Appendix

Data structure

Day	Month	Year	Dollar/Pound	Yen/Pound	Deutsche mark/Pound
3	1	1986	1.438	291.5	3.5425
6	1	1986	1.433	290	3.515
7	1	1986	1.443	290	3.515
8	1	1986	1.4598	291.5	3.545
9	1	1986	1.471	293.5	3.555
10	1	1986	1.4505	294.5	3.5725
13	1	1986	1.445	295	3.5725
14	1	1986	1.4375	291.75	3.5557
15	1	1986	1.4425	291.75	3.55
16	1	1986	1.4355	291	3.5475
17	1	1986	1.4375	290.75	3.5425
20	1	1986	1.4375	286.5	3.4975
21	1	1986	1.411	284.75	3.4575
22	1	1986	1.397	281	3.4125
23	1	1986	1.3865	279.5	3.395
24	1	1986	1.3915	273.25	3.372
27	1	1986	1.3885	272.25	3.337
28	1	1986	1.407	275.75	3.38
29	1	1986	1.4022	272	3.3475
30	1	1986	1.4145	272.25	3.355
31	1	1986	1.4122	272.5	3.375
.	.	.	.	.	.
1	4	1994	1.474	152.5375	2.4996
4	4	1994	1.468	151.2909	2.4892
5	4	1994	1.4625	151.8565	2.4987
6	4	1994	1.469	153.49	2.5173
7	4	1994	1.473	153.778	2.5204
8	4	1994	1.4775	155.132	2.52645
11	4	1994	1.4705	152.27	2.517
12	4	1994	1.4755	152.43	2.5356

Programming preliminary result and statistical modelling

```
% program ch31.m
% investigate distributions of exchange rates
% using the US dollar as the reference currency
%
getfile dpypmp
y = getnum;
n = size(y,1);
day = (1:n)';
pd = 1./y(:,4);                 % pound/dollar
yd = (y(:,5)/100).*pd;          % 100 yen/dollar
md = y(:,6).*pd;                % DM/dollar
y = [pd yd md];
putnum(y)
fn = {'pound/dollar' '100 yen/dollar' 'DM/dollar'};
putfn(fn)
putdn('Exchange rates: 3 Jan 86 - 12 Apr 94')

% Table 3.1: numerical summary of raw exchange rates
describe

% Figure 3.1: plot of raw exchange rates
xmax = 1.2*n;
xmin = 0;
ymax = max([max(pd),max(yd),max(md)]);
ymin = min([min(pd),min(yd),min(md)]);
yr = ymax-ymin;
ymax = ymax+0.05*yr;
ymin = ymin-0.05*yr;
figure
axes('Position',[0.05 0.1 0.91 0.82])
plot(day,pd,'k-',day,yd,'r-',day,md,'b-')
text(xmin-0.05*n,ymax+0.04*yr,'Exchange rate')
xcoord = zeros(3,1)+n+1;
ycoord = [pd(n) ; yd(n) ; md(n)];
lab = str2mat(fn{1},fn{2},fn{3});
text(xcoord,ycoord,lab)
xlabel('trading day')
axis([xmin xmax ymin ymax])
%
% form samples comprising 100 successive trading days
% and plot log(sd) versus log(mean)
% to show that the data need transforming (Figure 3.2)
pd1 = reshape(pd(1:2100),100,21);
yd1 = reshape(yd(1:2100),100,21);
md1 = reshape(md(1:2100),100,21);
cd = [pd1 yd1 md1];
```

```
figure
axes('Position',[0.06 0.1 0.9 0.82])
x = log(mean(cd));
y = log(std(cd));
xmin = min(x);
xmax = max(x);
xr = xmax-xmin;
xmin = xmin-0.05*xr;
xmax = xmax+0.05*xr;
ymin = min(y);
ymax = max(y);
yr = ymax-ymin;
ymin = ymin-0.05*yr;
ymax = ymax+0.05*yr;
plot(x,y,'k.')
text(xmin-0.06*xr,ymax+0.05*yr,'log of standard deviation')
xlabel('log of mean exchange rate')
axis([xmin xmax ymin ymax])
%
% take log transformation
% and plot log(sd) versus mean of transformed data
% to create Figure 3.3
pd = log(pd);
yd = log(yd);
md = log(md);
pd1 = reshape(pd(1:2100),100,21);
yd1 = reshape(yd(1:2100),100,21);
md1 = reshape(md(1:2100),100,21);
cd = [pd1 yd1 md1];
x = mean(cd);
y = log(std(cd));
xmin = min(x);
xmax = max(x);
xr = xmax-xmin;
xmin = xmin-0.05*xr;
xmax = xmax+0.05*xr;
ymin = min(y);
ymax = max(y);
yr = ymax-ymin;
ymin = ymin-0.05*yr;
ymax = ymax+0.05*yr;
figure
axes('Position',[0.06 0.1 0.9 0.82])
plot(x,y,'k.')
text(xmin-0.06*xr,ymax+0.05*yr,'log of st.dev of log(exchange rate)')
xlabel('mean of log(exchange rate)')
axis([xmin xmax ymin ymax])
```

```
%
% plot time series of transformed data
% to create Figure 3.4
xmax = 1.2*n;
xmin = 0;
ymax = max([max(pd),max(yd),max(md)]);
ymin = min([min(pd),min(yd),min(md)]);
yr = ymax-ymin;
ymax = ymax+0.05*yr;
ymin = ymin-0.05*yr;
figure
axes('Position',[0.05 0.1 0.91 0.82])
plot(day,pd,'k-',day,yd,'r-',day,md,'b-')
text(xmin-0.05*n,ymax+0.04*yr,'log(Exchange rate)')
ycoord = [pd(n) ; yd(n) ; md(n)];
text(xcoord,ycoord,lab)
xlabel('trading day')
axis([xmin xmax ymin ymax])
%
% show that data need to be differenced
% to remove serial correlation (Figures 3.5 & 3.6)
y = [day pd];
y1 = y(1:1041,:);
putnum(y1)
fn = {'trading day' 'log(pound/dollar)'};
putfn(fn)
putdn('Exchange rate: 3 Jan 86 - 29 Dec 89')
tsplot cf=1 pg=3
tsplot cf=-1 pg=3 ar=1 ts=-1
y1 = y(1042:2086,:);
putnum(y1)
putdn('Exchange rate: 1 Jan 90 - 31 Dec 93')
tsplot cf=1 pg=3
tsplot cf=-1 pg=3 ar=1 ts=-1
%
% create first differences as percentages
% and give extended numerical summaries
% Table 3.2
dpd = 100*(pd(2:n)-pd(1:n-1));
dyd = 100*(yd(2:n)-yd(1:n-1));
dmd = 100*(md(2:n)-md(1:n-1));
y = [dpd dyd dmd];
putnum(y)
fn = {'pound/dollar' '100 yen/dollar' 'DM/dollar'};
putfn(fn)
putdn('Exchange rates: daily % returns 4 Jan 86 - 12 Apr 94')
describe typ=2
```

```
% program ch32.m
% creates scatterplot matrices for exchange rate returns
% using each of the four currencies in turn as the reference.
