Algorithmic Trading Project

High Frequency Momentum Trading Stategy with Cryptocurrencies

Weihang Ren, April 20th 2020

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Data

Obtained from CryptoCompare via their official Python API, the data consists of the **hourly** prices of 7 cryptocurrencies versus the US Dollar over three chosen stating dates until 14:00 on April 30th 2020:

- `2019-10-30 00:00` (6 months)
- `2019-04-30 00:00` (1 year)
- `2018-04-30 00:00` (2 years)

Select different time range `'TR'` to see visualization and results accordingly.

Import data

```
% initialize
clear
% select time range: 6month, 1year or 2year
TR = "6m";

% config plots x limits
switch TR
    case "6m"
        xrange = [datetime(2019,10,29) datetime(2020,5,1)];
    case "1y"
        xrange = [datetime(2019,4,25) datetime(2020,5,1)];
    case "2y"
        xrange = [datetime(2018,4,25) datetime(2020,5,1)];
    otherwise
        warning('Unexpected plot range. No time selected.')
end

opts = delimitedTextImportOptions("NumVariables", 8);

% Specify range and delimiter
opts.DataLines = [2, Inf];
opts.Delimiter = ",";

% Specify column names and types
opts.VariableNames = ["time", "Bitcoin", "Ethereum", "Ripple", "BitcoinCash", "Tether",
opts.VariableTypes = ["datetime", "double", "double", "double", "double", "double", "do

% Specify file level properties
opts.ExtraColumnsRule = "ignore";
opts.EmptyLineRule = "read";

% Specify variable properties
opts = setvaropts(opts, "time", "InputFormat", "yyyy-MM-dd HH:mm:ss");

% Import the data
crypto = readtimetable("data/crypto_"+TR+".csv", opts);

clear opts
```

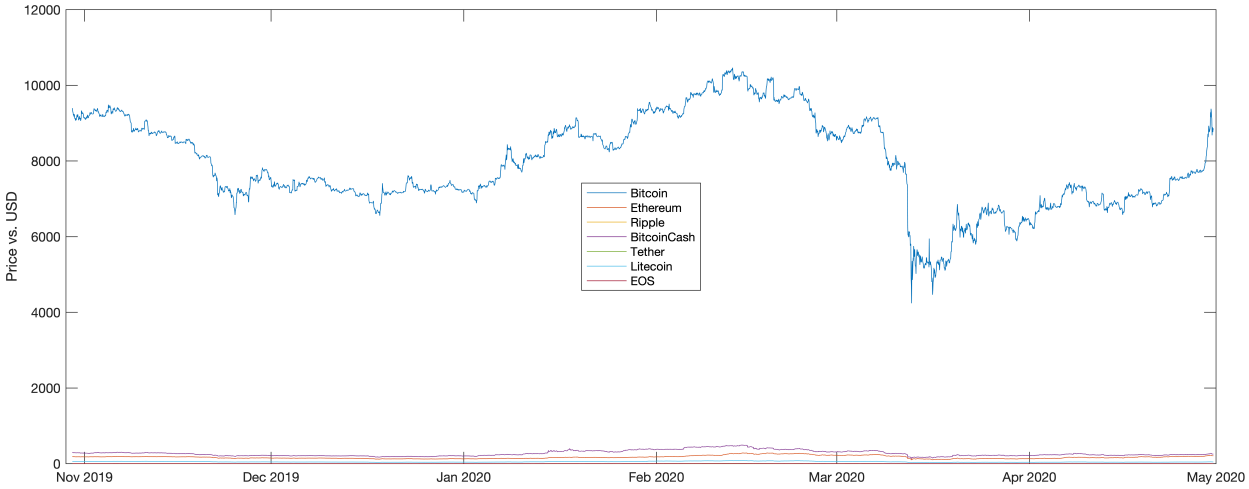
(TODO) Statistics summary

```
% head(crypto)
% corrplot(crypto);
```

Plot price

```
f=figure;
f.Position(3)= 2*f.Position(3);

plot(crypto.time,crypto.Bitcoin,'DisplayName','crypto.Bitcoin');hold on;plot(crypto.tim

legend({'Bitcoin','Ethereum','Ripple','BitcoinCash','Tether','Litecoin','EOS'},'Locatio
ylabel('Price vs. USD')
```

```
xlim(xrange)
```



Index price

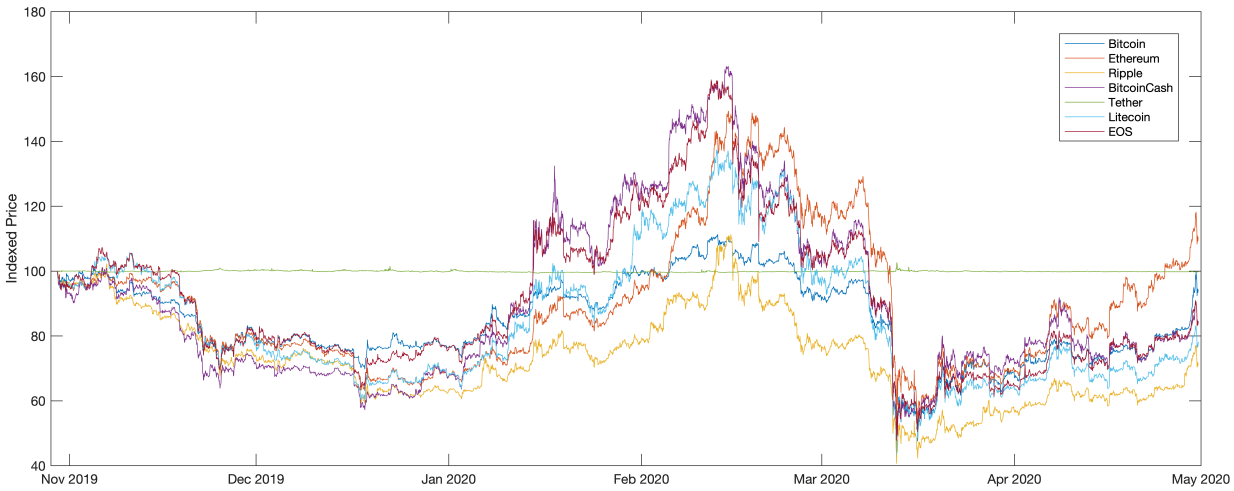
We use indexed price to better capture the volatility across cryptocurrencies and use it to build our signal.
Calculation reference: this page

$$\hat{X}_t = \frac{X_t}{X_0}$$

```
indexedPrice = crypto;
indexedPrice{2:end,:} = indexedPrice{2:end,:}./indexedPrice{1,:}*100;
indexedPrice{1,:} = 100;
```

Plot indexed price

```
plot(indexedPrice.time,indexedPrice.Bitcoin,'DisplayName','indexedPrice.Bitcoin');hold

legend({'Bitcoin','Ethereum','Ripple','BitcoinCash','Tether','Litecoin','EOS'},'Locatio
ylabel('Indexed Price')
xlim(xrange)
```



Tether is a stable coin.

Method

Exponential moving average

Ref: Chu, 2020.

$$EMA_t(P,\alpha) = \alpha \cdot P_t + (1-\alpha)EMA_{t-1}(P,\alpha) \;\; (t>0),\; EMA_0 = P_0 = 1,$$

where P_t is the indexed exchange rate of a cryptocurrency at time t, and $\alpha = \frac{1}{n_k}$ is the exponential smoothing ratio.

