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# APPENDIX 01

## Parameter Estimation of Four SDE Models

```matlab
%This program compute the parameters of four SDE models
Brownian motion, Geometric Brownian motion, CIR model and
Vasicek model according to the Sri Lankan gold price using
maximum likelihood method
clc;
format long;
gold=xlsread('gold rate.xlsx'); %Read the excel file which
contains gold price data
N=length(gold)-1;
dt=1/252;                    %The length of the time step

%Parameters of Brownian motion using maximum likelihood
method
alpha_bm=(gold(end)-gold(1))/(dt*N);

SS1=0;
for i=1:N
    SS1=SS1+(gold(i+1)-gold(i)-alpha_bm*dt)^2;
End

sigma_bm=sqrt(SS1/(N*dt));

%Parameters of Geometric Brownian motion using maximum
likelihood method
SS2=0;
```

```matlab
for j=1:N
    SS2=SS2+(gold(j+1)-gold(j))/gold(j);
End


beta_gbm=SS2/(dt*N);


SS22=0;
for k=1:N
    SS22=SS22+((gold(k+1)-
(1+beta_gbm*dt)*gold(k))/gold(k))^2;
end


sigma_gbm=sqrt(SS22/(N*dt));



%Parameters of CIR model using maximum likelihood method
alpha_cir=(N*(gold(end)-gold(1))-(sum(gold)-
gold(end))*SS2)/(dt*(N^2-(sum(gold)-
gold(end))*(sum(1./gold)-1/gold(end))));


beta_cir=(gold(end)-gold(1)-alpha_cir*N*dt)/(dt*(sum(gold)-
gold(end)));


SS3=0;
for m=1:N
    SS3=SS3+(gold(m+1)-alpha_cir*dt-
(1+beta_cir*dt)*gold(m))^2/gold(m);
End


sigma_cir=sqrt(SS3/(N*dt));
```

```matlab
%Parameters  of  Vasicek  model  using  maximum  likelihood
method
SS41=0;
for b=1:N
    SS41=SS41+(gold(b+1)-gold(b))*gold(b);
end
sum_1=(((sum(gold)-gold(end))*SS41)-((gold(end)-
gold(1))*(sum(gold.^2)-gold(end)^2)))/(dt*((sum(gold)-
gold(end))^2-N*(sum(gold.^2)-gold(end)^2)));

alpha_vas=(((sum(gold)-gold(end))*SS41)-((gold(end)-
gold(1))*(sum(gold.^2)-gold(end)^2)))/(dt*((sum(gold)-
gold(end))^2-N*(sum(gold.^2)-gold(end)^2)));

beta_vas=(gold(end)-gold(1)-sum_1*N*dt)/(dt*(sum(gold)-
gold(end)));

SS4=0;
for p=1:N
    SS4=SS4+(gold(p+1)-alpha_vas*dt-
(1+beta_vas*dt)*gold(p))^2;
End

sigma_vas=sqrt(SS4/(N*dt));

%Create the table of parameters.
```

```matlab
parameter={'alpha(BM)';'sigma(BM)';'beta(GBM)';'sigma(GBM)'
;'alpha(CIR)';'beta(CIR)';'sigma(CIR)';'alpha(Vasicek)';'be
ta(Vasicek)';'sigma(Vasicek)'};

MLE=[alpha_bm;sigma_bm;beta_gbm;sigma_gbm;alpha_cir;beta_ci
r;sigma_cir;alpha_vas;beta_vas;sigma_vas];

T1=table(parameter,MLE);

fprintf('Parameters  of  four  SDE  models  using  maximum
likelihood estimation method \n');

disp(T1); %Display the table of parameters
```

