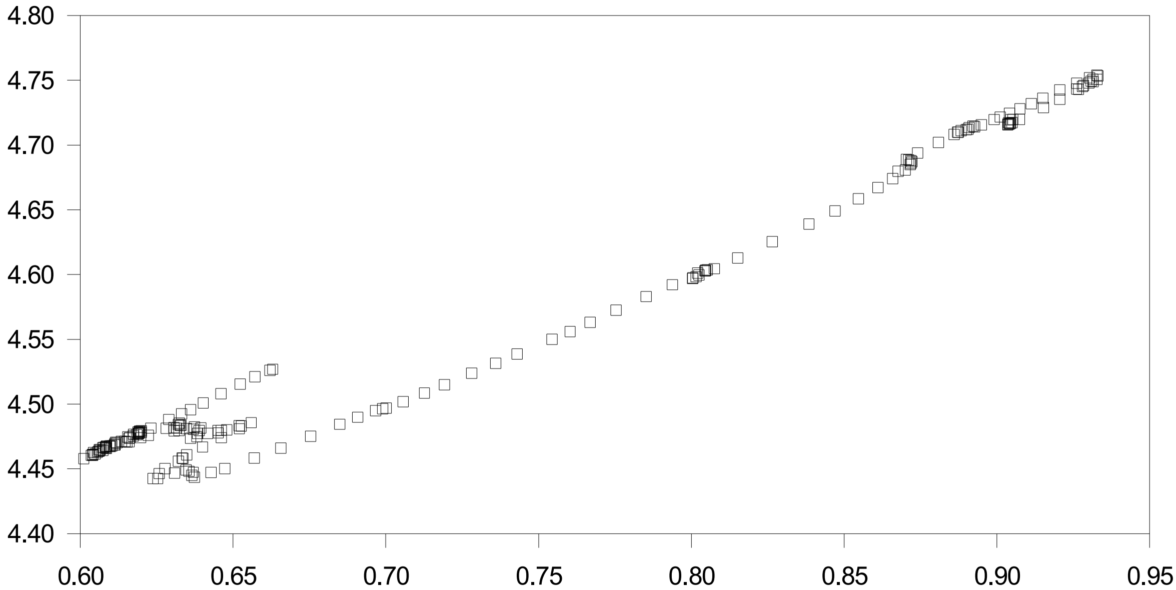


Figure 9.4 Level of treatment vs level of control

```
Re-estimation, restricting level disturbances to rank one and
* eliminating coefficient on the seatbelt term.
*
nonlin sigmaeps pxi bpetrol bkilos blaw blaw(2)=0.0 pxi(2,2)=0.0
dlm(start=(sw=%%DLMSetupSW()),sw=sw,a=a,c=c,f=f,sv=sigmaeps,$
  y=||front-explan(1),rear-explan(2)||,exact,$
  method=bfgs)
dlm(start=(sw=%%DLMSetupSW()),sw=sw,a=a,c=c,f=f,sv=sigmaeps,$
  y=||front-explan(1),rear-explan(2)||,exact,$
  type=smoothed,what=what) / xstates

nonlin sigmaeps pxi bpetrol bkilos blaw blaw(2)=0.0 pxi(2,2)=0.0
dlm(start=(sw=%%DLMSetupSW()),sw=sw,a=a,c=c,f=f,sv=sigmaeps,$
  y=||front-explan(1),rear-explan(2)||,exact,$
  method=bfgs)
dlm(start=(sw=%%DLMSetupSW()),sw=sw,a=a,c=c,f=f,sv=sigmaeps,$
  y=||front-explan(1),rear-explan(2)||,exact,$
  type=smoothed,what=what) / xstates

DLM - Estimation by BFGS
Convergence in    25 Iterations. Final criterion was  0.0000096 <=  0.0000100
Monthly Data From 1969:01 To 1984:12
Usable Observations                    192
Rank of Observables                    360
Log Likelihood                    385.9659

   Variable                    Coeff      Std Error      T-Stat      Signif
*******************************************************************************
**
1.  SIGMAEPS(1,1)              0.005433242  0.000436311     12.45269  0.00000000
2.  SIGMAEPS(2,1)              0.004377075  0.000290141     15.08601  0.00000000
```