Span/windowsize, alpha, half-life conversion see pandas.ewm doc.

```
% arbitrarily, n_k for short and long emas are [n_s, n_l] (days)
n = [8,24;16,48;32,96]
```

```
n = 3×2
     8    24
    16    48
    32    96
```

```
% n = 2.*n-1; % span
```

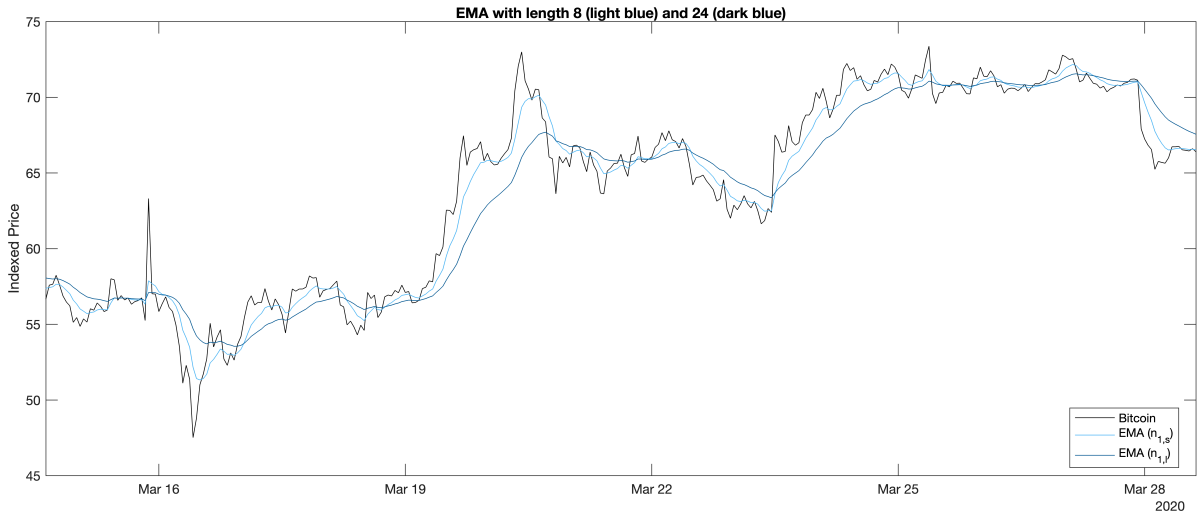
It can often be seen that the exchange rates of cryptocurrencies show short bursts of upwards or downwards movements over the course of a few hours, and an EMA can capture this shorter term influence.

```
ema = indexedPrice;
type = 'exponential';
for i = 1:3
    for j = 1:2
        windowSize = round(n(i,j));
        ema(:,end+1:end+7) = movavg(ema(:,1:7),type,windowSize);
    end
```

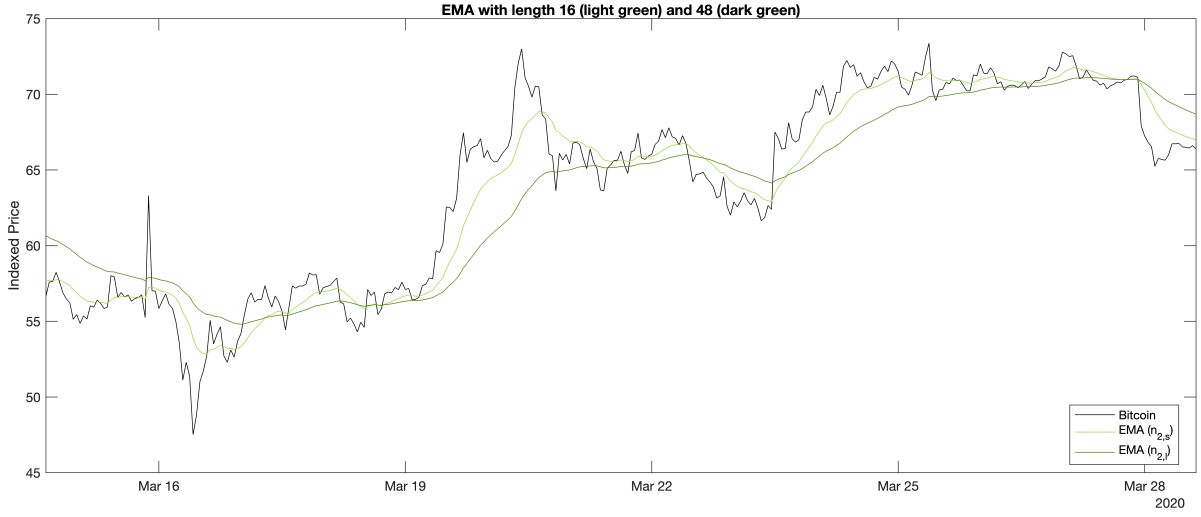
```
end

% head(ema)

bitcoinEma = ema(:,[1 8 15 22 29 36 43]);
bitcoinEma.Properties.VariableNames = {'Bitcoin' '8' '24' '16' '48' '32' '96'};
ethereumEma = ema(:,[2 9 16 23 30 37 44]);
ethereumEma.Properties.VariableNames = {'Ethereum' '8' '24' '16' '48' '32' '96'};
rippleEma = ema(:,[3 10 17 24 31 38 45]);
rippleEma.Properties.VariableNames = {'Ripple' '8' '24' '16' '48' '32' '96'};
bitcoincashEma = ema(:,[4 11 18 25 32 39 46]);
bitcoincashEma.Properties.VariableNames = {'BitcoinCash' '8' '24' '16' '48' '32' '96'};
tetherEma = ema(:,[5    12    19    26    33    40    47]);
tetherEma.Properties.VariableNames = {'Tether' '8' '24' '16' '48' '32' '96'};
litecoinEma = ema(:,[6    13    20    27    34    41    48]);
litecoinEma.Properties.VariableNames = {'Litecoin' '8' '24' '16' '48' '32' '96'};
eosEma = ema(:,[7    14    21    28    35    42    49]);
eosEma.Properties.VariableNames = {'EOS' '8' '24' '16' '48' '32' '96'};
```

