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Furthermore, I confirm that I understand the definition of plagiarism that is used by Durham University, and that all source material has been appropriate cited and referenced.

I understand that only the content in the main body of the work will be marked, and that the content in the Appendices will be checked, but will not contribute to the marking of my assignment.

Instructions:

The main text of your assignment should come first in your submission, followed by all Tables and diagrams, and any additional but secondary content, which should be placed at the back of the assignment in the 'Appendices' section, after the References/Bibliography.

This assignment should be produced in Arial, 12pt, with 1.5 line spacing.

Please note that these instructions overrule guidance that you may have seen elsewhere.

Durham University Business School

Durham University

Pricing FX Options Using European Volatility Surface - Modeling and Empirical Analysis

Z0189061

International Financial Asset Pricing

Dr Williams

2 May 2023

Part 1: Motivation and Modelling Choices for Each Currency Pair

a)

There are several models which may be used to construct a European volatility surface for pricing FX options; however the selection of models depends on the characteristics of each currency - such as whether the currency is free-floating and the option's trading liquidity. The following section will discuss the characteristics of the Euro (EUR)/Swiss Franc (CHF), Norwegian Krone (NOK)/Swedish Krona (SEK) and U.S. Dollar(USD)/Taiwanese New Dollar(TWD). Furthermore, Part 1 will use these characteristics to determine which model best suits the mentioned currency pairs.

To begin, both the EUR and CHF are free-floating currencies meaning that market forces of supply and demand determine their exchange rates in the foreign exchange market. Being that they are both free-float currencies, there are no official pegs or fixed exchange rates between them and any other currency. Similarly, the NOK and the CHF, are both also considered to be free-floating currencies. While the central banks of Norway and Sweden have historically intervened with the foreign exchange markets, they do not officially have pegged exchange rates with each other nor with any other currency. Similarly, since NOK and SEK are both actively traded currencies, there is an active options market for NOKSEK options. For the USD and the TWD there has been a historic intervention with Taiwan's central bank where they have managed the exchange rate of the TWD resulting in periods when the TWD has been pegged to the USD. While the TWD has been considered to be a "dirty-float currency," it is not officially deemed as a pegged currency. Meanwhile, the USD is considered a free-float currency and non pegged either (Zucchi 2023). Since each currency is free-floated, has an active options market, is not pegged, and has adequate market data, one may proceed by calibrating the model off the options data itself. However, to adequately plot the European Surface of each currency pair, it is best to plot the 10 and 25 delta puts/calls so one may choose adequate dates for the European surface plots and also understand the historical pegs or geopolitical affairs which may have affected it.

b)

For all the currency pairs, it will be useful to use the market quotes (option price) datasets to construct the European Volatility surface; since there is options data on each of the studied currencies, it is worthwhile to use the options data to do this. However, it is essential to keep in mind that the data used is limited to exchange rate data, interest rate data, and options data. While the data is limited, it is necessary to use the given options data of each of these currencies and select appropriate dates for the European surface; this is possible by plotting a time series of different delta values, then noting any implied volatility jumps, and comparing other European surfaces on dates both before and after the spike; while none of the currencies are necessarily pegged, choosing the optimal date for plotting the volatility surface should be prioritised. Furthermore, each country has distinct geopolitical histories and trading deals which greatly affect their European surface; with no data on this limited information it is hard to holistically model the European surface and not all confounding variables are accounted for.

An important consideration for the EUR/CHF pairing is that there have been periods where the EUR/CHF exchange rate was effectively pegged. For example, in January 2015, there was a peg-breaking event between the CHF and the Euro, which completely impacted the distribution of returns and the estimation of volatility (Inman 2015). Furthermore, the liquidity and availability of options for the EUR/CHF pair can be limited, making it challenging to construct a robust volatility index. In response, it may be necessary to use a range of options with different maturities and strike prices, and to carefully consider the impact of any outliers or illiquid options on calculating implied volatility. The concerns for the NOK/SEK and EUR/CHF pairing are similar to the EUR/CHF pairing. Still, additionally, there is the concern of erroneous historical price data/missing risk-free interest rates: the risk-free interest rate is an important input in calculating implied volatility, and it can significantly impact the calculated volatility. Similarly, if the historical price data is incorrect or incomplete, it may lead to errors in the volatility calculations. Lastly, the limitations for these two currencies in light of adequate market data that is always in question. Specifically, Norway's European volatility surface will be largely driven by their exposure to gasoline (Internal Monetary Report 2015); while for Taiwan, variables on trading, such as semiconductor information and alternative geopolitical information, are very useful to have as they put pressure on peg breaks and lead to changes in volatility (Taiwan Stock Availability 2022). Not having access to all types of external information puts major constraints on the ability to forecast effectively; however, using the proper plotting tools, the ramifications of these historical events are made clear.

<u>**Part 2: Implementation of Model and Illustration of Appropriate Pricing Curves**</u>

c)

Since none of the currencies are pegged, the models above can be produced by simply using the market quotes (options data) given. The process of providing European Volatility Indices for FX pricing options for the given currency pairs will entails the rigorous process of going through the databases of each currency pair, and investigating the maturity and using the maturity to calculate the european surface which saves the european surface to a new database named "output." Here, the output will have all the maturities from 1month to two years, and within output will be all the delta puts, delta calls, volatility of the puts, volatilities of the calls, and the tictimes; all of which will be used to estimate the European Volatility surface. Using this data, it is possible to create both the European volatility surface for all currency pairs in addition to the individual plots depicting "slices" of this surface. This is done by creating a matrix consisting of the number of maturities by 1000; for each maturity stored in the matrix the European volatility surface plots every slice, and now the surface can be made using the surf command - which allows for a plot of the parametric surface. Using the surf command, it is possible then to construct the figure for the European volatility surface as depicted by delta and maturity.