**<u>Simulation and Forecasting Accuracy Measures</u>**

```matlab
%Written by WMHN Weerasinghe
%This  program  simulate  the  SDEs  using  Euler   Maruyama
method
%and test the forecasting accuracy using two tests RMSE and
MAPE

%Simulation
parameters;    %Run the program parameters

y=xlsread('gold_forecast.xlsx'); %Read the excel file which
contains the data use to forecast
m=length(y);
n=1:10:500000;
```

```matlab
BM=zeros(length(n),m);    %Vector of generating values of
Brownian motion

GBM=zeros(length(n),m);  %Vector of generating values of
Geometric Brownian motion

CIR=zeros(length(n),m); %Vector of generating values of CIR
model

Vasicek=zeros(length(n),m); %Vector of generating values of
Vasicek model
x0=y(1);    %Initial value

BM(:,1)=x0;
GBM(:,1)=x0;
CIR(:,1)=x0;
Vasicek(:,1)=x0;

for p=1:length(n)

A=randn([n(p),m-1]); %A matrix of random numbers

B=zeros(1,m-1);

    for b=1:m-1

    B(b)=mean(A(:,b));       %Calculate the mean of each
column of A

    end
```

```
    for c=2:m


 BM(p,c)=BM(p,c-1)+alpha_bm*dt+sigma_bm*sqrt(dt)*B(c-1);


 GBM(p,c)=GBM(p,c-1)+beta_gbm*GBM(p,c-1)*dt+
            sigma_gbm*GBM(p,c-1)*sqrt(dt)*B(c-1);


 CIR(p,c)=CIR(p,c-1)+((alpha_cir)+beta_cir*CIR(p,c-1))*dt+
            sigma_cir*sqrt(CIR(p,c-1))*sqrt(dt)*B(c-1);
  Vasicek(p,c)=Vasicek(p,c-1)+((alpha_vas)+
        beta_vas*Vasicek(p,c-
        1))*dt+sigma_vas*sqrt(dt)*B(c-1);


    end
end

for z=2:m

    figure;

    plot(n,BM(:,z)','r-',n,GBM(:,z)','b-',n,CIR(:,z)',
     'k-',n,Vasicek(:,z)','g-',n,y(z)*ones(1,length(n)));

    legend('BM','GBM','CIR','Vasicek','Actual');

end
x=1:length(gold)+length(y);
figure;
```

```matlab
plot(x,[gold' y']);

title('Gold price of Sri Lanka from 01st of October 2015 to
28th of October 2016');
xlabel('Date');
ylabel('Gold Price');
figure;

subplot(2,2,1);
plot(1:length(y),BM(length(n),:),1:length(y),y,'*');
title('Plot of past gold prices and forecasted gold prices
using BM model');

subplot(2,2,2);
plot(1:length(y),GBM(length(n),:),1:length(y),y,'*');
title('Plot of past gold prices and forecasted gold prices
using GBM model');

subplot(2,2,3);
plot(1:length(y),CIR(length(n),:),1:length(y),y,'*');
title('Plot of past gold prices and forecasted gold prices
using CIR model');

subplot(2,2,4);
plot(1:length(y),Vasicek(length(n),:),1:length(y),y,'*');
title('Plot of past gold prices and forecasted gold prices
using Vasicek model');
actual_data=y;
model1=BM(length(n),:)';
model2=GBM(length(n),:)';
```

```matlab
model3=CIR(length(n),:)';
model4=Vasicek(length(n),:)';
figure;
t=0:length(y)-1;
plot(t,model1','k-',t,model2','g-',t,model3','b-
',t,model4',
'c-',t,y,'r-');
legend('BM','GBM','CIR','Vasicek','actual');


T1=table(actual_data,model1,model2,model3,model4);
disp(T1);




A11=(y'-BM(length(n),:));
B11=(y'-GBM(length(n),:));
C11=(y'-CIR(length(n),:));
D11=(y'-Vasicek(length(n),:));

figure;
subplot(2,2,1);
plot(1:length(y),A11,'*');
subplot(2,2,2);
plot(1:length(y),B11,'*');
subplot(2,2,3);
plot(1:length(y),C11,'*');
subplot(2,2,4);
plot(1:length(y),D11,'*');
```

```matlab
%Forecasting accuracy

RMSE1=sqrt(sum(abs(A11).^2)/length(y));
RMSE2=sqrt(sum(abs(B11).^2)/length(y));
RMSE3=sqrt(sum(abs(C11).^2)/length(y));
RMSE4=sqrt(sum(abs(D11).^2)/length(y));


MAPE1=(sum(abs(A11)./BM(length(n),:))/length(y))*100;
MAPE2=(sum(abs(B11)./GBM(length(n),:))/length(y))*100;
MAPE3=(sum(abs(C11)./CIR(length(n),:))/length(y))*100;
MAPE4=(sum(abs(D11)./Vasicek(length(n),:))/length(y))*100;


model={'Brownian  Motion';  'Geometric  Brownian  Motion';
'CIR';'Vasicek'};


RMSE=[RMSE1;RMSE2;RMSE3;RMSE4];


MAPE=[MAPE1;MAPE2;MAPE3;MAPE4];


T2=table(model,RMSE,MAPE);


disp(T2);
```