Visualization

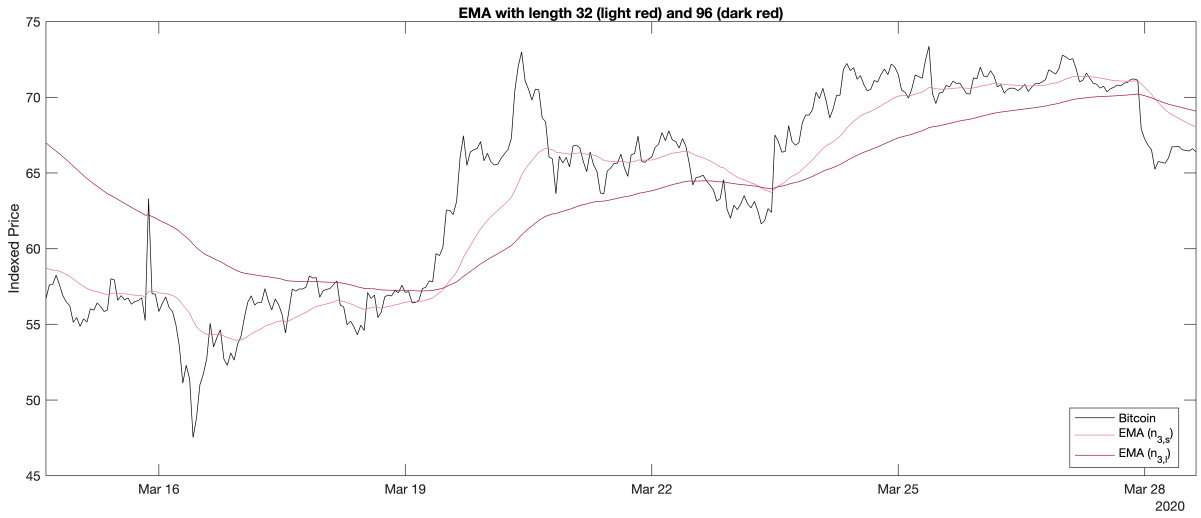
```
% change the symbol to see other crypto
symbol = bitcoinEma;
% change the datetime span to adjust plots horizon
span = [datetime(2020,3,14,15,0,0) datetime(2020,3,28,15,0,0)];


name = symbol.Properties.VariableNames(1);
name = string(name);

% plot n1
plot(symbol.time,symbol.(name),'k','DisplayName','bitcoinEma.Bitcoin');hold on;plot(sym

xlim(span)
legend({name,'EMA (n_{1,s})','EMA (n_{1,l})'},'Location','best')
title('EMA with length 8 (light blue) and 24 (dark blue)')
ylabel('Indexed Price')
```




```
% plot n2
plot(symbol.time,symbol.(name),'k','DisplayName','bitcoinEma.Bitcoin');hold on;plot(sym

xlim(span)
legend({name,'EMA (n_{2,s})','EMA (n_{2,l})'},'Location','best')
title('EMA with length 16 (light green) and 48 (dark green)')
ylabel('Indexed Price')
```




```
% plot n3
plot(symbol.time,symbol.(name),'k','DisplayName','bitcoinEma.Bitcoin');hold on;plot(sym

xlim(span)
legend({name,'EMA (n_{3,s})','EMA (n_{3,l})'},'Location','best')
title('EMA with length 32 (light red) and 96 (dark red)')
ylabel('Indexed Price')
```



Base signal for momentum strategy

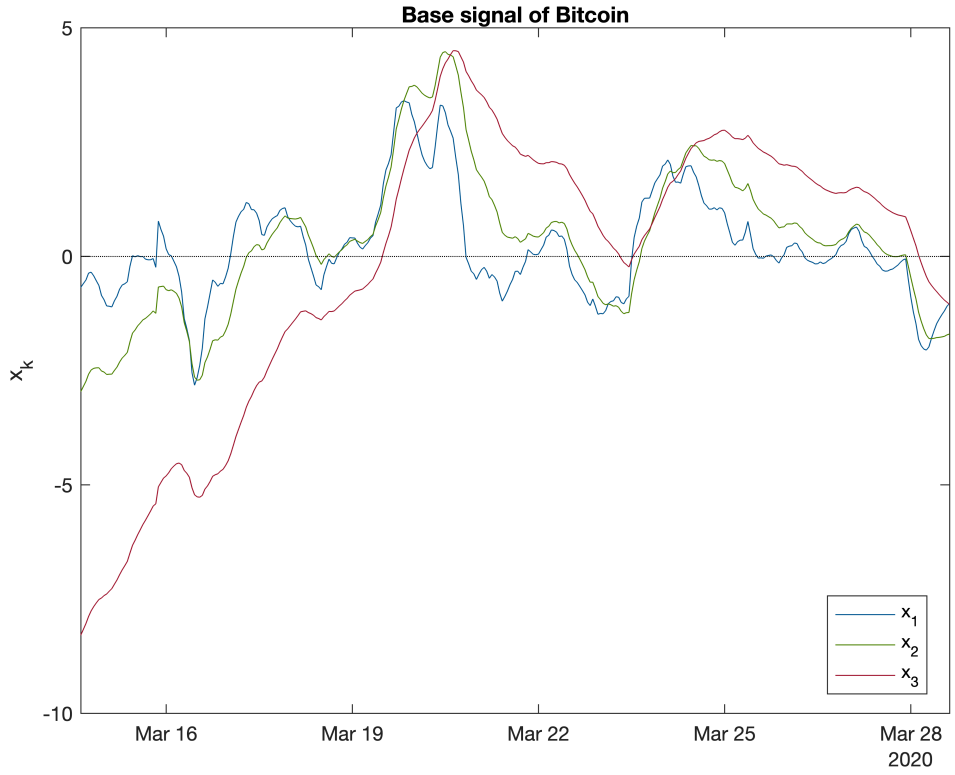
Its sign determines whether one goes long or short in this currency.

$$x_k = EMA\left(P, \frac{1}{n_{k,s}}\right) - EMA\left(P, \frac{1}{n_{k,l}}\right)$$

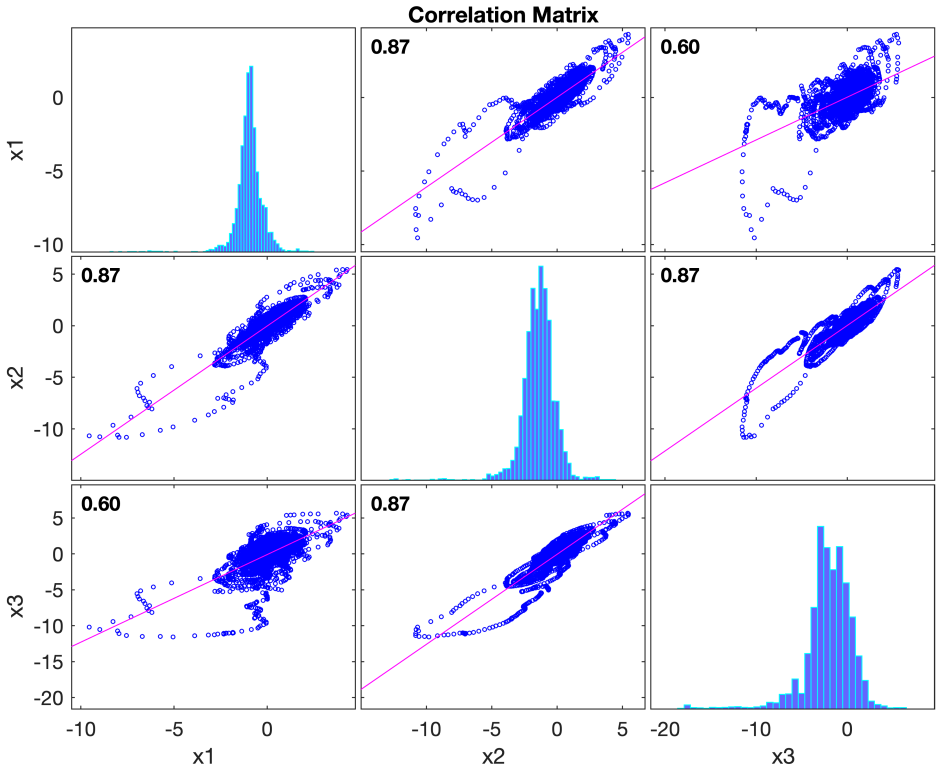
The values of x_k is

- positive: positive trend
- negative: negative trend
- equal to zero: the two EMAs intersect, trend changes direction.

```
% calculate base signal
baseSignal = timetable(symbol.time, symbol.(2)-symbol.(3),symbol.(4)-symbol.(5),symbol.

% plot
figure;
plot(baseSignal.Time,baseSignal.x1,'Color','#005891','DisplayName','baseSignal.x1');hol
hline(0,'k:');
xlim(span)
legend({'x_1','x_2','x_3'},'Location','best')
title('Base signal of '+name)
ylabel('x_k')
```




```
% correlation between x_k
corrplot(baseSignal);
```



Reducing the correlation leads to a longer time window, and vice versa.