Figures 1, 4 and 7 all depict the plots for the 10 and 25 delta puts and calls for the currency pairs over the time series. Using these delta puts and calls it is possible to choose two optimal dates (tictimes) to compare the European surfaces as seen in figures 2,3,5,6,8 and 9. These plots are vindicated when observing the time series of the different deltas given and comparing their spikes to historical peg breaks and external political factors affecting the market. For example, the peg break of the EUR/CHF is clearly shown in the time series (figure 1), and the changing European surfaces (figures 2 and 3) clearly show the financial ramifications of this peg break. Furthermore, the external political climate of the final two currencies makes sense in light of their high volatilities: the high volatilities of the NEK/SEK and the TWD/SEK are clearly the results of peg-breaking events and trading deals while ultimately affecting their European volatility surfaces.

Figure 1:

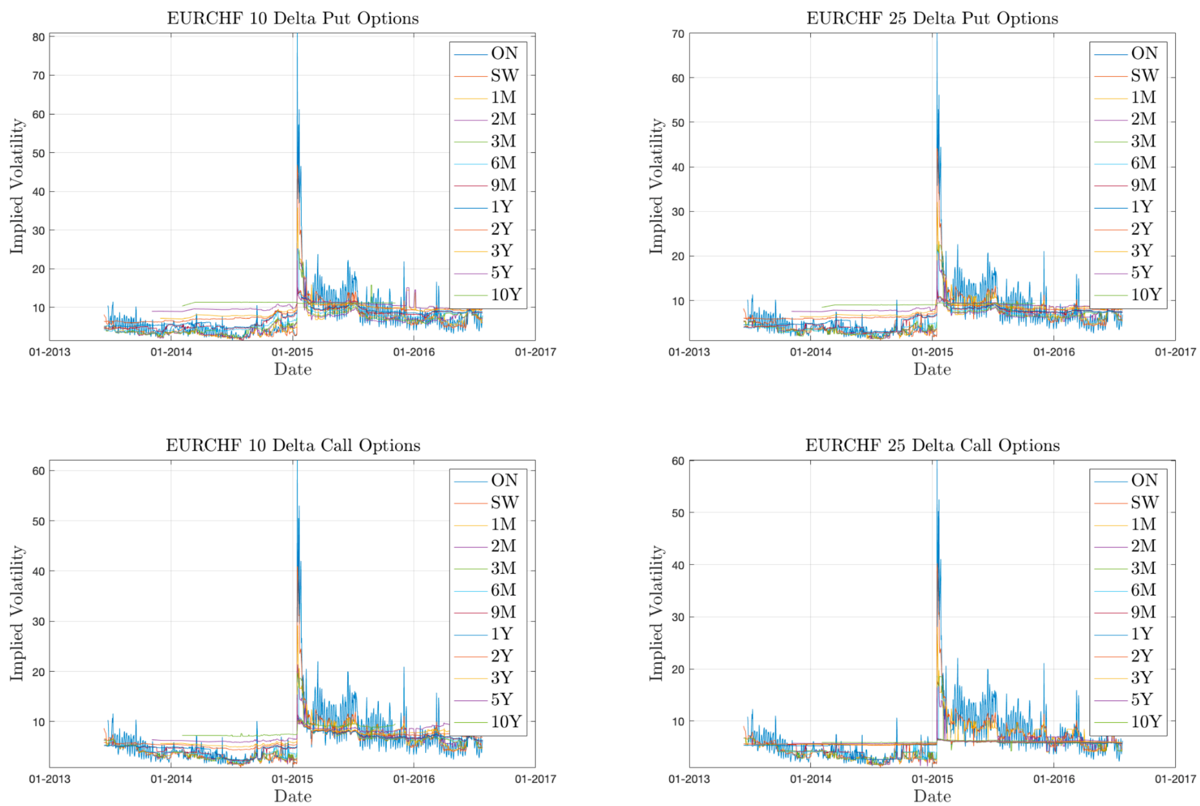


Figure 2:

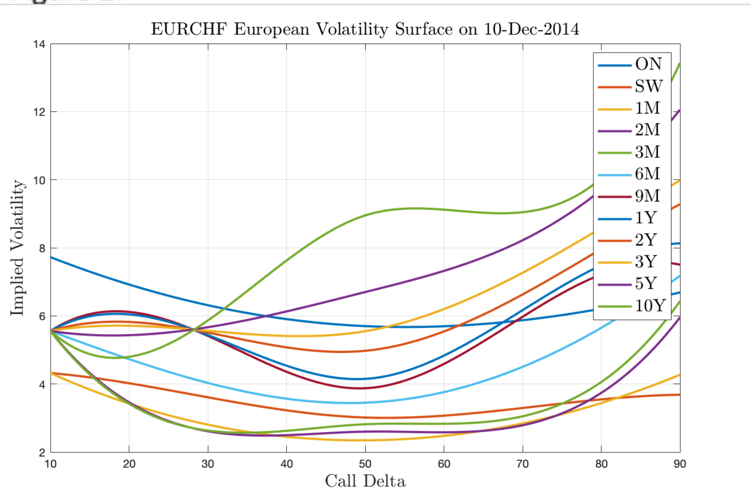
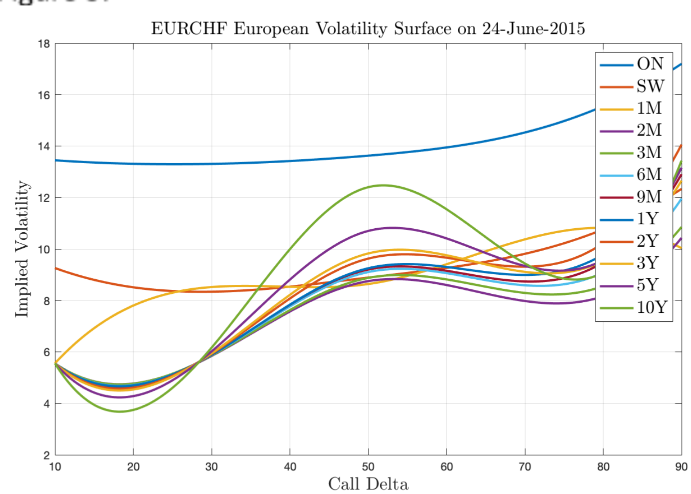


Figure 3:



D)

For the EUR/CHF we can see in the first time frame that the smile is pointed upward - with the exception of the overnight: leading up to January 2015 the market is anticipating a sudden change - inevitably a peg break event. Whereas after 2015, the smile is more curved in the middle. Furthermore, there is a distortionary factor with the short maturities: specifically, the overnight/spot week maturities -which have different patterns- will be driven by liquidity effects, whereas the longer maturities will be reflected in the overall expected pattern. There are more investors trading because they are speculating aggressively on changes in these particular cases. There is likely a more consistent pattern to the results of aggressive betting on reversals. Before January 2015 however, most of the maturities are sloping up: the overnight maturity holds an entirely different pattern because investors are not anticipating a peg-break to happen overnight.

Figure 4:

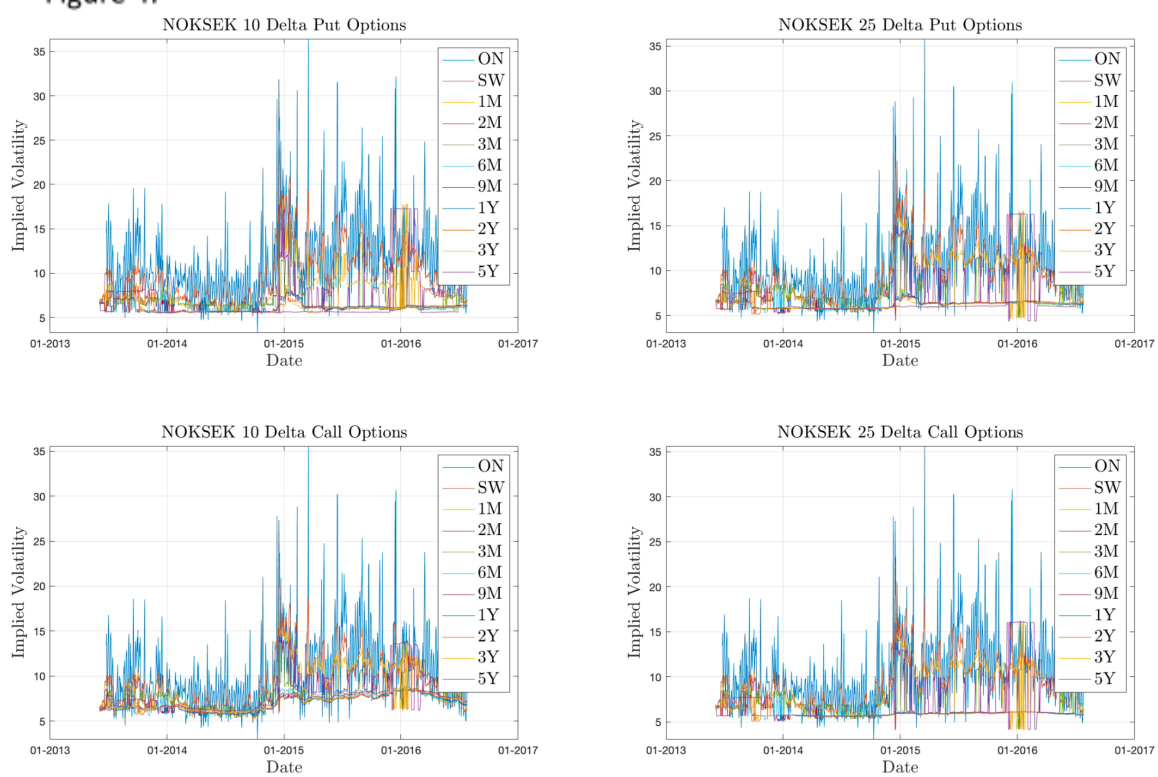


Figure 5:

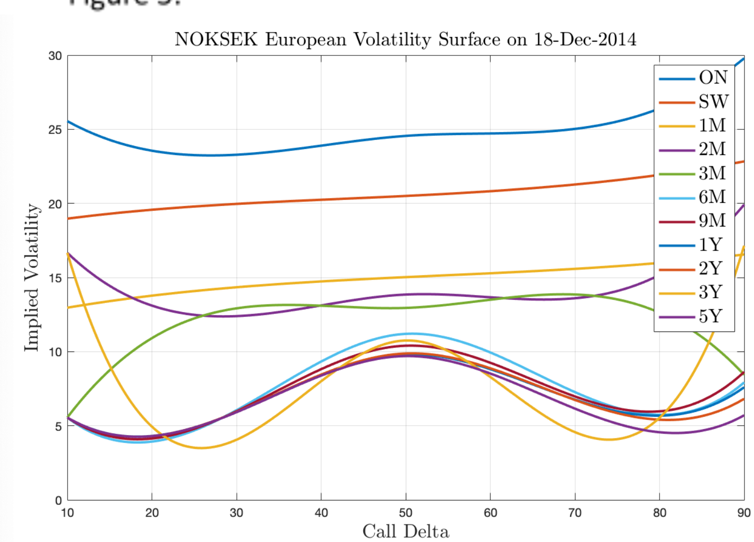
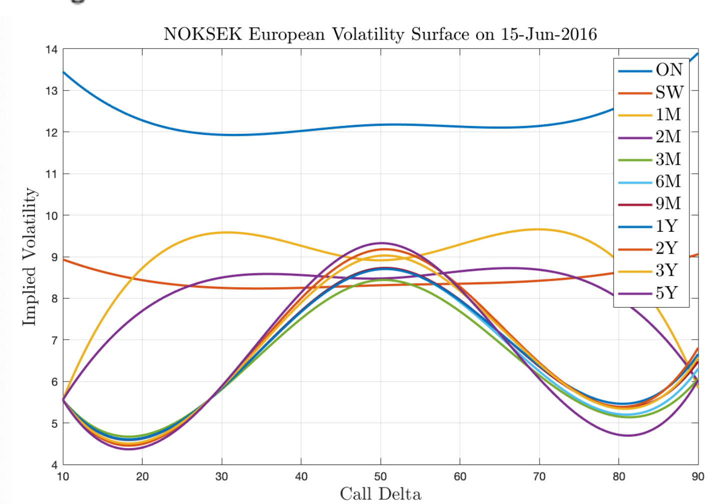


Figure 6:



NOK/SEK has a notably high range of volatility. With this currency pair the implied volatility increases both before and after January 2015 - thus, the European surface should also change between these dates. More specifically, the longer options tend to have the most flat implied volatility curves, so the options with longer maturities will have a more stable implied volatility. The high volatility is likely driven by a combination of factors related to commodity prices, divergent monetary policies, and political and economic risk. Furthermore, this is reflected in the European surface in 2016: the smile consists of longer maturities, which makes sense regarding the external factors that drive its implied volatility. Meanwhile, the short-term maturities don't tend to change very much.

Figure 7:

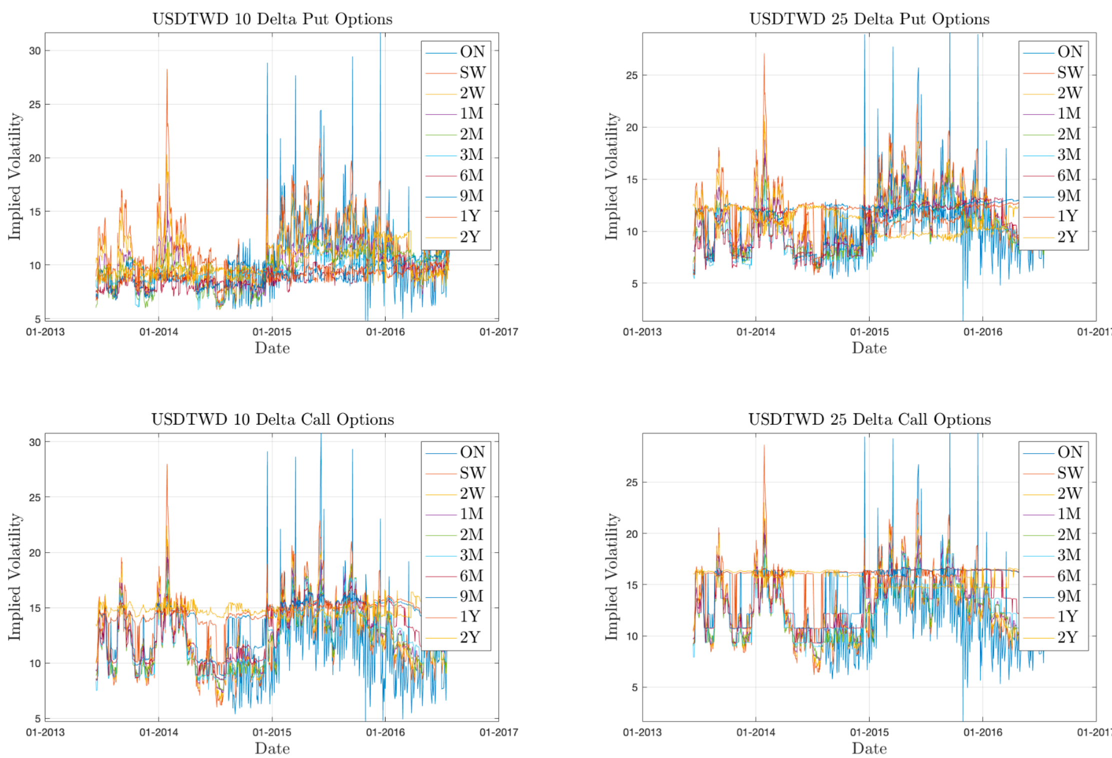


Figure 8:

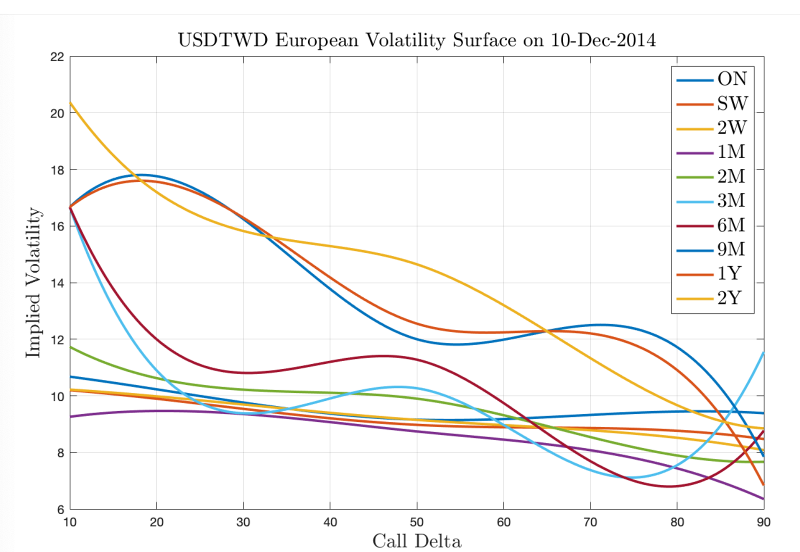
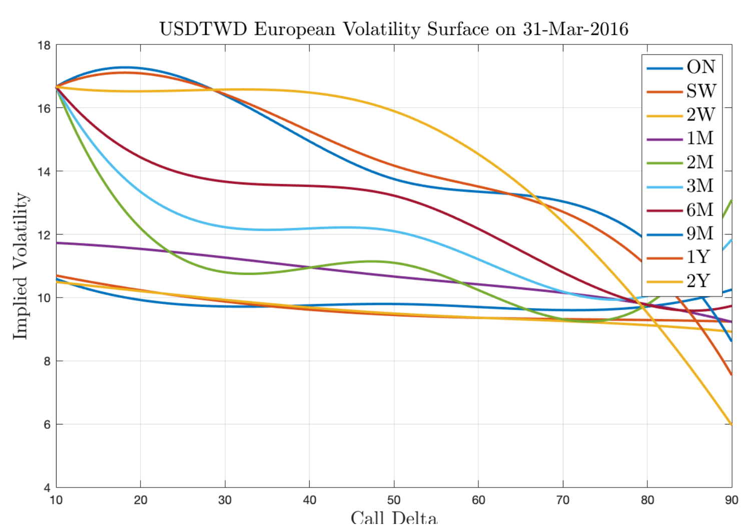


Figure 9:



TWD/USD has a notably high range of volatility as well - many of these volatility spikes are hitting at over 30 percent volatility. In high-trading countries such as Taiwan, it is likely that the volatility of the Taiwanese dollar, which is relatively high, is driven by external political factors. For example, a trade would happen between China and Taiwan, resulting in a new business deal between the two countries - thus, the market would reflect on stated currencies and then revealed currencies. While there are some trends in the volatility profile, this high level of variability was driven by the potential and ability to deliver on trade. With such high volatility currencies as the TWD, it makes sense that there are such large spikes which inflict the rampant volatility surface.

Next, it would be interesting to further this research to the point of studying the delta 50 to investigate the money straddles. Here one must construct a price strangle that straddles the two sides (closest option price) of the spot price so it gives you a forward payoff - in that case, one must hold the option and the spot; any movement in the spot is exactly offset by any movement in the option price and thus be completely risk neutral.

Part 3: Linkages to Other derivative Products and Reviews

e)

The NOK/SEK USD/TWD are highly volatile assets, while the EUR/CHF is quite volatile as it undergoes a peg break. Using this information, it is possible to research useful derivative assets such as risk reversals. Risk reversals are complex financial instruments that derive their value from the value of an underlying asset. They involve buying a call option and selling a put option on the same underlying asset with the same expiration date and the same strike price. When comparing the implied volatility of the at-the-money straddles (at delta 50) with that of the risk reversal, one may determine the relative cost of the call and put options, and identify any potential arbitrage opportunities.

One could also use the outputs from parts 1 and 2 to pursue the 2vol butterfly. The only step necessary to take in this step is to take the average of the puts and calls sides and subtract them at the money straddle. The 2vol butterfly should be particularly useful in volatile markets like the currency pairs studied, where the underlying asset's price is expected to fluctuate significantly. Using the outputs from parts 1 and 2, one may pursue the 2vol butterfly such that investors can gain a deeper understanding of the market sentiment and identify potential trading opportunities.

f)

The past writing created code in order to depict the European Surface for pricing FX options for 3 distinct currencies: the Euro (EUR)/Swiss Franc (CHF), Norwegian Krone (NOK)/Swedish Krona (SEK) and U.S. Dollar(USD)/Taiwanese New Dollar(TWD). In Part 1, the characteristics of each currency paired were mentioned then assigned appropriate models in light of these characteristics. Part 2 then describes and implements the modelling choice and discusses its findings; the plots created illustrate the 10 and 25 delta values on time-series and which shed light on pegging events and historical/political events that may have inflicted an implied volatility spike for certain maturities. Lastly, part 3 highlights the challenges of completing these tasks with the given data and creates ideas for how these results could be used to price other derivatives.