3. SIGMAEPS(2,2)	0.008783080	0.000572940	15.32983	0.00000000
4. PXI(1,1)	0.014462289	0.003485918	4.14878	0.00003343
5. PXI(2,1)	0.013843980	0.003354440	4.12706	0.00003674
6. PXI(2,2)	0.000000000	0.000000000	0.00000	0.00000000
7. BPETROL(1)	-0.320194980	0.096411092	-3.32114	0.00089650
8. BPETROL(2)	-0.091019606	0.099661993	-0.91328	0.36109371
9. BKILOS(1)	0.176273004	0.119301036	1.47755	0.13952881
10. BKILOS(2)	0.420190879	0.134777568	3.11766	0.00182292
11. BLAW(1)	-0.335841160	0.020201738	-16.62437	0.00000000
12. BLAW(2)	0.000000000	0.000000000	0.00000	0.00000000

```
set level1 = xstates(t)(1)
set level2 = xstates(t)(2)
scatter(footer="Figure 9.6 Level of treatment vs level of control")
# level2 level1
```


```
set level1 = xstates(t)(1)
set level2 = xstates(t)(2)
scatter(footer="Figure 9.6 Level of treatment vs level of control")
# level2 level1
```

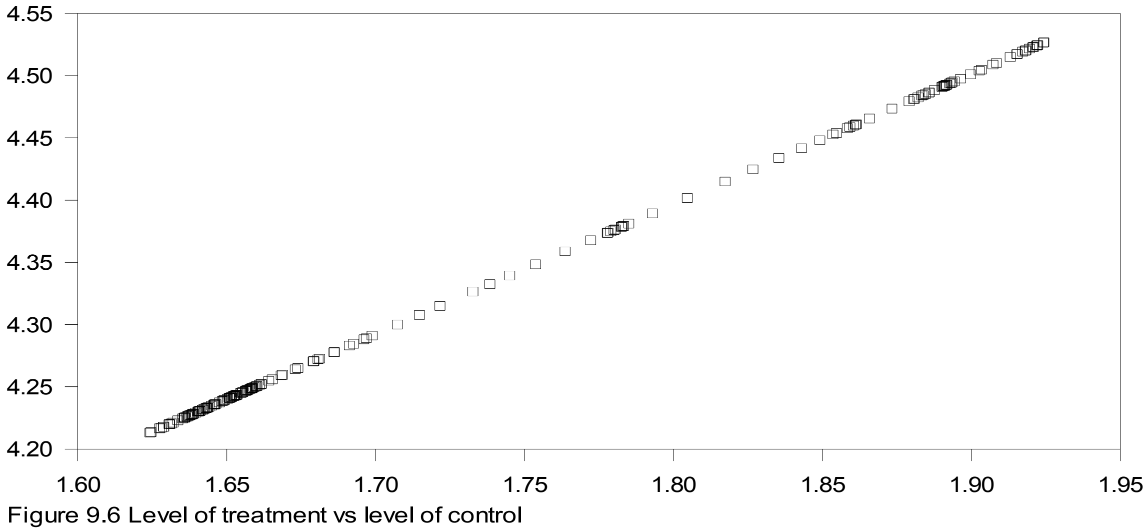



Figure 9.6 Level of treatment vs level of control

```
spgraph(vfields=2,samesize,$
 footer="Figure 9.7 Levels of treatment and control series in the rank one model")
graph(key=upright,klabels=||"level front"||)
# level1
graph(key=upright,klabels=||"level rear"||)
# level2
spgraph(done)
```