(TODO:) One can optimize the n_k for each currency, but the risk of **overfitting** must be considered.

Two-step normalization

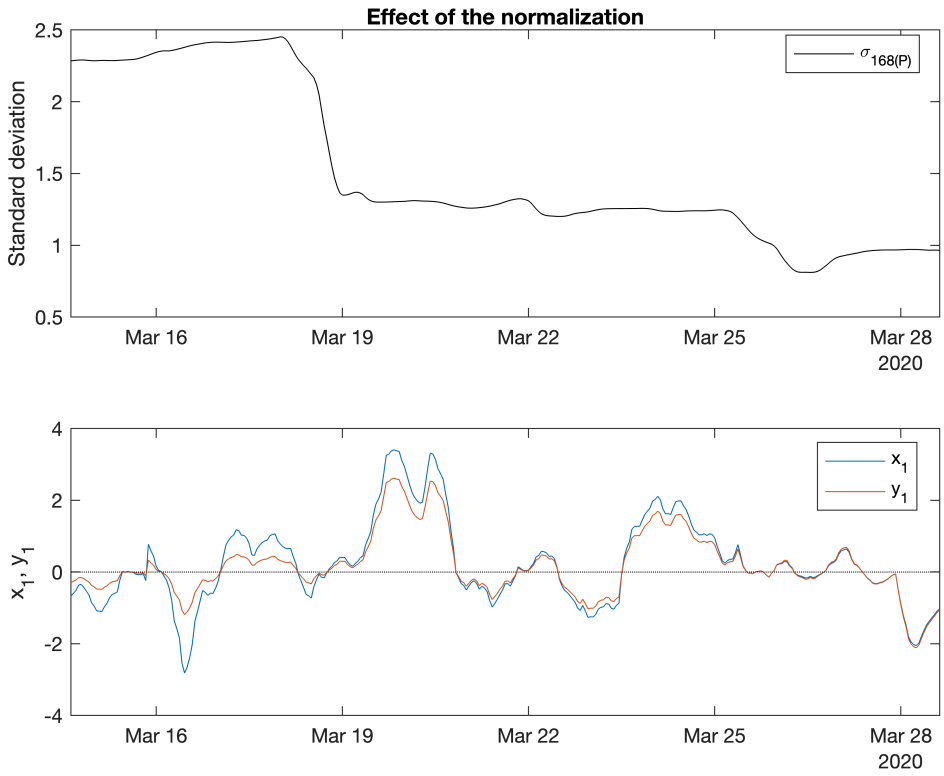
We use time frames of 168 h or one week (short) rolling standard deviations, and 1440 h or two month (long) rolling standard deviations with a 20% hold-out.

$$y_k = \frac{x_k}{\sigma_{168}(P)}, \quad z_k = \frac{y_k}{\sigma_{1440}(P)}$$

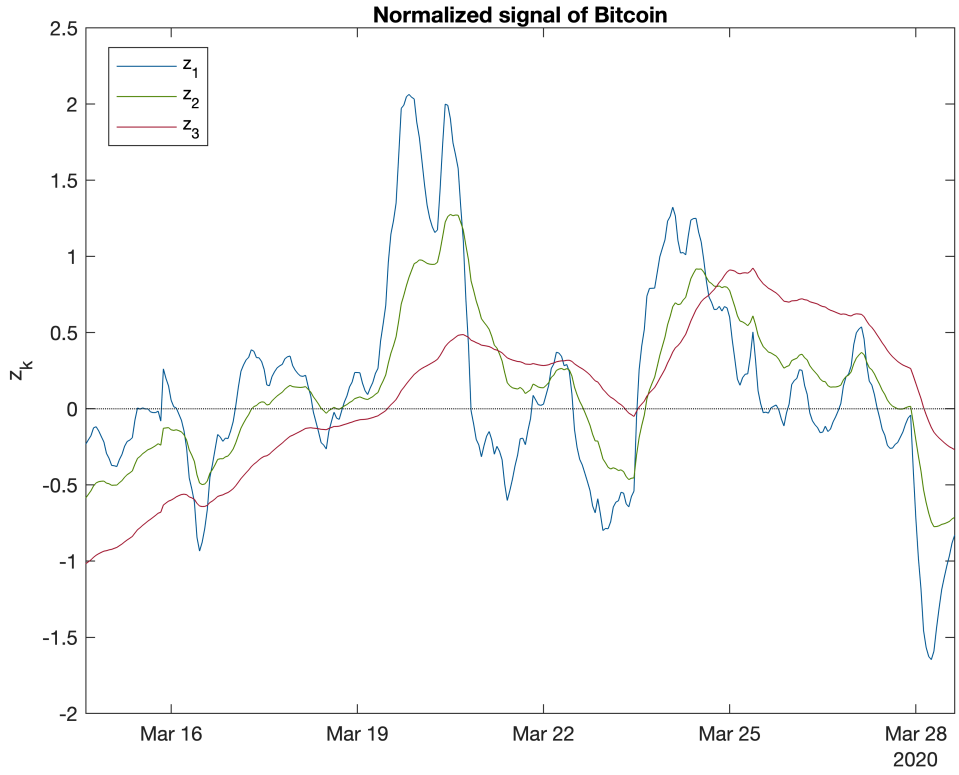
First transformation lowers high volatitly and amplifies low volatility. The second's effect is similar.

```
norm = baseSignal;
shortStd = movstd(norm.Variables,[134 33]);  % 168  = 134  +1 +33
longStd = movstd(norm.Variables,[1152 287]); % 1440 = 1152 +1 +287

yBaseSignal = norm.Variables./shortStd;
zBaseSignal = yBaseSignal./longStd;
norm(:,["y1" "y2" "y3"]) = array2table(yBaseSignal);
norm(:,["z1" "z2" "z3"]) = array2table(zBaseSignal);
norm(:,["std_s1" "std_s2" "std_s3"]) = array2table(shortStd);
norm(:,["std_l1" "std_l2" "std_l3"]) = array2table(longStd);

% plot effect of normalization
figure;
subplot(2,1,1);
```

```
plot(norm.Time,norm.std_s1,'k')
xlim(span)
legend({'\sigma_{168(P)}'},'Location','best')
title('Effect of the normalization')
ylabel('Standard deviation')
subplot(2,1,2);
plot(norm.Time,norm.x1,'DisplayName','norm.x1');hold on;plot(norm.Time,norm.y1,'Display
xlim(span)
hline(0,'k:');
legend({'x_1','y_1'},'Location','best')
ylabel('x_1, y_1');
```




```
% plot z_k
figure;
plot(norm.Time,norm.z1,'Color','#005891','DisplayName','norm.z1');hold on;plot(norm.Tim
hline(0,'k:');
xlim(span)
legend({'z_1','z_2','z_3'},'Location','best')
title('Normalized signal of '+name)
ylabel('z_k')
```