There were several difficulties while creating plots for the European Surface due to improper file saving due to issues with the computer used, resulting in the unavailability of datasets for the currencies researched. A significant issue was that the computer used would improperly save options data which would ultimately lead to a comprehensive system of having to redownload all the options data every time the document was reopened. There were also undesirable smiles created in comparison to the idealised versions reviewed in class - however they gave a realistic view of its application. Overall, despite encountering initial difficulties, the experience was informative and exciting.

Appendix:

EUR/CHF 10 and 25 Delta Time Series:

```
clear;clc;close all
addpath(genpath("../../"));

CCY1 = 'EUR';
CCY2 = 'CHF';


A = recoverOptionPriceData(CCY1,CCY2);
B = structureOptionData(A);


maturity = B.Maturities;
codes = B.Codes;
nmat = length(codes);

DeltaType = 'spot';
pipsPer = 'per';


for i=1:nmat
    [dv,IA,IB] = unique(floor(B.OptionData.(codes{i}).TickTimes),'last');
    ndays = length(dv);
    quotes = B.OptionData.(codes{i}).Quotes(IA,:);
    r = log(1+B.OptionData.(codes{i}).YldCCY1(IA)./100);
    q = log(1+B.OptionData.(codes{i}).YldCCY2(IA)./100);
    S = B.OptionData.(codes{i}).SpotPrice(IA);
    T = maturity(i);
    deltaPut = zeros(ndays,50);
    deltaCall = zeros(ndays,50);
    volPut = zeros(ndays,50);
    volCall = zeros(ndays,50);
    for j=1:ndays
        [delta,vol,K] = drawSurface(quotes(j,:),r(j),q(j),T,S(j),DeltaType,pipsPer);
        deltaPut(j,:) = delta(1,:);
        deltaCall(j,:) = delta(2,:);
        volPut(j,:) = vol(1,:);
```

```
axis tight;datetick('x','mm-yyyy');grid on
legentries = strrep(codes,'m','');
G = legend(legentries);set(G,'interpreter','latex','fontsize',16);
G = title([CCY1,CCY2,' 25 Delta Put Options']);set(G,'interpreter','latex','fontsize',16);
G = xlabel('Date');set(G,'interpreter','latex','fontsize',16);
G = ylabel('Implied Volatility');set(G,'interpreter','latex','fontsize',16);
% 10 Call
subplot(2,2,3);
for i=1:nmat
    x = output.(codes{i}).TickTimes;
    y = output.(codes{i}).volCall(:,10);
    plot(x,y);hold on;
end
axis tight;datetick('x','mm-yyyy');grid on
legentries = strrep(codes,'m','');
G = legend(legentries);set(G,'interpreter','latex','fontsize',16);
G = title([CCY1,CCY2,' 10 Delta Call Options']);set(G,'interpreter','latex','fontsize',16);
G = xlabel('Date');set(G,'interpreter','latex','fontsize',16);
G = ylabel('Implied Volatility');set(G,'interpreter','latex','fontsize',16);
% 25 Call
subplot(2,2,4);
for i=1:nmat
    x = output.(codes{i}).TickTimes;
    y = output.(codes{i}).volCall(:,25);
    plot(x,y);hold on;
end
axis tight;datetick('x','mm-yyyy');grid on
legentries = strrep(codes,'m','');
G = legend(legentries);set(G,'interpreter','latex','fontsize',16);
G = title([CCY1,CCY2,' 25 Delta Call Options']);set(G,'interpreter','latex','fontsize',16);
G = xlabel('Date');set(G,'interpreter','latex','fontsize',16);
G = ylabel('Implied Volatility');set(G,'interpreter','latex','fontsize',16);
```

```
    end
    output.(codes{i}).deltaPut = deltaPut;
    output.(codes{i}).deltaCall = deltaCall;
    output.(codes{i}).volPut = volPut;
    output.(codes{i}).volCall = volCall;
    output.(codes{i}).TickTimes = dv;
    disp(['Completed: ',codes{i}]);
end

%% Doing Some Plotting

[center,topright,bottomright,topleft,bottomleft,fullsc,halfleft,halfright] = ...
    dynamicFigureLocations(0.9);
figure('position',center,'color','w');
nmat = length(B.Maturities);
% 10 Put
subplot(2,2,1);
for i=1:nmat
    x = output.(codes{i}).TickTimes;
    y = output.(codes{i}).volPut(:,10);
    plot(x,y);hold on;
end
axis tight;datetick('x','mm-yyyy');grid on
legentries = strrep(codes,'m','');
G = legend(legentries);set(G,'interpreter','latex','fontsize',16);
G = title([CCY1,CCY2,' 10 Delta Put Options']);set(G,'interpreter','latex','fontsize',16);
G = xlabel('Date');set(G,'interpreter','latex','fontsize',16);
G = ylabel('Implied Volatility');set(G,'interpreter','latex','fontsize',16);
% 25 Put
subplot(2,2,2);
for i=1:nmat
    x = output.(codes{i}).TickTimes;
    y = output.(codes{i}).volPut(:,25);
    plot(x,y);hold on;
end
```