% (select dollar reference for Figure 3.7)

getfile dpypmp
y = getnum;
n = size(y,1);
y1 = y(:,4);                    % dollar/pound
y2 = y(:,5)/100;                % 100 yen/pound
y3 = y(:,6);                    % DM/pound
y1 = 100*log( y1(2:n)./y1(1:n-1) );
y2 = 100*log( y2(2:n)./y2(1:n-1) );
y3 = 100*log( y3(2:n)./y3(1:n-1) );
z = [y1 y2 y3];
fn = {'dollar/pound' '100 yen/pound' 'DM/pound'};
putnum(z)
putfn(fn)
putdn('exchange rates: daily % returns')
relate lin=1 cor=1
y1 = 1./y(:,4);                 % pound/dollar
y2 = y1.*y(:,5)/100;            % 100yen/dollar
y3 = y1.*y(:,6);                % DM/dollar
y1 = 100*log( y1(2:n)./y1(1:n-1) );
y2 = 100*log( y2(2:n)./y2(1:n-1) );
y3 = 100*log( y3(2:n)./y3(1:n-1) );
z = [y1 y2 y3];
fn = {'pound/dollar' '100 yen/dollar' 'DM/dollar'};
putnum(z)
putfn(fn)
putdn('exchange rates: daily % returns')
relate lin=1 cor=1
y1 = 100./y(:,5);               % pound/100yen
y2 = y1.*y(:,4);                % dollar/100yen
y3 = y1.*y(:,6);                % DM/100yen
y1 = 100*log( y1(2:n)./y1(1:n-1) );
y2 = 100*log( y2(2:n)./y2(1:n-1) );
y3 = 100*log( y3(2:n)./y3(1:n-1) );
z = [y1 y2 y3];
fn = {'pound/100yen' 'dollar/100yen' 'DM/100yen'};
putnum(z)
putfn(fn)
putdn('exchange rates: daily % returns')
relate lin=1 cor=1
y1 = 1./y(:,6);                 % pound/DM
y2 = y1.*y(:,4);                % dollar/DM
```

```
y3 = y1.*y(:,5)/100;              % 100yen/DM
y1 = 100*log( y1(2:n)./y1(1:n-1) );
y2 = 100*log( y2(2:n)./y2(1:n-1) );
y3 = 100*log( y3(2:n)./y3(1:n-1) );
z = [y1 y2 y3];
fn = {'pound/DM' 'dollar/DM' '100 yen/DM'};
putnum(z)
putfn(fn)
putdn('exchange rates: daily % returns')
relate lin=1 cor=1

% program ch33.m to create Figure 3.8
% (histograms of daily compounded returns/dollar)
%
getfile dpypmp
y = getnum;
n = size(y,1);            % number of trading days
y1 = 1./y(:,4);           % pound/dollar
y2 = y1.*y(:,5)/100;      % 100 yen/dollar
y3 = y1.*y(:,6);          % DM/dollar
%
% compute compounded % returns
y1 = 100*log(y1(2:n)./y1(1:n-1));
y2 = 100*log(y2(2:n)./y2(1:n-1));
y3 = 100*log(y3(2:n)./y3(1:n-1));
y = [y1 y2 y3];
nbins = [30 33 28];
currency = {'pound','yen','DM'};
for j=1:3
  figure
  axes('Position',[0.09,0.14,0.88,0.76])
  hist1(y(:,j),nbins(j))
  msskk = edmom(y(:,j),4);
  m = msskk(1);
  s = msskk(2);
  sk = msskk(3);
  k = msskk(4);
  x = (1:81)';
  x = (x-41)/10;
  f = ((n-1)*(6/23.3)/(sqrt(2*pi)*s))*exp(-0.5*((x-m)/s).^2);
  hold on
  plot(x,f,'r-')
  axis([-4.9 4.4 0 491])
  text(-5.4,509,'frequency')
  text(-4.5,455,['mean = ' num2str(m)])
  text(-4.5,420,['st.dev = ' num2str(s)])
  text(-4.5,385,['skewness = ' num2str(sk)])
```

```
 text(-4.5,350,['kurtosis = ' num2str(k)])
 title([currency{j} '/dollar: 4 Jan 1986 - 12 April 1994'])
 xlabel('compounded daily return (%)')
end

% program ch34.m to create Figure 3.9
% ribbon plots of compounded % exchange rate(/dollar) means
% and st.devs in periods of fixed length
%
getfile dpypmp
y = getnum;
n = size(y,1);          % number of trading days
y1 = 1./y(:,4);         % pound/dollar
y2 = y1.*y(:,5)/100;    % 100 yen/dollar
y3 = y1.*y(:,6);        % DM/dollar
%
% compute compounded percentage returns
y1 = 100*log(y1(2:n)./y1(1:n-1));
y2 = 100*log(y2(2:n)./y2(1:n-1));
y3 = 100*log(y3(2:n)./y3(1:n-1));
y = [y1 y2 y3];
fn = {'pound/dollar' '100 yen/dollar' 'DM/dollar'};
%
period = 50;
np = floor(n/period);
n = np*period;
x = (1:np)';
x = x*period-period/2;
x1 = [x ; flipud(x) ; x(1)];
for j=1:3
  yj = reshape(y(1:n,j),period,np);
  ms = edmom(yj,2)';
  m = ms(:,1);
  se = ms(:,2)/sqrt(np);
  yj = m+1.96*se;
  yj = [yj ; flipud(m-1.96*se) ; yj(1)];
  axes('Position',[0.06 0.1+0.283*(3-j) 0.91 0.263])
  fill(x1,yj,'c')
  hold on
  plot(x1,yj,'k-',x,m,'k-',[x(1) x(np)],[0 0],'r-')
  axis([0 2175 -0.7 0.7])
  text(20,0.6,fn{j})
  if j<3
    set(gca,'XTickLabel',[])
  end
  if j==1
    text(-70,0.83,['Mean ' int2str(period) '-day percentage return & 95% CI'])
```

```
 end
end
xlabel('Trading day from 4 January 1986')

% program ch35.m to create Figure 3.10
% volatilities of compounded % exchange rates (/dollar)
% in periods of fixed length (50 & 25 days)
%
getfile dpypmp
y = getnum;
n = size(y,1);          % number of trading days