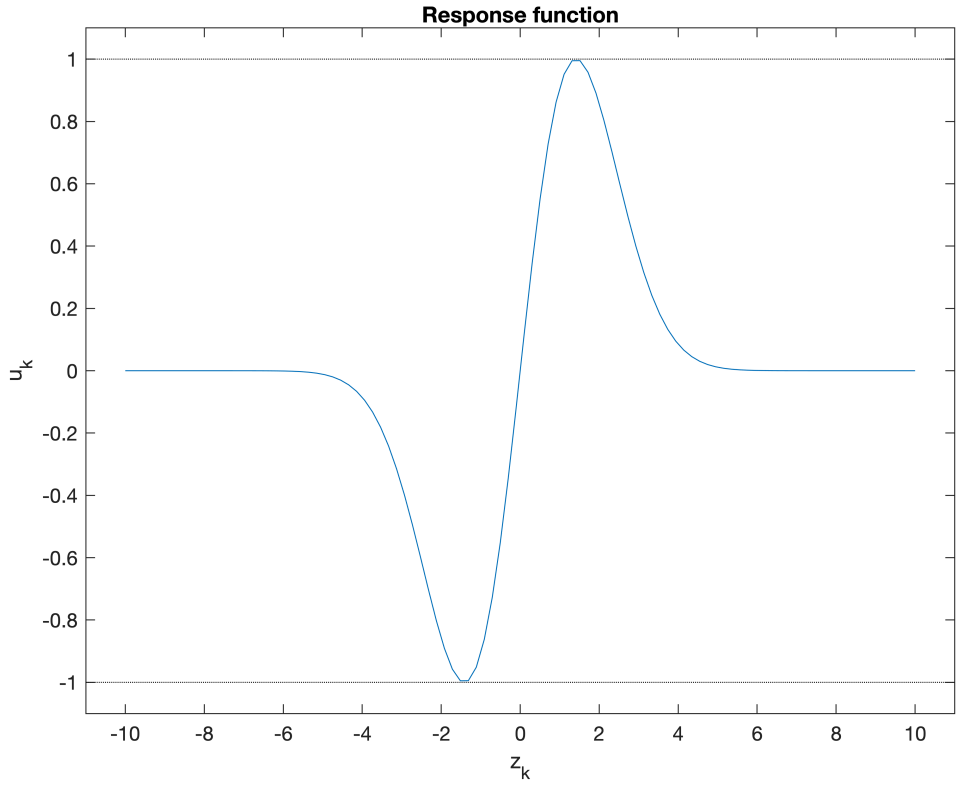


Generate signal

To scale z_k between -1 and 1, we use **response function** proposed by Rohrbach et al. (2017), which used geometric Brownian Motion.

$$u_k(z_k) = \frac{z_k \cdot e^{-z_k^2/4}}{\sqrt{2} \cdot e^{-1/2}}$$

```
z = linspace(-10,10);
u = (z.*exp(-z.^2/4)) / (sqrt(2)*exp(-1/2));
figure;
plot(z,u);
xlim([-11 11])
ylim([-1.1 1.1])
hline(1,'k:');
hline(-1,'k:');
title('Response function')
xlabel('z_k')
ylabel('u_k')
```



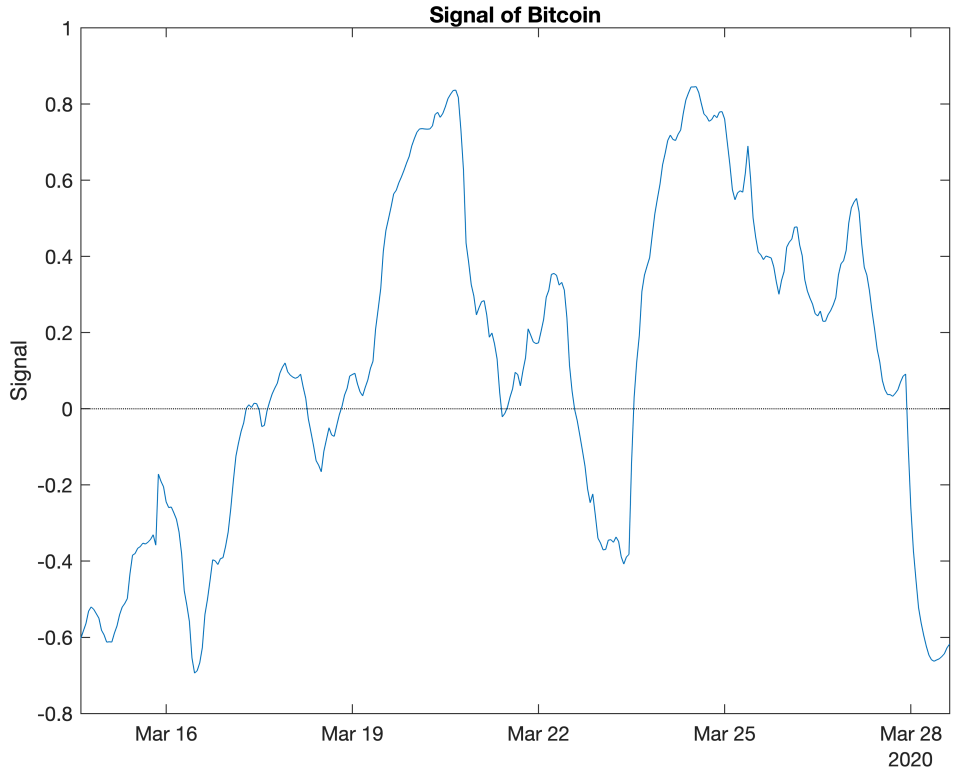

```
z_k = norm{:,["z1" "z2" "z3"]};
u_k = (z_k.*exp(-z_k.^2/4)) / (sqrt(2)*exp(-1/2));
```

Final signal is calculated as

$$Signal = \sum_{k=1}^{3} w_k u_k$$

with equal weighted $w_k = 1/3$.

```
signal = timetable(norm.Properties.RowTimes,mean(u_k,2));
signal.Properties.VariableNames = {'Signal'};
plot(signal.Time,signal.Signal);
xlim(span);
hline(0,'k:');
ylabel('Signal');
title('Signal of '+name);
```



Create signal for all cryptos

```
symbolsEma = {bitcoinEma,ethereumEma,rippleEma,bitcoincashEma,tetherEma,litecoinEma,eos

% table of signals
signalT = genRohrbachSignal(symbolsEma);
head(signalT)
```

```
ans = 8×7 timetable
```

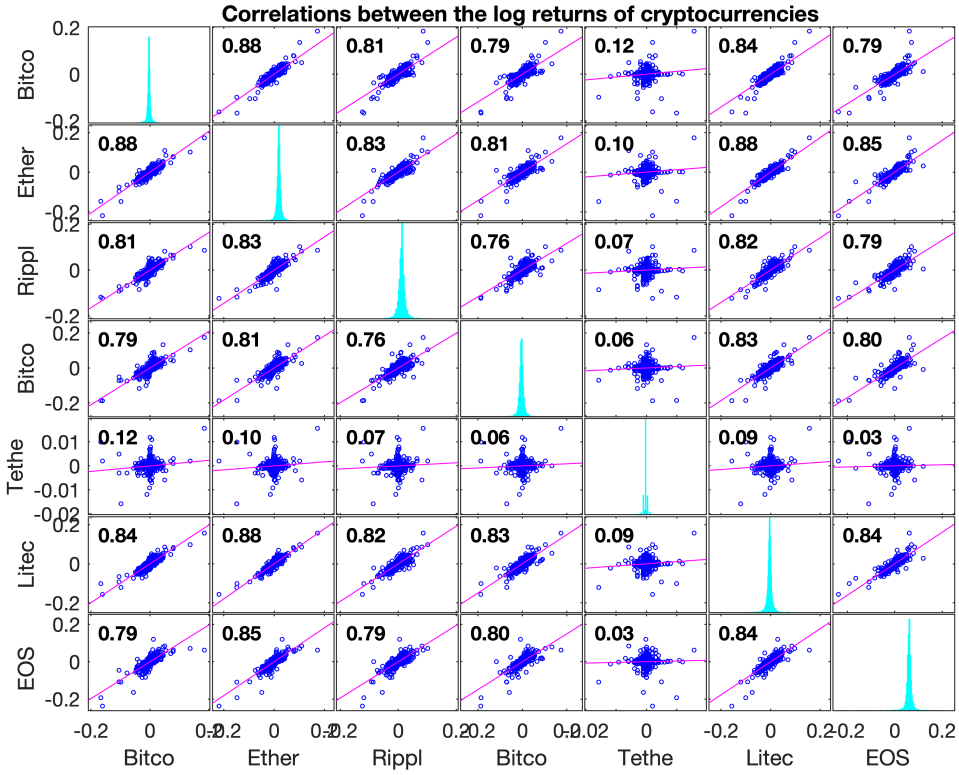
...