**Sample Paths Generation**

```matlab
%This program generates sample paths for the SDE models,
Brownian motion, geometric Brownian motion, CIR model and
Vasicek model.

parameters;
```

```matlab
y=xlsread('gold_forecast.xlsx'); %Read the excel file which
contains the data use to forecast

m=101;
n=5;
BM=zeros(n,m);   %Vector of generating values of Brownian
motion
GBM=zeros(n,m); %Vector of generating values of Geometric
Brownian motion
CIR=zeros(n,m); %Vector of generating values of CIR model
Vasicek=zeros(n,m); %Vector of generating values of Vasicek
model


x0=y(1);    %Initial value

BM(:,1)=x0;
GBM(:,1)=x0;
CIR(:,1)=x0;
Vasicek(:,1)=x0;

for p=1:n
    A=randn([n,m-1]); %A matrix of random numbers

    for c=2:m

  BM(p,c)=BM(p,c-1)+alpha_bm*dt+sigma_bm*sqrt(dt)*A(p,c-1);

  GBM(p,c)=GBM(p,c-1)+beta_gbm*GBM(p,c-1)*dt+
            sigma_gbm*GBM(p,c-1)*sqrt(dt)*A(p,c-1);
```

```matlab
        CIR(p,c)=CIR(p,c-1)+((alpha_cir)+beta_cir*CIR(p,c-1))*dt+
            sigma_cir*sqrt(CIR(p,c-1))*sqrt(dt)*A(p,c-1);


        Vasicek(p,c)=Vasicek(p,c-1)+
            ((alpha_vas)+beta_vas*Vasicek(p,c-1))*dt+
            sigma_vas*sqrt(dt)*A(p,c-1);


        end

end
figure

for i_1=1:n
    hold on;
    plot(0:m-1,BM(i_1,:));
end

figure;

for i_2=1:n
    hold on;
    plot(0:m-1,GBM(i_2,:));
end

figure;

for i_3=1:n
    hold on;
    plot(0:m-1,CIR(i_3,:));
```
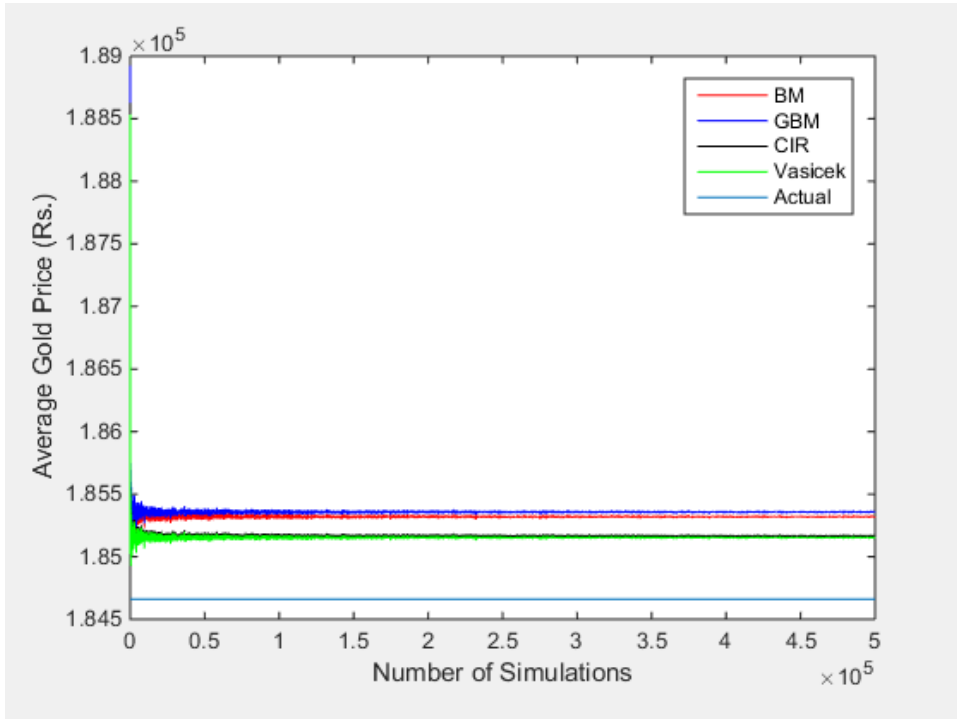
```matlab
end
figure;

for i_4=1:n
    hold on;
    plot(0:m-1,Vasicek(i_4,:));
end
```
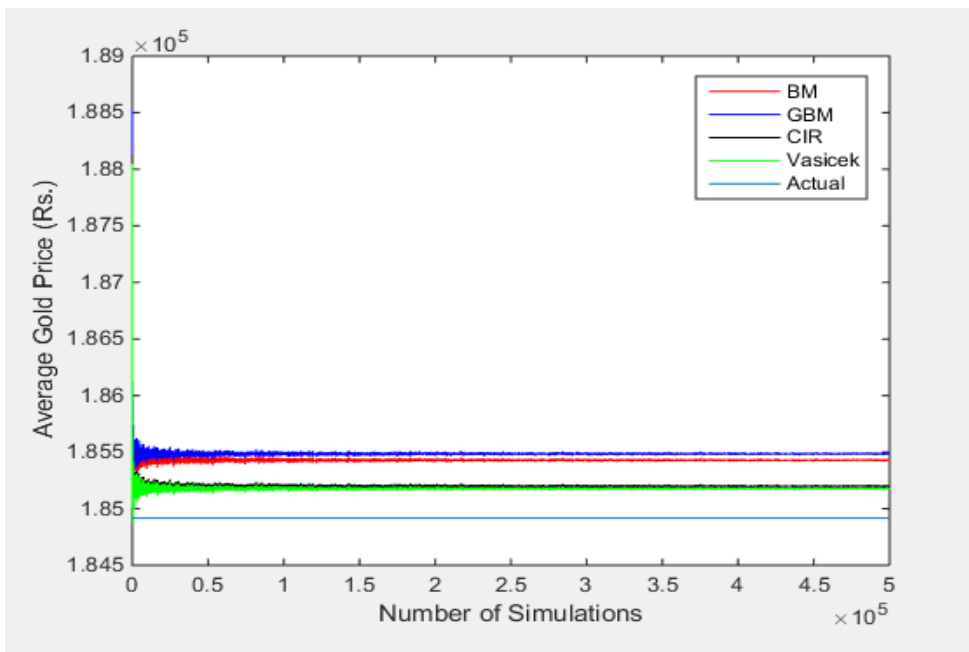
# APPENDIX 02