y1 = 1./y(:,4);         % pound/dollar
y2 = y1.*y(:,5)/100;    % 100 yen/dollar
y3 = y1.*y(:,6);        % DM/dollar
%
% compute compounded percentage returns
y1 = 100*log(y1(2:n)./y1(1:n-1));
y2 = 100*log(y2(2:n)./y2(1:n-1));
y3 = 100*log(y3(2:n)./y3(1:n-1));
y = [y1 y2 y3];
fn = {'pound/dollar' '100 yen/dollar' 'DM/dollar'};
%
for j=1:3
  ms = edmom(y(:,j),2);
  s = ms(2);
  period = 50;
  np = floor(n/period);
  n1 = np*period;
  yj = reshape(y(1:n1,j),period,np);
  ms = edmom(yj,2)';
  s1 = ms(:,2);
  x1 = (1:np)';
  x1 = x1*period-period/2;
  period = 25;
  np = floor(n/period);
  n2 = np*period;
  yj = reshape(y(1:n2,j),period,np);
  ms = edmom(yj,2)';
  s2 = ms(:,2);
  x2 = (1:np)';
  x2 = x2*period-period/2;
  axes('Position',[0.06 0.1+0.283*(3-j) 0.91 0.263])
  plot(x1,s1,'k-',x2,s2,'m-',[x2(1) x2(np)],[0 0],'r-',[x2(1) x2(np)],[s s],'m-')
  axis([0 2175 -0.1 1.6])
  text(20,1.4,[fn{j} ': overall st.dev = ' num2str(s)])
  if j<3
    set(gca,'XTickLabel',[])
```

```
 end
 if j==1
  tit=['standard deviations of 25-day (grey) & 50-day (black) samples of percentage
returns'];
  text(-5,1.8,tit)
 end
end
xlabel('Trading day from 4 January 1986')

% program ch36.m to create Figure 3.11
% skewnesseses of compounded % exchange rates (/dollar)
% in periods of fixed length (50 & 25 days)
%
getfile dpypmp
y = getnum;
n = size(y,1);          % number of trading days
y1 = 1./y(:,4);         % pound/dollar
y2 = y1.*y(:,5)/100;    % 100 yen/dollar
y3 = y1.*y(:,6);        % DM/dollar
%
% compute compounded percentage returns
y1 = 100*log(y1(2:n)./y1(1:n-1));
y2 = 100*log(y2(2:n)./y2(1:n-1));
y3 = 100*log(y3(2:n)./y3(1:n-1));
y = [y1 y2 y3];
fn = {'pound/dollar' '100 yen/dollar' 'DM/dollar'};
%
for j=1:3
 ms = edmom(y(:,j),3);
 sk = ms(3);
 period = 50;
 np = floor(n/period);
 n1 = np*period;
 yj = reshape(y(1:n1,j),period,np);
 ms = edmom(yj,3)';
 sk1 = ms(:,3);
 x1 = (1:np)';
 x1 = x1*period-period/2;
 period = 25;
 np = floor(n/period);
 n2 = np*period;
 yj = reshape(y(1:n2,j),period,np);
 ms = edmom(yj,3)';
 sk2 = ms(:,3);
 x2 = (1:np)';
 x2 = x2*period-period/2;
 axes('Position',[0.06 0.1+0.283*(3-j) 0.91 0.263])
```

```
 plot(x1,sk1,'k-',x2,sk2,'m-',[x2(1) x2(np)],[0 0],'r-',[x2(1) x2(np)],[sk sk],'m-')
 axis([0 2175 -2.9 2.9])
 text(20,2.4,[fn{j} ': overall skewness = ' num2str(sk)])
 if j<3
  set(gca,'XTickLabel',[])
 end
 if j==1
  tit=['skewnesses of 25-day (grey) & 50-day (black) samples of percentage returns'];
  text(-5,3.4,tit)
 end
end
xlabel('Trading day from 4 January 1986')

% program ch37.m to create Figure 3.12
% kurtoses of compounded % exchange rates (/dollar)
% in periods of fixed length (50 & 25 days)
%
getfile dpypmp
y = getnum;
n = size(y,1);          % number of trading days
y1 = 1./y(:,4);         % pound/dollar
y2 = y1.*y(:,5)/100;    % 100 yen/dollar
y3 = y1.*y(:,6);        % DM/dollar
%
% compute compounded percentage returns
y1 = 100*log(y1(2:n)./y1(1:n-1));
y2 = 100*log(y2(2:n)./y2(1:n-1));
y3 = 100*log(y3(2:n)./y3(1:n-1));
y = [y1 y2 y3];
fn = {'pound/dollar' '100 yen/dollar' 'DM/dollar'};
%
for j=1:3
 ms = edmom(y(:,j),4);
 k = ms(4);
 period = 50;
 np = floor(n/period);
 n1 = np*period;
 yj = reshape(y(1:n1,j),period,np);
 ms = edmom(yj,4)';
 k1 = ms(:,4);
 x1 = (1:np)';
 x1 = x1*period-period/2;
 period = 25;
 np = floor(n/period);
 n2 = np*period;
 yj = reshape(y(1:n2,j),period,np);
 ms = edmom(yj,4)';
```

```
 k2 = ms(:,4);
 x2 = (1:np)';
 x2 = x2*period-period/2;
 axes('Position',[0.06 0.1+0.283*(3-j) 0.91 0.263])
 plot([x2(1) x2(np)],[3 3],'r-',[x2(1) x2(np)],[k k],'m-')
 hold on
 plot([x2(1) x2(np)],[0 0],'r-',x1,k1,'k-',x2,k2,'m-')
 axis([0 2175 -1 12])
 text(20,10.5,[fn{j} ': overall kurtosis = ' num2str(k)])
 if j<3
  set(gca,'XTickLabel',[])
 end
 if j==1
  tit=['kurtoses of 25-day (grey) & 50-day (black) samples of percentage returns'];
  text(-5,13,tit)
 end
end
xlabel('Trading day from 4 January 1986')

% program ch38.m to create Figure 3.13
% scatterplot matrix of volatilites of exchange rate
% returns (/dollar) in periods of 50 days
%
getfile dpypmp
y = getnum;
n = size(y,1);          % number of trading days
y1 = 1./y(:,4);         % pound/dollar
y2 = y1.*y(:,5)/100;    % 100 yen/dollar