	Time	Bitcoin	Ethereum	Ripple	BitcoinCash	Tether	Litecoin
1	2019-10-...	0	0	0	0	0	0
2	2019-10-...	-0.3826	-0.0197	-0.2756	-0.3244	8.9672e-12	-0.1835
3	2019-10-...	-0.6693	-0.2524	-0.3150	-0.5926	1.8074e-11	-0.4759
4	2019-10-...	-0.7596	-0.5990	-0.5407	-0.6709	-4.2300e-09	-0.6628
5	2019-10-...	-0.7043	-0.6551	-0.7059	-0.6285	-8.6794e-08	-0.7370
6	2019-10-...	-0.6778	-0.6397	-0.7283	-0.5931	-3.5904e-30	-0.7759
7	2019-10-...	-0.5665	-0.6094	-0.7108	-0.5591	-4.3093e-64	-0.7870
8	2019-10-...	-0.5258	-0.5948	-0.7001	-0.5534	-1.0021e-106	-0.8177

Portfolio types

We find only Tether has weak correlationwith other cryptos' returns.

```
[rtn, intv] = tick2ret(crypto,'Method','Continuous'); % first timestamp dropped

% correlation
corrplot(rtn)
title('Correlations between the log returns of cryptocurrencies');
```



Times series port

Rebalancing every hour: buy (or sell) **1/n of the signal** units of US dollars for a cryptocurrency. n=7.

$$tsReturn_t = Signal_{t-1} \times \frac{1}{7} \times \frac{1}{P_{t-1}} \times R_t$$

where $1/P_{t-1}$ coincide with the indexed exchange rate of USD/crypto at signal period, R_t is the log return of indexed price at time t.

```
tsPort = signalT{:,:} ./7 ./crypto{:,:}; % cryptos
tsPort = array2table(tsPort,'VariableNames',{'Bitcoin','Ethereum','Ripple','BitcoinCash
tsPort = table2timetable(tsPort,"RowTimes",signalT.Properties.RowTimes);

tsRtn = tsPort{1:end-1,:} .* rtn{:,:};
tsRtn = array2table(tsRtn,'VariableNames',{'Bitcoin','Ethereum','Ripple','BitcoinCash',
tsRtn = table2timetable(tsRtn,"RowTimes",signalT.Properties.RowTimes(1:end-1));
```

Cross-sectional port

Each hour, we long the three cryptocurrencies with the largest signals, and short three with the most negative signals. These 6 trades are equally weighted in USD.

$$csReturn_t = \pm\frac{1}{6} \times \frac{1}{P_{t-1}} \times R_t$$

```
[B,posIdx] = maxk(signalT{:,:},3,2);
filterSignalT = signalT{:,:};
[C,negIdx] = mink(signalT{:,:},3,2);
for i = 2:length(filterSignalT)
    filterSignalT(i,posIdx(i,:)) =  1;
    filterSignalT(i,negIdx(i,:)) = -1;
end
filterSignalT((filterSignalT~=1) & (filterSignalT~=-1)) = 0;

csPort = filterSignalT(:,:) ./6 ./crypto{:,:};
csPort = array2table(csPort,'VariableNames',{'Bitcoin','Ethereum','Ripple','BitcoinCash
csPort = table2timetable(csPort,"RowTimes",signalT.Properties.RowTimes);

csRtn = csPort{1:end-1,:} .* rtn{:,:};
csRtn = array2table(csRtn,'VariableNames',{'Bitcoin','Ethereum','Ripple','BitcoinCash',
csRtn = table2timetable(csRtn,"RowTimes",signalT.Properties.RowTimes(1:end-1));
```

Benchmark

Equally weighted investment.

```
bmPort = 1 /7 ./crypto{:,:};
bmPort = array2table(bmPort,'VariableNames',{'Bitcoin','Ethereum','Ripple','BitcoinCash
bmPort = table2timetable(bmPort,"RowTimes",signalT.Properties.RowTimes);

bmRtn = rtn{:,:} .* bmPort{1:end-1,:};
bmRtn = array2table(bmRtn,'VariableNames',{'Bitcoin','Ethereum','Ripple','BitcoinCash',
bmRtn = table2timetable(bmRtn,"RowTimes",signalT.Properties.RowTimes(1:end-1));
```

Transaction Cost

(Lintilhac 2017) (Platanakis 2019)

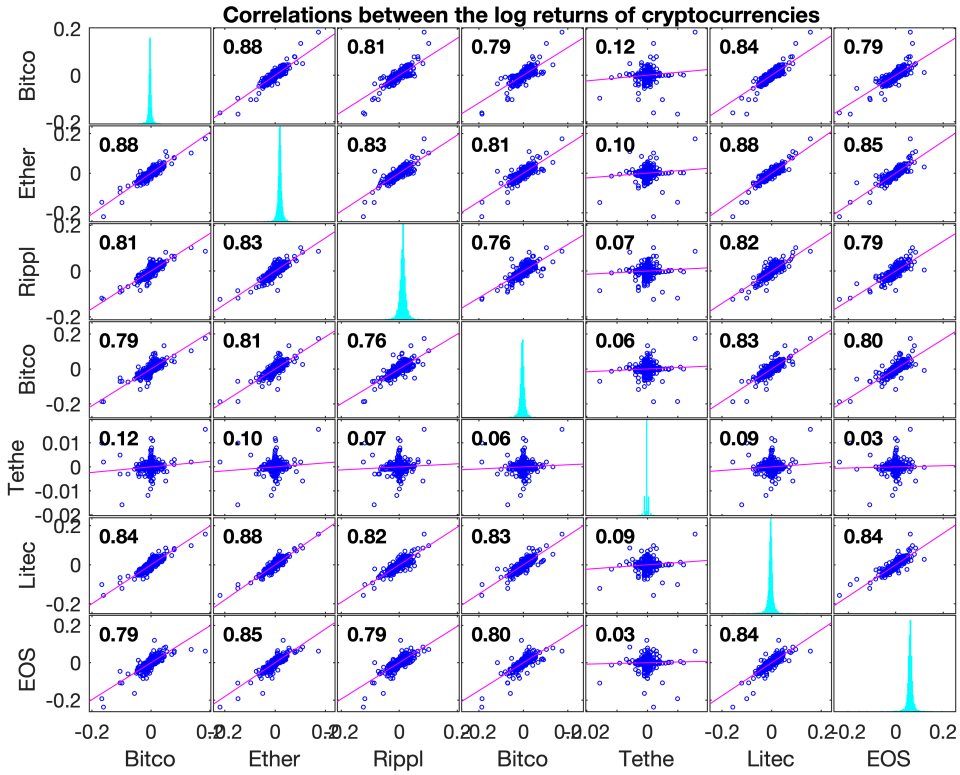
```
riskFreeRate      =   0.01/252; % PERCENT PER DAY
managementFeeRate =   0.01/252; % PERCENT PER DAY
```

(TODO) Market impact

```

```

Reorder colors. (Original third color yellow was hard to distinguish from the second color orange).