**Monte Carlo simulations of the forecasted gold prices from 12<sup>th</sup> of October 2016 to 14<sup>th</sup> of October 2016.**
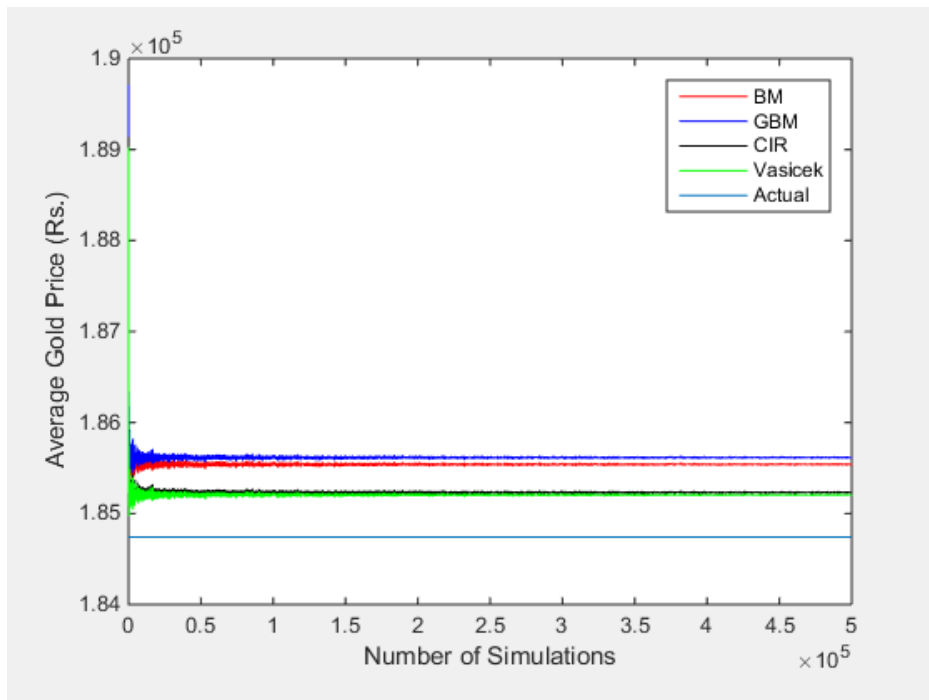
**<u>12/10/2016</u>**