y3 = y1.*y(:,6);        % DM/dollar
%
% compute compounded percentage returns
y1 = 100*log(y1(2:n)./y1(1:n-1));
y2 = 100*log(y2(2:n)./y2(1:n-1));
y3 = 100*log(y3(2:n)./y3(1:n-1));
y = [y1 y2 y3];;
%
s = [];
period = 50;
np = floor(n/period);
n = np*period;
for j=1:3
  yj = reshape(y(1:n,j),period,np);
  ms = edmom(yj,2)';
  s = [s ms(:,2)];
end
putnum(s)
fn = {'pound/dollar' '100 yen/dollar' 'DM/dollar'};
```

```
putfn(fn)
putdn('Volatilities in 50-day periods: 4 Jan 86 - 1 Apr 94')
relate cor=1 lin=1

% program ch39.m to create Figure 3.14
% scatterplot matrix of skewnesses of exchange rate
% returns (/dollar) in periods of 50 days
%
getfile dpypmp
y = getnum;
n = size(y,1);          % number of trading days
y1 = 1./y(:,4);         % pound/dollar
y2 = y1.*y(:,5)/100;    % 100 yen/dollar
y3 = y1.*y(:,6);        % DM/dollar
%
% compute compounded percentage returns
y1 = 100*log(y1(2:n)./y1(1:n-1));
y2 = 100*log(y2(2:n)./y2(1:n-1));
y3 = 100*log(y3(2:n)./y3(1:n-1));
y = [y1 y2 y3];;
%
sk = [];
period = 50;
np = floor(n/period);
n = np*period;
for j=1:3
  yj = reshape(y(1:n,j),period,np);
  ms = edmom(yj,3)';
  sk = [sk ms(:,3)];
end
putnum(sk)
fn = {'pound/dollar' '100 yen/dollar' 'DM/dollar'};
putfn(fn)
putdn('Skewnesses in 50-day periods: 4 Jan 86 - 1 Apr 94')
relate cor=1 lin=1

% program ch310.m to create Figures 3.15
% scatterplot matrix of kurtoses of exchange rate
% returns (/dollar) in periods of 50 days
%
getfile dpypmp
y = getnum;
n = size(y,1);          % number of trading days
y1 = 1./y(:,4);         % pound/dollar
y2 = y1.*y(:,5)/100;    % 100 yen/dollar
y3 = y1.*y(:,6);        % DM/dollar
%
```

```
% compute compounded percentage returns
y1 = 100*log(y1(2:n)./y1(1:n-1));
y2 = 100*log(y2(2:n)./y2(1:n-1));
y3 = 100*log(y3(2:n)./y3(1:n-1));
y = [y1 y2 y3];;
%
k = [];
period = 50;
np = floor(n/period);
n = np*period;
for j=1:3
  yj = reshape(y(1:n,j),period,np);
  ms = edmom(yj,4)';
  k = [k ms(:,4)];
end
putnum(k)
fn = {'pound/dollar' '100 yen/dollar' 'DM/dollar'};
putfn(fn)
putdn('Kurtoses in 50-day periods: 4 Jan 86 - 1 Apr 94')
relate cor=1 lin=1
k = log(k);
putnum(k)
putdn('log kurtoses in 50-day periods: 4 Jan 86 - 1 Apr 94')
relate cor=1 lin=1

% program ch41.m to create Figures 4.1-4.3
% time series analysis of
% volatilities of compounded % exchange rates (/dollar)
% in periods of fixed length
%
period = 25;
getfile dpypmp
y = getnum;
n = size(y,1);          % number of trading days
y1 = 1./y(:,4);         % pound/dollar
y2 = y1.*y(:,5)/100;    % 100 yen/dollar
y3 = y1.*y(:,6);        % DM/dollar
%
% compute compounded percentage returns
y1 = 100*log(y1(2:n)./y1(1:n-1));
y2 = 100*log(y2(2:n)./y2(1:n-1));
y3 = 100*log(y3(2:n)./y3(1:n-1));
y = [y1 y2 y3];
%
vol1 = [];
for j=1:3
  ms = edmom(y(:,j),2);
```

```
 s = ms(2);
 np = floor(n/period);
 n1 = np*period;
 yj = reshape(y(1:n1,j),period,np);
 ms = edmom(yj,2)';
 s1 = ms(:,2);
 x1 = (1:np)';
 x1 = x1*period-period/2;
 if j==1
  vol1 = [vol1 x1 s1];
 else
  vol1 = [vol1 s1];
 end
end
fn1 = {[int2str(period) ' trading days'] 'pound/dollar' '100 yen/dollar' 'DM/dollar'};
putdn('average volatility')
putnum(vol1)
putfn(fn1)
setvar z=1 y=2
tsplot pg=3 cf=-1 ar=1
setvar z=1 y=3
tsplot pg=3 cf=-1 ar=1
setvar z=1 y=4
tsplot pg=3 cf=-1 ar=1

% program ch42.m to create Figure 4.4
% fit limiting model
%
getfile dpypmp
y = getnum;
n = size(y,1);
day = (1:n)';
pd = 1./y(:,4);                 % pound/dollar
yd = (y(:,5)/100).*pd;          % 100 yen/dollar
md = y(:,6).*pd;                % DM/dollar
y = [pd yd md];
putnum(y)
fn = {'pound/dollar' '100 yen/dollar' 'DM/dollar'};
putfn(fn)
putdn('Exchange rates: 3 Jan 86 - 12 Apr 94')

% take log transformation
pd = log(pd);
yd = log(yd);
md = log(md);
%
% create first differences as percentages
```

```
dpd = 100*(pd(2:n)-pd(1:n-1));
dyd = 100*(yd(2:n)-yd(1:n-1));
dmd = 100*(md(2:n)-md(1:n-1));
y = [dpd dyd dmd];
putnum(y)
fn = {'pound/dollar' '100 yen/dollar' 'DM/dollar'};
putfn(fn)
putdn('Exchange rates: daily % returns 4 Jan 86 - 12 Apr 94')
maxlag = 80;
n = n-1;
y0 = y(maxlag:n,:);
r2 = [1 1 1];
for i=1:maxlag-1
 y1 = y(maxlag-i:n-i,:);
 r2i = [];
 for j=1:3
  c0 = y0(:,j);
  c1 = y1(:,j);
  c0 = c0.^2-mean(c0.^2);
  c1 = c1.^2-mean(c1.^2);