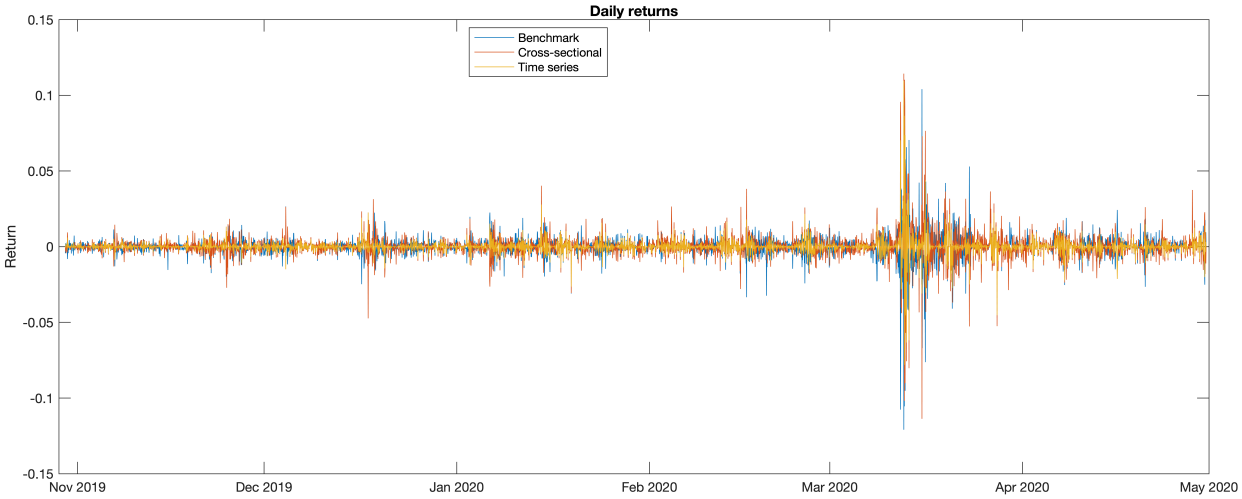
```
newcolors = [0 0.4470 0.7410
             0.8500 0.3250 0.0980
             0.4660 0.6740 0.1880];

colororder(newcolors)
```



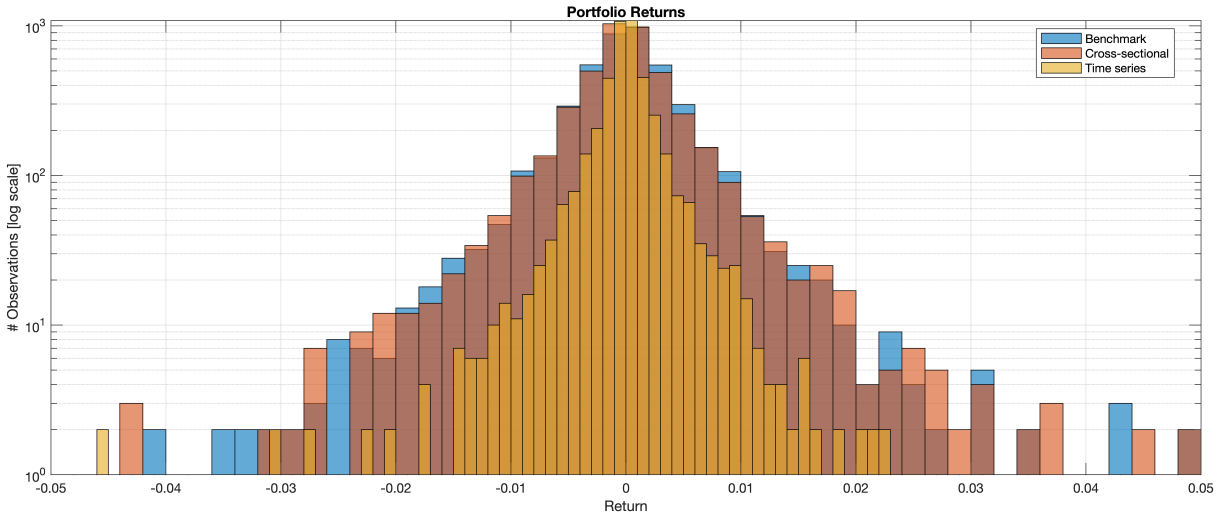
Performance Analysis

Returns

```
tsTotalRtn = sum(tsRtn{:,:},2);
csTotalRtn = sum(csRtn{:,:},2);
bmTotalRtn = sum(bmRtn{:,:},2);

% plot
f=figure;
f.Position(3)= 2*f.Position(3);
plot(indexedPrice.time(1:end-1),[bmTotalRtn csTotalRtn tsTotalRtn])
title('Daily returns');
legend({'Benchmark','Cross-sectional','Time series'},'Location','best');
ylabel('Return');
xlim(xrange)
```



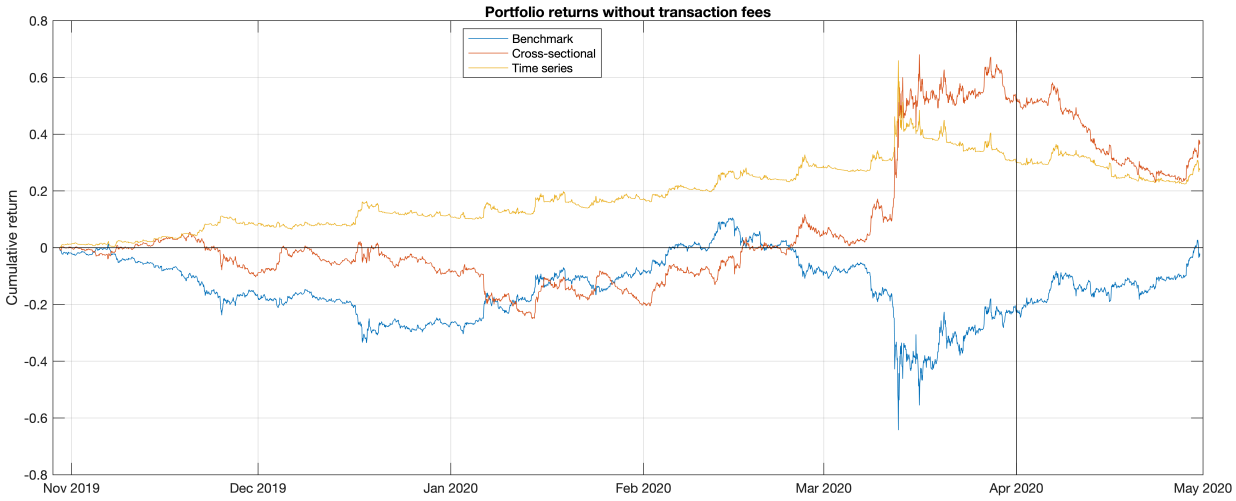

```
% histogram
histogram(bmTotalRtn); hold on;
histogram(csTotalRtn); hold on;
histogram(tsTotalRtn);
set(gca, 'YScale', 'log');
xlabel('Return');
ylabel('# Observations [log scale]');
title('Portfolio Returns');
legend({'Benchmark','Cross-sectional','Time series'},'Location','best');
grid on
% vline(0,'k-')
xlim([-5e-2 5e-2])
hold off;
```