**<u>13/10/2016</u>**

**14/10/2016**

# APPENDIX 03

## Gold Price of Sri Lanka in Rupees from 01/10/2015 to 14/10/2016

| Date | Gold Price (Rs.) | Date | Gold Price (Rs.) |
|------|------------------|------|------------------|
| 01.10.2015 | 157574.104 | 04.11.2015 | 158333.5129 |
| 02.10.2015 | 157134.843 | 05.11.2015 | 156819.7196 |
| 05.10.2015 | 160768.1198 | 06.11.2015 | 156934.9254 |
| 06.10.2015 | 160487.2945 | 09.11.2015 | 154711.1945 |
| 07.10.2015 | 161959.6559 | 11.11.2015 | 154970.0821 |
| 08.10.2015 | 160774.8253 | 12.11.2015 | 154546.4881 |
| 09.10.2015 | 160728.0625 | 13.11.2015 | 153732.0576 |
| 12.10.2015 | 162490.3533 | 16.11.2015 | 155136.5138 |
| 13.10.2015 | 162442.4899 | 17.11.2015 | 154112.8495 |
| 14.10.2015 | 164685.7591 | 18.11.2015 | 151885.0426 |
| 15.10.2015 | 166316.0396 | 19.11.2015 | 153455.7704 |
| 16.10.2015 | 166228.3504 | 20.11.2015 | 154174.6454 |
| 19.10.2015 | 165650.7861 | 23.11.2015 | 152459.4916 |
| 20.10.2015 | 164663.7863 | 24.11.2015 | 152738.933 |
| 21.10.2015 | 166008.0883 | 26.11.2015 | 153252.5517 |
| 22.10.2015 | 164343.1347 | 27.11.2015 | 153094.9603 |
| 23.10.2015 | 164931.795 | 30.11.2015 | 150926.2789 |
| 26.10.2015 | 164243.6864 | 01.12.2015 | 153616.6656 |
| 28.10.2015 | 164680.2028 | 02.12.2015 | 153187.3727 |
| 29.10.2015 | 163635.9117 | 03.12.2015 | 150522.2986 |
| 30.10.2015 | 161538.0497 | 04.12.2015 | 152087.5964 |
| 02.11.2015 | 160814.9254 | 07.12.2015 | 155407.1923 |
| 03.11.2015 | 160128.1341 | 08.12.2015 | 153197.9607 |
| | | 09.12.2015 | 154163.515 |