  r2i = [r2i (mean(c0.*c1))/(std(c0)*std(c1))];
 end
 r2 = [r2 ; r2i];
end
r2 = [(0:maxlag-1)' r2];
s2 = 0.435;
k2 = 0.355^2;
alpha1 = 0.95;
alpha2 = 0.9;
s = (1:maxlag-1)';
as1 = alpha1.^s;
as2 = alpha2.^s;
cov21 = as1*k2.*(2*s2+as1*k2)/(s2^2+8*s2*k2+4*k2^2);
cov22 = as2*k2.*(2*s2+as2*k2)/(s2^2+8*s2*k2+4*k2^2);
cov21 = [1 ; cov21];
cov22 = [1 ; cov22];
plot(r2(:,1),cov21,'r-',r2(:,1),cov22,'r:')
hold on
plot([0 maxlag],[0 0],'m-',r2(:,1),r2(:,2),'k*')
axis([-0.5 maxlag-0.5 -0.08 1.02])
xlabel('lag (trading days)')
text(-3,1.07,'autocorrelation function of squared returns: pound/dollar')

% program ch43a.m to create Figure 4.5 (top)
% simulations of average volatilities in fixed periods
% of compounded returns for exchange rates
% using model y(t) = (sigma+delta*v(t))*z(t)
```

```
%       where v(t) = alpha*v(t-1)+w(t)
%       and (z(t),w(t)) are indept white noise with stdev=1
%
seed = 13579;
n = 2157;
%
% estimates of parameters based on
% limiting model formulas and data

sigma = 0.66;

% assume alpha is 0.9
alpha = 0.9;
delta = 0.172;

randn('state',seed)
fn = {'simulation 1' 'simulation 2' 'simulation 3'};
zw = randn(n,6);
for j=1:3
  w = zw(:,j+3);
  z = zw(:,j);
  v = filter(1,[1 -alpha],w);
  y = (sigma+delta*v).*z;
  ms = edmom(y,2);
  s = ms(2);
  period = 50;
  np = floor(n/period);
  n1 = np*period;
  y1 = reshape(y(1:n1),period,np);
  ms = edmom(y1,2)';
  s1 = ms(:,2);
  x1 = (1:np)';
  x1 = x1*period-period/2;
  period = 25;
  np = floor(n/period);
  n2 = np*period;
  y2 = reshape(y(1:n2),period,np);
  ms = edmom(y2,2)';
  s2 = ms(:,2);
  x2 = (1:np)';
  x2 = x2*period-period/2;
  axes('Position',[0.06 0.1+0.283*(3-j) 0.91 0.263])
  plot(x1,s1,'k-',x2,s2,'m-',[x2(1) x2(np)],[0 0],'r-',[x2(1) x2(np)],[s s],'m-')
  axis([0 2175 -0.1 1.6])
  text(20,1.4,[fn{j} ': overall st.dev = ' num2str(s)])
  if j<3
    set(gca,'XTickLabel',[])
```

```
 end
 if j==1
  tit=['st.devs of 25-day(grey) & 50-day(black) samples of % returns (alpha='
num2str(alpha) ')'];
  text(-5,1.8,tit)
 end
end
xlabel('Trading day from 4 January 1986')

% program ch43b.m to create Figure 4.5 (bottom)
% simulations of average volatilities in fixed periods
% of compounded returns for exchange rates
% using model y(t) = (sigma+delta*v(t))*z(t)
%       where v(t) = alpha*v(t-1)+w(t)
%       and (z(t),w(t)) are indept white noise with stdev=1
%
seed = 13579;
n = 2157;
%
% estimates of parameters based on
% limiting model formulas and data

sigma = 0.66;

% assume alpha is 0.95
figure
alpha = 0.95;
delta = 0.117;

randn('state',seed)
fn = {'simulation 1' 'simulation 2' 'simulation 3'};
zw = randn(n,6);
for j=1:3
 w = zw(:,j+3);
 z = zw(:,j);
 v = filter(1,[1 -alpha],w);
 y = (sigma+delta*v).*z;
 ms = edmom(y,2);
 s = ms(2);
 period = 50;
 np = floor(n/period);
 n1 = np*period;
 y1 = reshape(y(1:n1),period,np);
 ms = edmom(y1,2)';
 s1 = ms(:,2);
 x1 = (1:np)';
 x1 = x1*period-period/2;
```

```
 period = 25;
 np = floor(n/period);
 n2 = np*period;
 y2 = reshape(y(1:n2),period,np);
 ms = edmom(y2,2)';
 s2 = ms(:,2);
 x2 = (1:np)';
 x2 = x2*period-period/2;
 axes('Position',[0.06 0.1+0.283*(3-j) 0.91 0.263])
 plot(x1,s1,'k-',x2,s2,'m-',[x2(1) x2(np)],[0 0],'r-',[x2(1) x2(np)],[s s],'m-')
 axis([0 2175 -0.1 1.6])
 text(20,1.4,[fn{j} ': overall st.dev = ' num2str(s)])
 if j<3
  set(gca,'XTickLabel',[])
 end
 if j==1
  tit=['st.devs of 25-day(grey) & 50-day(black) samples of % returns (alpha='
num2str(alpha) ')'];
  text(-5,1.8,tit)
 end
end
xlabel('Trading day from 4 January 1986')

% program ch43s.m to create Figure 4.6
% volatilities of compounded % exchange rates (/dollar)
% in periods of fixed length (25 days)
% compare based on the data & simulation
%
getfile dpypmp
y = getnum;
n = size(y,1);          % number of trading days
y1 = 1./y(:,4);         % pound/dollar
y2 = y1.*y(:,5)/100;    % 100 yen/dollar
y3 = y1.*y(:,6);        % DM/dollar
%
% compute compounded percentage returns
y1 = 100*log(y1(2:n)./y1(1:n-1));
y2 = 100*log(y2(2:n)./y2(1:n-1));
y3 = 100*log(y3(2:n)./y3(1:n-1));
y = [y1 y2 y3];
fn = {'pound/dollar' '100 yen/dollar' 'DM/dollar'};
%
seed = 13579;
n = 2157;
sigma = 0.66;
alpha = 0.9;
delta = 0.172;
```

```
randn('state',seed)