EUR/CHF European Surface:

```
clear;clc;close all
addpath(genpath("../../"));

CCY1 = 'EUR';
CCY2 = 'CHF';

A = recoverOptionPriceData(CCY1,CCY2);
B = structureOptionData(A);


maturity = B.Maturities;
codes = B.Codes;
nmat = length(codes);

DeltaType = 'spot';
pipsPer = 'per';


for i=1:nmat
    [dv,IA,IB] = unique(floor(B.OptionData.(codes{i}).TickTimes),'last');
    ndays = length(dv);
    quotes = B.OptionData.(codes{i}).Quotes(IA,:);
    r = log(1+B.OptionData.(codes{i}).YldCCY1(IA)./100);
    q = log(1+B.OptionData.(codes{i}).YldCCY2(IA)./100);
    S = B.OptionData.(codes{i}).SpotPrice(IA);
    T = maturity(i);
    deltaPut = zeros(ndays,50);
    deltaCall = zeros(ndays,50);
    volPut = zeros(ndays,50);
    volCall = zeros(ndays,50);
    for j=1:ndays
        [delta,vol,K] = drawSurface(quotes(j,:),r(j),q(j),T,S(j),DeltaType,pipsPer);
        deltaPut(j,:) = delta(1,:);
        deltaCall(j,:) = delta(2,:);
        volPut(j,:) = vol(1,:);
        volCall(j,:) = vol(2,:);
```

```
        volCall(j,:) = vol(2,:);
    end
    output.(codes{i}).deltaPut = deltaPut;
    output.(codes{i}).deltaCall = deltaCall;
    output.(codes{i}).volPut = volPut;
    output.(codes{i}).volCall = volCall;
    output.(codes{i}).TickTimes = dv;
    disp(['Completed: ',codes{i}]);
end


[center,topright,bottomright,topleft,bottomleft,fullsc,halfleft,halfright] = ...
     dynamicFigureLocations(0.5);
figure('position',topright,'color','w');
DateChoice = '24-June-2015';%'24-Jun-2015';
iij = datenum(DateChoice);
MTX = zeros(nmat,1000);

for i=1:nmat
    idx = find(output.(codes{i}).TickTimes == iij);
    volCall = output.(codes{i}).volCall(idx,[1 25 50]);
    volPut = output.(codes{i}).volPut(idx,[1 25 50]);
    deltaCall = output.(codes{i}).deltaCall(idx,[1 25 50]);
    deltaPut = output.(codes{i}).deltaPut(idx,[1 25 50]);
    DeltaVol = [1+deltaPut deltaCall];
    DeltaVol(3) = [];
    EurVol = [volPut volCall];
    EurVol(3) = [];
    DeltaVol = fliplr(DeltaVol).*100;
    EurVol = fliplr(EurVol);
    iDelta = linspace(10,90,1000);
    iEurVol = interp1(DeltaVol,EurVol,iDelta,"spline");
    MTX(i,:) = iEurVol;
    plot(iDelta,iEurVol,'linewidth',2);hold on
end

grid on;
legentries = strrep(codes,'m','');
G = legend(legentries);set(G,'interpreter','latex','fontsize',16);
G = title([CCY1,CCY2,' European Volatility Surface on ',DateChoice]);set(G,'interpreter','latex','fontsize',16);
G = xlabel('Call Delta');set(G,'interpreter','latex','fontsize',16);
G = ylabel('Implied Volatility');set(G,'interpreter','latex','fontsize',16);


figure('position',topleft,'color','w');
s = surf(iDelta,maturity,MTX);
s.EdgeColor = 'none';
G = title([CCY1,CCY2,' European Volatility Surface on ',DateChoice]);set(G,'interpreter','latex','fontsize',16);
G = xlabel('Delta');set(G,'interpreter','latex','fontsize',16);
G = ylabel('Maturity');set(G,'interpreter','latex','fontsize',16);
G = zlabel('Volatility');set(G,'interpreter','latex','fontsize',16);
```