Equity

Cross-sectional portfolio obtained highest cumulative return (without transaction cost) before April 2020.

```
% without transaction cost
tsCumRtn = cumsum(tsTotalRtn(:,:));
csCumRtn = cumsum(csTotalRtn(:,:));
bmCumRtn = cumsum(bmTotalRtn(:,:));

% plot
plot(indexedPrice.time(1:end-1),[bmCumRtn csCumRtn tsCumRtn])
grid on
hline(0,'k-');
vline(datetime(2020,4,1),'k-');
title('Portfolio returns without transaction fees');
legend({'Benchmark','Cross-sectional','Time series'},'Location','best');
ylabel('Cumulative return');
xlim(xrange)
```




```
% with transaction cost
```

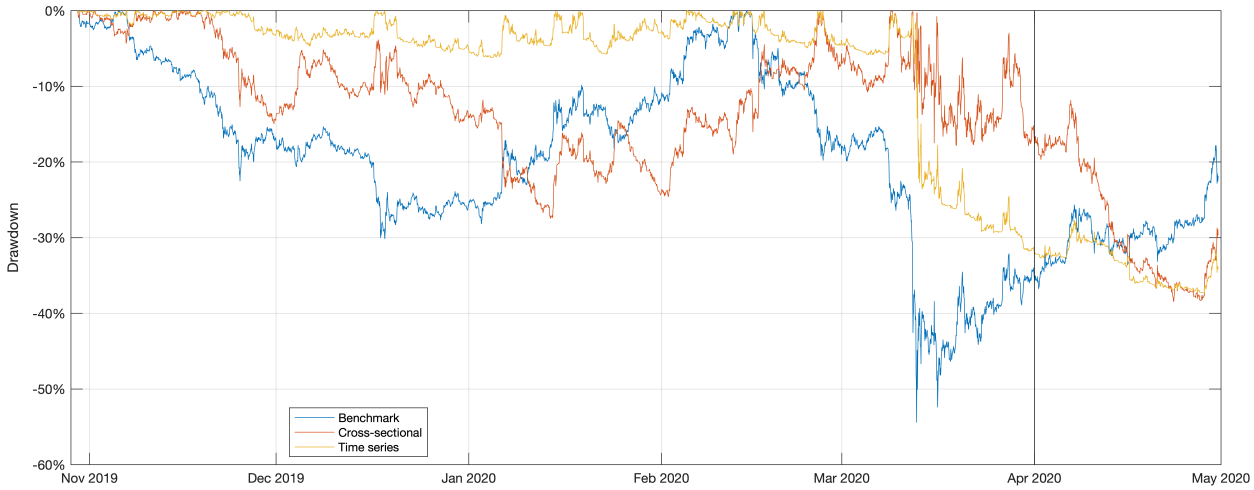
Drawdowns

"A drawdown is a peak-to-trough decline during a specific period for an investment, trading account, or fund. A drawdown is usually quoted as the percentage between the peak and the subsequent trough." (Investopedia)

We can see **cross-sectional** portfolio has least drawdown due to the COVID-19.

```
names = {'Benchmark','Cross-sectional','Time series'};
tsDD = 100.*-calculateDD(tsTotalRtn);
csDD = 100.*-calculateDD(csTotalRtn);
bmDD = 100.*-calculateDD(bmTotalRtn);

plot(rtn.time,[bmDD csDD tsDD]);
vline(datetime(2020,4,1),'k-');
ylabel('Drawdown');
ytickformat('%5.0f%%');
legend(strrep(names,'_',' '),'location','best');
```

```
grid on
xlim(xrange)
```



Performance summary

```
retns = table(bmTotalRtn,csTotalRtn,tsTotalRtn);
summaryPerformance(retns,riskFreeRate)
```

ans = 5×3 table

	bmTotalRtn	csTotalRtn	tsTotalRtn
1 TotalRetn	-0.0224	0.4442	0.3195
2 SharpeRatio	-0.0055	0.0053	0.0044
3 AverageRetn	-0.0000	0.0001	0.0001
4 Volatility	0.0081	0.0082	0.0052
5 MaxDrawdown	0.7486	0.4511	0.4361

Discussion and future work

Discussion

Strengths:

- Cross-sectional portfolio has the highest Sharpe ratio
- Time series portfolio performs better when not in crisis

Weakness:

- No single strategy beats others the whole time
- Long term Sharpe raios are small
- Asset selection is fixed

Future work

- **Data**: use TAQ data
- **Model**: Determine the mechanics set two strategies apart during crisis
- **Backtesting**: Take more specific transaction cost and market impact into account

Reference

1. Chu J, Chan S, Zhang Y. (2020) High frequency momentum trading with cryptocurrencies. *Research in international business and finance*. 52:101176.
2. Rohrbach, Janick and Suremann, Silvan and Osterrieder, Joerg (2017) Momentum and Trend Following Trading Strategies for Currencies and Bitcoin. *Combining Academia and Industry.*
3. P. S. Lintilhac & A. Tourin (2017) Model-based pairs trading in the bitcoin markets. *Quantitative Finance.* 17:5, 703-716.
4. Platanakis, Emmanouil & Urquhart, Andrew (2019) Portfolio management with cryptocurrencies: The role of estimation risk. *Economics Letters*. ISSN: 0165-1765, Volume 177, p. 76.

Local Functions

No need to include this part in slides.

Rohrbach Signal

```
function rohrbachSignal = genRohrbachSignal(symbolsEma)
    for i = 1:length(symbolsEma)
        symbol = symbolsEma{i};
        tick = symbol.Properties.VariableNames(1);
        tick = string(tick);
        baseSignal = timetable(symbol.time, symbol.(2)-symbol.(3),symbol.(4)-symbol.(5)

        shortStd = movstd(baseSignal.Variables,[134 33]);  % 168  = 134  +1 +33
        longStd = movstd(baseSignal.Variables,[1152 287]); % 1440 = 1152 +1 +287
        y = baseSignal.Variables./shortStd;
        z = y./longStd;
        u = (z.*exp(-z.^2/4)) / (sqrt(2)*exp(-1/2));

        signal = timetable(baseSignal.Properties.RowTimes,mean(u,2));
        signal.Properties.VariableNames = tick;

        rohrbachSignal(:,i) = signal;
        rohrbachSignal.Properties.VariableNames(i) = tick;
    end
end
```

Calculate Drawdowns

```
function DD = calculateDD(r)
Px = 100.*(cumprod(1+r)); % PRICE
for j=1:size(r,2)
    for i=1:length(Px)
        if i==1
```

```
            c(1,j) = Px(1,j);
            DD(1,j) = 0;
        else
            c(i,j) = max(Px(i,j),c(i-1,j));
            if c(i,j)==Px(i,j)
                DD(i,j)=DD(i-1,j);
            else
                DD(i,j) = 1-Px(i,j)./c(i,j);
            end
        end
    end
end
end
```

Performance of strategy

```
function performanceTable = summaryPerformance(returnTable,riskFreeRate)
    % compute performance metrics
    retns = returnTable{:,:};
    MeanRetn = mean(retns);
    StdRetn = sqrt(var(retns));
    SharpeRatio = (MeanRetn-riskFreeRate)./StdRetn;

    cmpRetn = ret2tick(retns, 'method', 'Continuous');
    MaxDD = maxdrawdown(cmpRetn,'geometric');
    TotalRetn = cmpRetn(end, :)-1;
    perfData = [TotalRetn', SharpeRatio', MeanRetn', StdRetn', MaxDD']';

    metricNames = {'TotalRetn', 'SharpeRatio', 'AverageRetn', 'Volatility', 'MaxDrawdow
    colStratsNames = (returnTable.Properties.VariableNames)';


    performanceTable = array2table(perfData, 'VariableNames', colStratsNames, 'RowNames

end
```