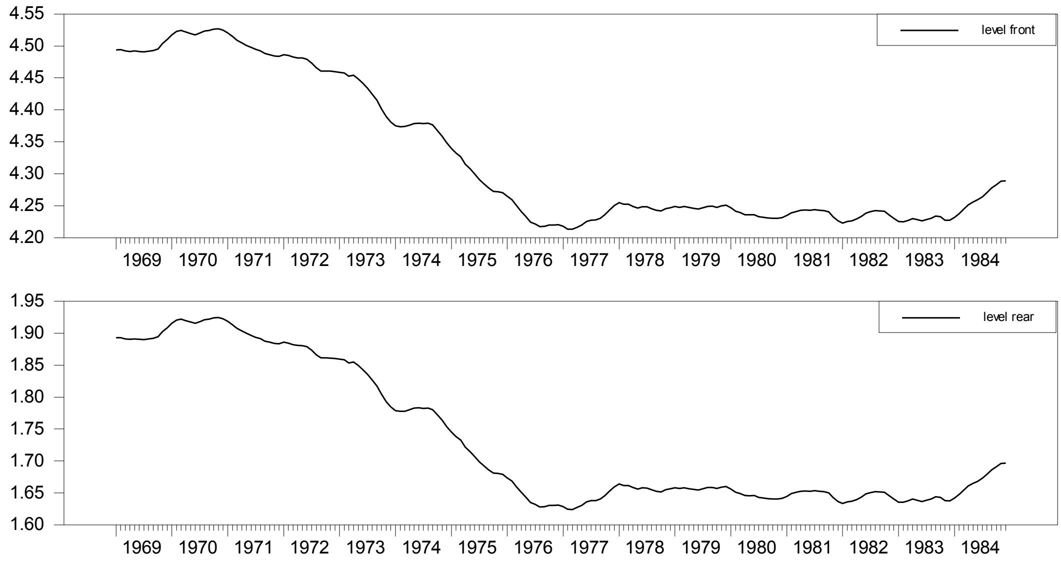


Figure 9.7 Levels of treatment and control series in the rank one model

```
set levelplus1 = level1+blaw(1)*seatbelt
spgraph(vfields=2,samesize,$
 footer="Figure 9.8 Levels of treatment plus intervention\\and control series in the rank one model")
graph(key=upright,klabels=||"level front"||)
# levelplus1
graph(key=upright,klabels=||"level rear"||)
# level2
spgraph(done)
```

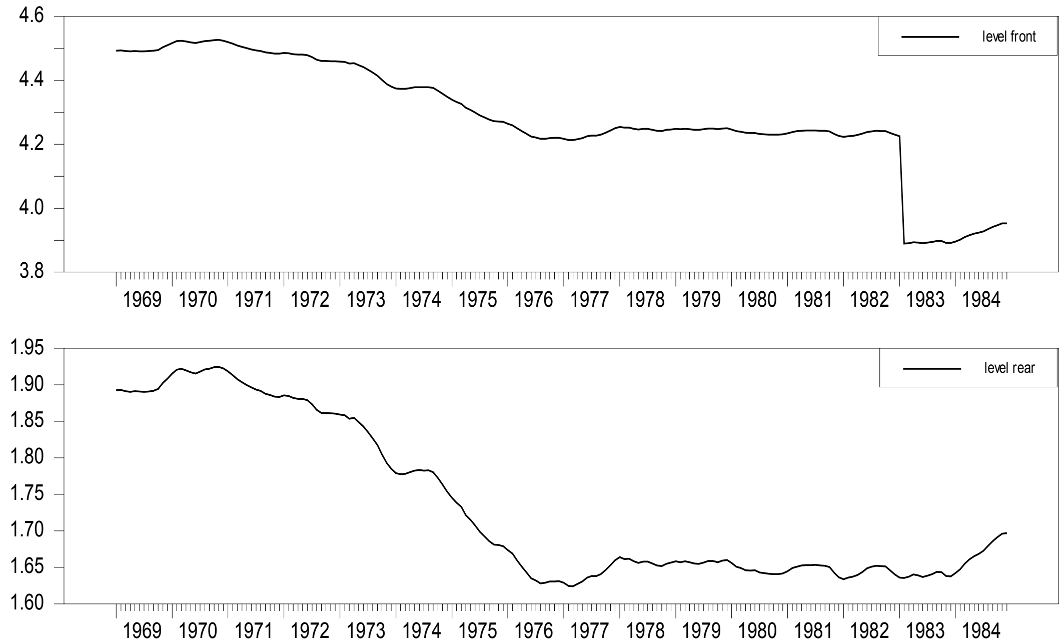


Figure 9.8 Levels of treatment plus intervention and control series in the rank one model

```
set seas1 = xstates(t)(3)
set seas2 = xstates(t)(4)
spgraph(vfields=2,samesize,$
  footer="Figure 9.9 Deterministic seasonal of treatment and control series, rank one model")
graph(key=upleft,klabels=||"seasonal front"||)
# seas1
graph(key=upleft,klabels=||"seasonal rear"||)
# seas2
spgraph(done)
```