fn1 = {'simulation 1' 'simulation 2' 'simulation 3'};
zw = randn(n,6);
%
for j=1:3
 ms = edmom(y(:,j),2);
 s = ms(2);
 period = 25;
 np = floor(n/period);
 n1 = np*period;
 yj = reshape(y(1:n1,j),period,np);
 ms = edmom(yj,2)';
 s1 = ms(:,2);
 x1 = (1:np)';
 x1 = x1*period-period/2;
 w = zw(:,j+3);
 z = zw(:,j);
 v = filter(1,[1 -alpha],w);
 ys = (sigma+delta*v).*z;
 ms = edmom(ys,2);
 ss = ms(2);
 period = 25;
 np = floor(n/period);
 n2 = np*period;
 y1 = reshape(ys(1:n1),period,np);
 ms = edmom(y1,2)';
 s2 = ms(:,2);
 x2 = (1:np)';
 x2 = x2*period-period/2;
 axes('Position',[0.06 0.1+0.283*(3-j) 0.91 0.263])
 plot(x1,s1,'k-',x2,s2,'m-',[x2(1) x2(np)],[0 0],'r-',[x2(1) x2(np)],[s s],'m-')
 axis([0 2175 -0.1 1.6])
 text(20,1.4,[fn{j} ': overall st.dev = ' num2str(s)])
 text(1200,1.4,[fn1{j} ': overall st.dev = ' num2str(ss)])
 if j<3
  set(gca,'XTickLabel',[])
 end
 if j==1
  tit=['st.devs of 25-day data (black) & 25-day simulations samples (grey) of  %
returns (alpha = 0.9)'];
  text(-5,1.8,tit)
 end
end
xlabel('Trading day from 4 January 1986')
```

```
% program ch44a.m to create Figure 4.7 (top)
% simulations of average skewnesses in fixed periods
% of compounded returns for exchange rates
% using model y(t) = (sigma+delta*v(t))*z(t)
%       where v(t) = alpha*v(t-1)+w(t)
%       and (z(t),w(t)) are indept white noise with stdev=1
%
seed = 13579;
n = 2157;
%
% guesstimates of parameters
sigma = 0.66;

% assume alpha is 0.9
alpha = 0.9;
delta = 0.172;

randn('state',seed)
fn = {'simulation 1' 'simulation 2' 'simulation 3'};
zw = randn(n,6);
for j=1:3
  w = zw(:,j+3);
  z = zw(:,j);
  v = filter(1,[1 -alpha],w);
  y = (sigma+delta*v).*z;
  ms = edmom(y,3);
  sk = ms(3);
  period = 50;
  np = floor(n/period);
  n1 = np*period;
  y1 = reshape(y(1:n1),period,np);
  ms = edmom(y1,3)';
  sk1 = ms(:,3);
  x1 = (1:np)';
  x1 = x1*period-period/2;
  period = 25;
  np = floor(n/period);
  n2 = np*period;
  y2 = reshape(y(1:n2),period,np);
  ms = edmom(y2,3)';
  sk2 = ms(:,3);
  x2 = (1:np)';
  x2 = x2*period-period/2;
  axes('Position',[0.06 0.1+0.283*(3-j) 0.91 0.263])
  plot(x1,sk1,'k-',x2,sk2,'m-',[x2(1) x2(np)],[0 0],'r-',[x2(1) x2(np)],[sk sk],'m-')
  axis([0 2175 -2.9 2.9])
```

```
 text(20,2.4,[fn{j} ': overall skewness = ' num2str(sk)])
 if j<3
  set(gca,'XTickLabel',[])
 end
 if j==1
  tit=['skewnesses of 25-day (grey) & 50-day(black) samples of % returns (alpha='
num2str(alpha) ')'];
  text(-5,3.4,tit)
 end
end
xlabel('Trading day from 4 January 1986')

% program ch44b.m to create Figure 4.7 (bottom)
% simulations of average skewnesses in fixed periods
% of compounded returns for exchange rates
% using model y(t) = (sigma+delta*v(t))*z(t)
%       where v(t) = alpha*v(t-1)+w(t)
%       and (z(t),w(t)) are indept white noise with stdev=1
%
seed = 13579;
n = 2157;
%
% guesstimates of parameters
sigma = 0.66;

% assume alpha is 0.95
alpha = 0.95;
delta = 0.117;
randn('state',seed)
fn = {'simulation 1' 'simulation 2' 'simulation 3'};
zw = randn(n,6);
for j=1:3
 w = zw(:,j+3);
 z = zw(:,j);
 v = filter(1,[1 -alpha],w);
 y = (sigma+delta*v).*z;
 ms = edmom(y,3);
 sk = ms(3);
 period = 50;
 np = floor(n/period);
 n1 = np*period;
 y1 = reshape(y(1:n1),period,np);
 ms = edmom(y1,3)';
 sk1 = ms(:,3);
 x1 = (1:np)';
 x1 = x1*period-period/2;
 period = 25;
```

```
 np = floor(n/period);
 n2 = np*period;
 y2 = reshape(y(1:n2),period,np);
 ms = edmom(y2,3)';
 sk2 = ms(:,3);
 x2 = (1:np)';
 x2 = x2*period-period/2;
 axes('Position',[0.06 0.1+0.283*(3-j) 0.91 0.263])
 plot(x1,sk1,'k-',x2,sk2,'m-',[x2(1) x2(np)],[0 0],'r-',[x2(1) x2(np)],[sk sk],'m-')
 axis([0 2175 -2.9 2.9])
 text(20,2.4,[fn{j} ': overall skewness = ' num2str(sk)])
 if j<3
  set(gca,'XTickLabel',[])
 end
 if j==1
  tit=['skewnesses of 25-day (grey) & 50-day(black) samples of % returns (alpha='
num2str(alpha) ')'];
  text(-5,3.4,tit)
 end
end
xlabel('Trading day from 4 January 1986')

% program ch44s.m to create Figure 4.8
% skewnesses of compounded % exchange rates (/dollar)
% in periods of fixed length (25 days)
% compare based on the data and simulations
%
getfile dpypmp
y = getnum;
n = size(y,1);          % number of trading days
y1 = 1./y(:,4);         % pound/dollar