| | | | |
|---|---|---|---|
| 10.12.2015 | 153780.3309 | 27.01.2016 | 161285.5816 |
| 11.12.2015 | 152829.6352 | 28.01.2016 | 161164.864 |
| 14.12.2015 | 154150.6484 | 29.01.2016 | 160529.2603 |
| 15.12.2015 | 152803.6777 | 01.02.2016 | 161311.9 |
| 16.12.2015 | 152638.9139 | 02.02.2016 | 162226.4738 |
| 17.12.2015 | 153312.7431 | 03.02.2016 | 162419.2105 |
| 18.12.2015 | 151484.4273 | 05.02.2016 | 166259.5578 |
| 21.12.2015 | 153315.7149 | 08.02.2016 | 167758.2265 |
| 22.12.2015 | 154716.2058 | 09.02.2016 | 171661.2504 |
| 23.12.2015 | 154189.7187 | 10.02.2016 | 171579.165 |
| 28.12.2015 | 154134.3139 | 11.02.2016 | 173622.545 |
| 29.12.2015 | 154247.0284 | 12.02.2016 | 178058.1478 |
| 30.12.2015 | 153982.5198 | 15.02.2016 | 176002.7446 |
| 31.12.2015 | 153015.7719 | 16.02.2016 | 172935.1131 |
| 01.01.2016 | 152822.509 | 17.02.2016 | 173040.231 |
| 04.01.2016 | 153507.5012 | 18.02.2016 | 173903.15 |
| 05.01.2016 | 155184.4858 | 19.02.2016 | 176602.11 |
| 06.01.2016 | 155207.84 | 23.02.2016 | 174999.9904 |
| 07.01.2016 | 158331.7341 | 24.02.2016 | 176730.9793 |
| 08.01.2016 | 158796.2628 | 25.02.2016 | 177616.3693 |
| 11.01.2016 | 158874.4732 | 26.02.2016 | 178082.7255 |
| 12.01.2016 | 157582.4629 | 29.02.2016 | 176876.9562 |
| 13.01.2016 | 155826.0485 | 01.03.2016 | 179291.175 |
| 14.01.2016 | 157105.9157 | 02.03.2016 | 176636.1159 |
| 18.01.2016 | 156989.6548 | 03.03.2016 | 178804.8162 |
| 19.01.2016 | 156956.5374 | 04.03.2016 | 181787.1656 |
| 20.01.2016 | 157114.0797 | 08.03.2016 | 183199.09 |
| 21.01.2016 | 158324.0206 | 09.03.2016 | 180597.7545 |
| 22.01.2016 | 158188.5505 | 10.03.2016 | 180130.7807 |
| 25.01.2016 | 158333.17 | 11.03.2016 | 184523.7413 |
| 26.01.2016 | 159846.0911 | 14.03.2016 | 180600.9755 |

| | | | | |
|---|---|---|---|---|
| 15.03.2016 | 176673.225 | | 05.05.2016 | 186595.6066 |
| 16.03.2016 | 177317.591 | | 06.05.2016 | 186511.8118 |
| 17.03.2016 | 180702.425 | | 09.05.2016 | 187537.0032 |
| 18.03.2016 | 181760.09 | | 10.05.2016 | 184255.8889 |
| 21.03.2016 | 180321.09 | | 11.05.2016 | 184993.0894 |
| 23.03.2016 | 179084.1829 | | 12.05.2016 | 185651.9775 |
| 24.03.2016 | 175202.5113 | | 13.05.2016 | 184737.3963 |
| 28.03.2016 | 174234.5413 | | 16.05.2016 | 186248.433 |
| 29.03.2016 | 175485.3305 | | 17.05.2016 | 186488.904 |
| 30.03.2016 | 178063.875 | | 18.05.2016 | 186112.6838 |
| 31.03.2016 | 176679.7005 | | 19.05.2016 | 183309.0463 |
| 01.04.2016 | 176953.1105 | | 20.05.2016 | 183083.8625 |
| 04.04.2016 | 175334.955 | | 24.05.2016 | 181939.725 |
| 05.04.2016 | 176270.305 | | 25.05.2016 | 178937.275 |
| 06.04.2016 | 176787.6255 | | 26.05.2016 | 179549.425 |
| 07.04.2016 | 176392.62 | | 27.05.2016 | 177261.15 |
| 08.04.2016 | 178018.69 | | 30.05.2016 | 175220.65 |
| 11.04.2016 | 179975.73 | | 31.05.2016 | 176874.9125 |
| 12.04.2016 | 180600.9755 | | 01.06.2016 | 177780.4877 |
| 15.04.2016 | 176709.2 | | 02.06.2016 | 177328.5583 |
| 18.04.2016 | 177846.01 | | 03.06.2016 | 176673.9345 |
| 19.04.2016 | 177140.9 | | 06.06.2016 | 181326.405 |
| 20.04.2016 | 180378.65 | | 07.06.2016 | 181560.878 |
| 22.04.2016 | 179910.2555 | | 08.06.2016 | 181823.125 |
| 25.04.2016 | 177546.7811 | | 09.06.2016 | 183973.4659 |
| 26.04.2016 | 178406.5005 | | 10.06.2016 | 184399.1276 |
| 27.04.2016 | 179169.89 | | 13.06.2016 | 184745.9643 |
| 28.04.2016 | 178709.41 | | 14.06.2016 | 185493.7931 |
| 29.04.2016 | 183342.99 | | 15.06.2016 | 185884.79 |
| 03.05.2016 | 186285.745 | | 16.06.2016 | 187842.075 |
| 04.05.2016 | 186575.2044 | | 17.06.2016 | 185016.4683 |