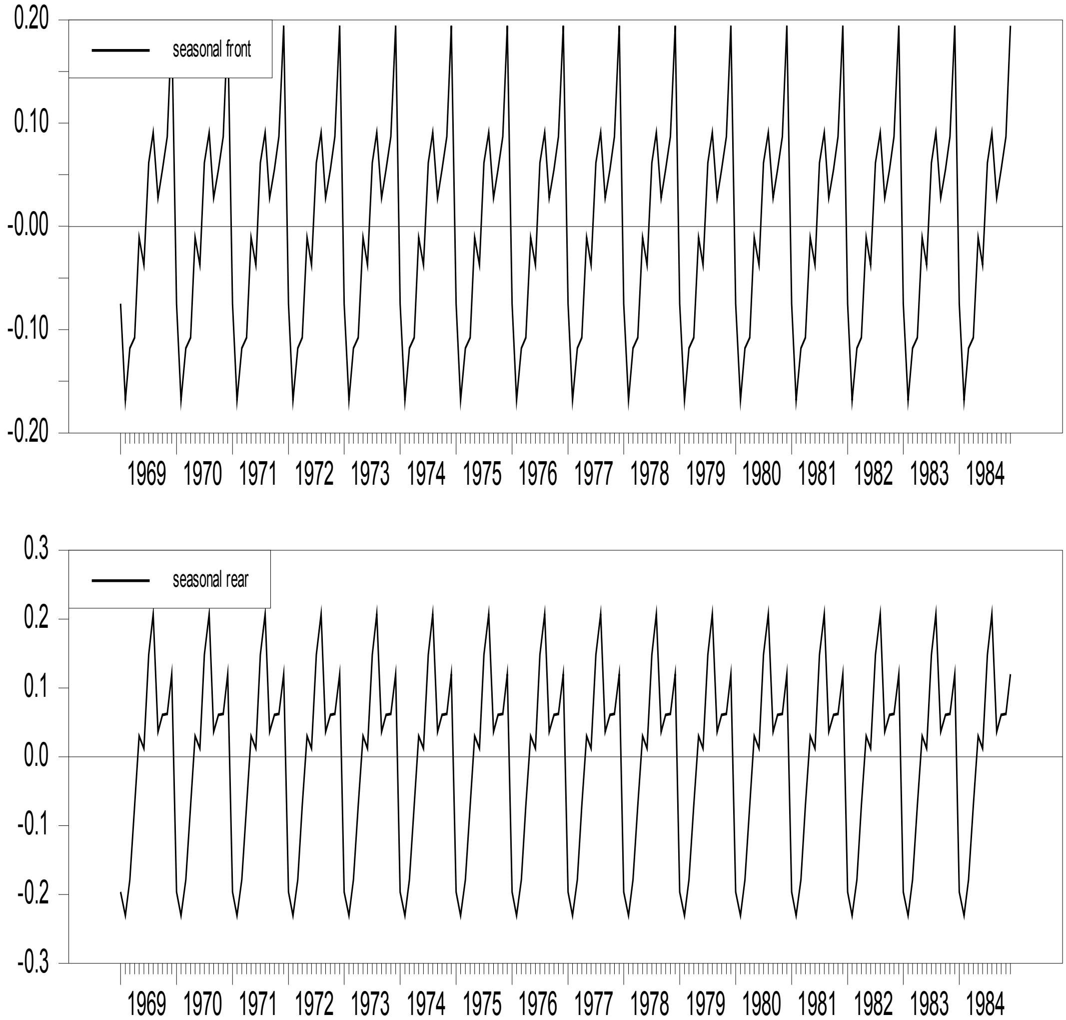


Figure 9.9 Deterministic seasonal of treatment and control series, rank one model

References

1. Jacques J. F. Commandeur, Siem Jan Koopman, (2007), *An introduction to state space time series analysis*, Oxford university press,
2. RATS Procedure and Example Files: https://estima.com/ARCH-GARCH.shtml