y2 = y1.*y(:,5)/100;    % 100 yen/dollar
y3 = y1.*y(:,6);        % DM/dollar
%
% compute compounded percentage returns
y1 = 100*log(y1(2:n)./y1(1:n-1));
y2 = 100*log(y2(2:n)./y2(1:n-1));
y3 = 100*log(y3(2:n)./y3(1:n-1));
y = [y1 y2 y3];
fn = {'pound/dollar' '100 yen/dollar' 'DM/dollar'};
%
seed = 13579;
n = 2157;
sigma = 0.66;
alpha = 0.9;
delta = 0.172;
randn('state',seed)
```

```
fn1 = {'simulation 1' 'simulation 2' 'simulation 3'};
zw = randn(n,6);
%
for j=1:3
 ms = edmom(y(:,j),3);
 sk = ms(3);
 period = 25;
 np = floor(n/period);
 n1 = np*period;
 yj = reshape(y(1:n1,j),period,np);
 ms = edmom(yj,3)';
 sk1 = ms(:,3);
 x1 = (1:np)';
 x1 = x1*period-period/2;
 w = zw(:,j+3);
 z = zw(:,j);
 v = filter(1,[1 -alpha],w);
 ys = (sigma+delta*v).*z;
 ms = edmom(ys,3);
 sks = ms(3);
 period = 25;
 np = floor(n/period);
 n2 = np*period;
 y1 = reshape(ys(1:n1),period,np);
 ms = edmom(y1,3)';
 sk2 = ms(:,3);
 x2 = (1:np)';
 x2 = x2*period-period/2;
 axes('Position',[0.06 0.1+0.283*(3-j) 0.91 0.263])
 plot(x1,sk1,'k-',x2,sk2,'m-',[x2(1) x2(np)],[0 0],'r-',[x2(1) x2(np)],[sk sk],'m-')
 axis([0 2175 -2.9 2.9])
 text(20,2.4,[fn{j} ': overall skewness = ' num2str(sk)])
 text(1100,2.4,[fn1{j} ': overall skewness = ' num2str(sks)])
 if j<3
  set(gca,'XTickLabel',[])
 end
 if j==1
  tit=['skewnesses of 25-day data (black) & 25-day simulations samples (grey) of  %
returns (alpha = 0.9)'];
  text(-55,3.4,tit)
 end
end
xlabel('Trading day from 4 January 1986')
```

```
% program ch45a.m to create Figure 4.9 (top)
% simulations of average kurtoses in fixed periods
% of compounded returns for exchange rates
% using model y(t) = (sigma+delta*v(t))*z(t)
%       where v(t) = alpha*v(t-1)+w(t)
%       and (z(t),w(t)) are indept white noise with stdev=1
%
seed = 13579;
n = 2157;
%
% guesstimates of parameters
sigma = 0.66;

% assume alpha is 0.9
alpha = 0.9;
delta = 0.172;

randn('state',seed)
fn = {'simulation 1' 'simulation 2' 'simulation 3'};
zw = randn(n,6);
for j=1:3
  w = zw(:,j+3);
  z = zw(:,j);
  v = filter(1,[1 -alpha],w);
  y = (sigma+delta*v).*z;
  ms = edmom(y,4);
  k = ms(4);
  period = 50;
  np = floor(n/period);
  n1 = np*period;
  y1 = reshape(y(1:n1),period,np);
  ms = edmom(y1,4)';
  k1 = ms(:,4);
  x1 = (1:np)';
  x1 = x1*period-period/2;
  period = 25;
  np = floor(n/period);
  n2 = np*period;
  y2 = reshape(y(1:n2),period,np);
  ms = edmom(y2,4)';
  k2 = ms(:,4);
  x2 = (1:np)';
  x2 = x2*period-period/2;
  axes('Position',[0.06 0.1+0.283*(3-j) 0.91 0.263])
  plot([x2(1) x2(np)],[3 3],'r-',[x2(1) x2(np)],[k k],'m-')
  hold on
```

```
 plot([x2(1) x2(np)],[0 0],'r-',x1,k1,'k-',x2,k2,'m-')
 axis([0 2175 -1 12])
 text(20,10.5,[fn{j} ': overall kurtosis = ' num2str(k)])
 if j<3
  set(gca,'XTickLabel',[])
 end
 if j==1
  tit=['kurtoses of 25-day (grey) & 50-day(black) samples of % returns (alpha='
num2str(alpha) ')'];
  text(-5,13,tit)
 end
end
xlabel('Trading day from 4 January 1986')

% program ch45b.m to create Figure 4.9 (bottom)
% simulations of average kurtoses in fixed periods
% of compounded returns for exchange rates
% using model y(t) = (sigma+delta*v(t))*z(t)
%       where v(t) = alpha*v(t-1)+w(t)
%       and (z(t),w(t)) are indept white noise with stdev=1
%
seed = 13579;
n = 2157;
%
% guesstimates of parameters
sigma = 0.66;

% assume alpha is 0.95
alpha = 0.95;
delta = 0.118;

randn('state',seed)
fn = {'simulation 1' 'simulation 2' 'simulation 3'};
zw = randn(n,6);
for j=1:3
  w = zw(:,j+3);
  z = zw(:,j);
  v = filter(1,[1 -alpha],w);
  y = (sigma+delta*v).*z;
  ms = edmom(y,4);
  k = ms(4);
  period = 50;
  np = floor(n/period);
  n1 = np*period;
  y1 = reshape(y(1:n1),period,np);
  ms = edmom(y1,4)';
  k1 = ms(:,4);
```

```
x1 = (1:np)';
x1 = x1*period-period/2;
period = 25;
np = floor(n/period);
n2 = np*period;
y2 = reshape(y(1:n2),period,np);
ms = edmom(y2,4)';
k2 = ms(:,4);
x2 = (1:np)';
x2 = x2*period-period/2;
axes('Position',[0.06 0.1+0.283*(3-j) 0.91 0.263])
plot([x2(1) x2(np)],[3 3],'r-',[x2(1) x2(np)],[k k],'m-')
hold on
plot([x2(1) x2(np)],[0 0],'r-',x1,k1,'k-',x2,k2,'m-')
axis([0 2175 -1 12])
text(20,10.5,[fn{j} ': overall kurtosis = ' num2str(k)])
if j<3
  set(gca,'XTickLabel',[])
end
if j==1