| Date | Value | | Date | Value |
|---|---|---|---|---|
| 20.06.2016 | 185573.4025 | | 04.08.2016 | 197765.6975 |
| 21.06.2016 | 186180.0418 | | 05.08.2016 | 198085.3093 |
| 22.06.2016 | 184273.7825 | | 08.08.2016 | 194674.48 |
| 23.06.2016 | 183850.1875 | | 09.08.2016 | 194271.168 |
| 24.06.2016 | 185933.7988 | | 10.08.2016 | 196370.72 |
| 27.06.2016 | 192731.4988 | | 11.08.2016 | 195700.96 |
| 28.06.2016 | 191889.775 | | 12.08.2016 | 194986.0123 |
| 29.06.2016 | 191809.8875 | | 15.08.2016 | 194729.1975 |
| 30.06.2016 | 191170.7875 | | 16.08.2016 | 195495.9825 |
| 01.07.2016 | 192876.7488 | | 18.08.2016 | 197093.5725 |
| 04.07.2016 | 196820.2863 | | 19.08.2016 | 196010.325 |
| 05.07.2016 | 195225.1486 | | 22.08.2016 | 194094.09 |
| 07.07.2016 | 198798.2002 | | 23.08.2016 | 194542.23 |
| 08.07.2016 | 196973.525 | | 24.08.2016 | 194651.355 |
| 11.07.2016 | 198984.5113 | | 25.08.2016 | 192829.8546 |
| 12.07.2016 | 197169.6125 | | 26.08.2016 | 193043.0764 |
| 13.07.2016 | 193876.63 | | 29.08.2016 | 191658.3833 |
| 14.07.2016 | 194670.5863 | | 30.08.2016 | 192720.5204 |
| 15.07.2016 | 193065.5738 | | 31.08.2016 | 191475.738 |
| 18.07.2016 | 193022.725 | | 01.09.2016 | 190839.0033 |
| 20.07.2016 | 193507.86 | | 02.09.2016 | 191121.7462 |
| 21.07.2016 | 190912.2425 | | 05.09.2016 | 192579.2945 |
| 22.07.2016 | 193789.2 | | 06.09.2016 | 192866.5032 |
| 25.07.2016 | 191945.4625 | | 07.09.2016 | 196240.1892 |
| 26.07.2016 | 192345.5463 | | 08.09.2016 | 195801.9492 |
| 27.07.2016 | 192163.3588 | | 09.09.2016 | 194602.9175 |
| 28.07.2016 | 194877.7789 | | 13.09.2016 | 193267.6899 |
| 29.07.2016 | 195048.3024 | | 14.09.2016 | 191694.3008 |
| 01.08.2016 | 196728.9775 | | 15.09.2016 | 192861.6922 |
| 02.08.2016 | 196529.3 | | 19.09.2016 | 191707.1159 |
| 03.08.2016 | 198660.6372 | | 20.09.2016 | 191849.9963 |

| | |
|---|---|
| 21.09.2016 | 191775.8014 |
| 22.09.2016 | 194711.5757 |
| 23.09.2016 | 194834.86 |
| 26.09.2016 | 195314.8651 |
| 27.09.2016 | 195402.5499 |
| 28.09.2016 | 193956.3162 |
| 29.09.2016 | 194065.7428 |
| 30.09.2016 | 194305.1365 |
| 03.10.2016 | 193448.7159 |
| 04.10.2016 | 192048.5351 |
| 05.10.2016 | 186601.3864 |
| 06.10.2016 | 185938.9861 |
| 07.10.2016 | 184526.5768 |
| 10.10.2016 | 185099.7832 |
| 11.10.2016 | 184942.1631 |
| 12.10.2016 | 184661.3795 |
| 13.10.2016 | 184916.9855 |
| 14.10.2016 | 184741.44 |