  tit=['kurtoses of 25-day (grey) & 50-day(black) samples of % returns (alpha='
num2str(alpha) ')'];
  text(-5,13,tit)
end
end
xlabel('Trading day from 4 January 1986')

% program ch45s.m to create Figure 4.10
% kurtoses of compounded % exchange rates (/dollar)
% in periods of fixed length (25 days)
% compare based on the data and simulations
%
getfile dpypmp
y = getnum;
n = size(y,1);          % number of trading days
y1 = 1./y(:,4);         % pound/dollar
y2 = y1.*y(:,5)/100;    % 100 yen/dollar
y3 = y1.*y(:,6);        % DM/dollar
%
% compute compounded percentage returns
y1 = 100*log(y1(2:n)./y1(1:n-1));
y2 = 100*log(y2(2:n)./y2(1:n-1));
y3 = 100*log(y3(2:n)./y3(1:n-1));
y = [y1 y2 y3];
fn = {'pound/dollar' '100 yen/dollar' 'DM/dollar'};
%
seed = 13579;
```

```
n = 2157;
sigma = 0.66;
alpha = 0.9;
delta = 0.172;
randn('state',seed)
fn1 = {'simulation 1' 'simulation 2' 'simulation 3'};
zw = randn(n,6);
%
for j=1:3
 ms = edmom(y(:,j),4);
 k = ms(4);
 period = 25;
 np = floor(n/period);
 n1 = np*period;
 yj = reshape(y(1:n1,j),period,np);
 ms = edmom(yj,4)';
 k1 = ms(:,4);
 x1 = (1:np)';
 x1 = x1*period-period/2;
 w = zw(:,j+3);
 z = zw(:,j);
 v = filter(1,[1 -alpha],w);
 ys = (sigma+delta*v).*z;
 ms = edmom(ys,4);
 kk = ms(4);
 period = 25;
 np = floor(n/period);
 n2 = np*period;
 y1 = reshape(ys(1:n1),period,np);
 ms = edmom(y1,4)';
 k2 = ms(:,4);
 x2 = (1:np)';
 x2 = x2*period-period/2;
 axes('Position',[0.06 0.1+0.283*(3-j) 0.91 0.263])
 plot([x2(1) x2(np)],[3 3],'r-',[x2(1) x2(np)],[k k],'m-')
 hold on
 plot([x2(1) x2(np)],[0 0],'r-',x1,k1,'k-',x2,k2,'m-')
 axis([0 2175 -1 12])
 text(20,10.5,[fn{j} ': overall kurtosis = ' num2str(k)])
 text(1200,10.5,[fn1{j} ': overall kurtosis = ' num2str(kk)])
 if j<3
  set(gca,'XTickLabel',[])
 end
 if j==1
  tit=['kurtoses of 25-day data (black) & 25-day simulations samples (grey) of %
returns (alpha = 0.9)'];
  text(-5,13,tit)
```

```
 end
end
xlabel('Trading day from 4 January 1986')

% program ch46.m to create Figures 4.11
% time series analyses of average volatilities
% in fixed periods based on simulations
% of compounded returns for exchange rates
% using model y(t) = (sigma+delta*v(t))*z(t)
%       where v(t) = alpha*v(t-1)+w(t)
%       and (z(t),w(t)) are indept white noise with stdev=1
%
seed = 13579;
n = 2157;
period = 25;
%
% guesstimates of parameters
sigma = 0.66;
delta = 0.172;
alpha = 0.9;
randn('state',seed)
zw = randn(n,6);
vol1 = [];
for j=1:3
  w = zw(:,j+3);
  z = zw(:,j);
  v = filter(1,[1 -alpha],w);
  y = (sigma+delta*v).*z;
  ms = edmom(y,2);
  s = ms(2);
  np = floor(n/period);
  n1 = np*period;
  yj = reshape(y(1:n1),period,np);
  ms = edmom(yj,2)';
  s1 = ms(:,2);
  x1 = (1:np)';
  x1 = x1*period-period/2;
  if j==1
    vol1 = [vol1 x1 s1];
  else
    vol1 = [vol1 s1];
  end
end
fn1 = {[int2str(period) ' trading days'] 'simulation 1 : alpha = 0.9' 'simulation 2 : alpha
= 0.9' 'simulation 3 : alpha = 0.9'};
putdn('average volatility')
putnum(vol1)
```

```
putfn(fn1)
setvar z=1 y=2
tsplot pg=3 cf=-1 ar=1
setvar z=1 y=3
tsplot pg=3 cf=-1 ar=1
setvar z=1 y=4
tsplot pg=3 cf=-1 ar=1

% program ch47.m to create Figures 4.12
% time series analyses of average volatilities
% in fixed periods based on simulations
% of compounded returns for exchange rates
% using model y(t) = (sigma+delta*v(t))*z(t)
%       where v(t) = alpha*v(t-1)+w(t)
%       and (z(t),w(t)) are indept white noise with stdev=1
%
seed = 13579;
n = 2157;
period = 25;
%
% guesstimates of parameters
sigma = 0.66;
delta = 0.117;
alpha = 0.95;
randn('state',seed)
zw = randn(n,6);
vol1 = [];
for j=1:3
  w = zw(:,j+3);
  z = zw(:,j);
  v = filter(1,[1 -alpha],w);
  y = (sigma+delta*v).*z;
  ms = edmom(y,2);
  s = ms(2);
  np = floor(n/period);
  n1 = np*period;
  yj = reshape(y(1:n1),period,np);
  ms = edmom(yj,2)';
  s1 = ms(:,2);
  x1 = (1:np)';
  x1 = x1*period-period/2;
  if j==1
    vol1 = [vol1 x1 s1];
  else
    vol1 = [vol1 s1];
  end
end
```

```
fn1 = {[int2str(period) ' trading days'] 'simulation 1   alpha = 0.95' 'simulation 2
alpha = 0.95' 'simulation 3   alpha = 0.95'};
putdn('average volatility')
putnum(vol1)
putfn(fn1)
setvar z=1 y=2
tsplot pg=3 cf=-1 ar=1
setvar z=1 y=3
tsplot pg=3 cf=-1 ar=1
setvar z=1 y=4
tsplot pg=3 cf=-1 ar=1
```