NOK/SEK 10 and 25 Delta Time Series:

```matlab
clear;clc;close all
addpath(genpath("../../"));

CCY1 = 'NOK';
CCY2 = 'SEK';


A = recoverOptionPriceData(CCY1,CCY2);
B = structureOptionData(A);


maturity = B.Maturities;
codes = B.Codes;
nmat = length(codes);

DeltaType = 'spot';
pipsPer = 'per';


for i=1:nmat
    [dv,IA,IB] = unique(floor(B.OptionData.(codes{i}).TickTimes),'last');
    ndays = length(dv);
    quotes = B.OptionData.(codes{i}).Quotes(IA,:);
    r = log(1+B.OptionData.(codes{i}).YldCCY1(IA)./100);
    q = log(1+B.OptionData.(codes{i}).YldCCY2(IA)./100);
    S = B.OptionData.(codes{i}).SpotPrice(IA);
    T = maturity(i);
    deltaPut = zeros(ndays,50);
    deltaCall = zeros(ndays,50);
    volPut = zeros(ndays,50);
    volCall = zeros(ndays,50);
    for j=1:ndays
        [delta,vol,K] = drawSurface(quotes(j,:),r(j),q(j),T,S(j),DeltaType,pipsPer);
        deltaPut(j,:) = delta(1,:);
        deltaCall(j,:) = delta(2,:);
        volPut(j,:) = vol(1,:);
        volCall(j,:) = vol(2,:);
    end
    output.(codes{i}).deltaPut = deltaPut;
    output.(codes{i}).deltaCall = deltaCall;
    output.(codes{i}).volPut = volPut;
    output.(codes{i}).volCall = volCall;
    output.(codes{i}).TickTimes = dv;
    disp(['Completed: ',codes{i}]);
end

%% Doing Some Plotting

[center,topright,bottomright,topleft,bottomleft,fullsc,halfleft,halfright] = ...
    dynamicFigureLocations(0.9);
figure('position',center,'color','w');
nmat = length(B.Maturities);
% 10 Put
subplot(2,2,1);
for i=1:nmat
    x = output.(codes{i}).TickTimes;
    y = output.(codes{i}).volPut(:,10);
    plot(x,y);hold on;
end
axis tight;datetick('x','mm-yyyy');grid on
legentries = strrep(codes,'m','');
G = legend(legentries);set(G,'interpreter','latex','fontsize',16);
G = title([CCY1,CCY2,' 10 Delta Put Options']);set(G,'interpreter','latex','fontsize',16);
G = xlabel('Date');set(G,'interpreter','latex','fontsize',16);
G = ylabel('Implied Volatility');set(G,'interpreter','latex','fontsize',16);
% 25 Put
subplot(2,2,2);
for i=1:nmat
    x = output.(codes{i}).TickTimes;
    y = output.(codes{i}).volPut(:,25);
    plot(x,y);hold on;
end
```

```
axis tight;datetick('x','mm-yyyy');grid on
legentries = strrep(codes,'m','');
G = legend(legentries);set(G,'interpreter','latex','fontsize',16);
G = title([CCY1,CCY2,' 25 Delta Put Options']);set(G,'interpreter','latex','fontsize',16);
G = xlabel('Date');set(G,'interpreter','latex','fontsize',16);
G = ylabel('Implied Volatility');set(G,'interpreter','latex','fontsize',16);
% 10 Call
subplot(2,2,3);
for i=1:nmat
    x = output.(codes{i}).TickTimes;
    y = output.(codes{i}).volCall(:,10);
    plot(x,y);hold on;
end
axis tight;datetick('x','mm-yyyy');grid on
legentries = strrep(codes,'m','');
G = legend(legentries);set(G,'interpreter','latex','fontsize',16);
G = title([CCY1,CCY2,' 10 Delta Call Options']);set(G,'interpreter','latex','fontsize',16);
G = xlabel('Date');set(G,'interpreter','latex','fontsize',16);
G = ylabel('Implied Volatility');set(G,'interpreter','latex','fontsize',16);
% 25 Call
subplot(2,2,4);
for i=1:nmat
    x = output.(codes{i}).TickTimes;
    y = output.(codes{i}).volCall(:,25);
    plot(x,y);hold on;
end
axis tight;datetick('x','mm-yyyy');grid on
legentries = strrep(codes,'m','');
G = legend(legentries);set(G,'interpreter','latex','fontsize',16);
G = title([CCY1,CCY2,' 25 Delta Call Options']);set(G,'interpreter','latex','fontsize',16);
G = xlabel('Date');set(G,'interpreter','latex','fontsize',16);
G = ylabel('Implied Volatility');set(G,'interpreter','latex','fontsize',16);
```

NOK/SEK European Volatility Surface:

```
clear;clc;close all
addpath(genpath("../../"));

CCY1 = 'NOK';
CCY2 = 'SEK';

A = recoverOptionPriceData(CCY1,CCY2);
B = structureOptionData(A);


maturity = B.Maturities;
codes = B.Codes;
nmat = length(codes);

DeltaType = 'spot';
pipsPer = 'per';


for i=1:nmat
    [dv,IA,IB] = unique(floor(B.OptionData.(codes{i}).TickTimes),'last');
    ndays = length(dv);
    quotes = B.OptionData.(codes{i}).Quotes(IA,:);
    r = log(1+B.OptionData.(codes{i}).YldCCY1(IA)./100);
    q = log(1+B.OptionData.(codes{i}).YldCCY2(IA)./100);
    S = B.OptionData.(codes{i}).SpotPrice(IA);
    T = maturity(i);
    deltaPut = zeros(ndays,50);
    deltaCall = zeros(ndays,50);
    volPut = zeros(ndays,50);
    volCall = zeros(ndays,50);
    for j=1:ndays
        [delta,vol,K] = drawSurface(quotes(j,:),r(j),q(j),T,S(j),DeltaType,pipsPer);
        deltaPut(j,:) = delta(1,:);
```

```
        deltaCall(j,:) = delta(2,:);
        volPut(j,:) = vol(1,:);
        volCall(j,:) = vol(2,:);
    end
    output.(codes{i}).deltaPut = deltaPut;
    output.(codes{i}).deltaCall = deltaCall;
    output.(codes{i}).volPut = volPut;
    output.(codes{i}).volCall = volCall;
    output.(codes{i}).TickTimes = dv;
    disp(['Completed: ',codes{i}]);
end


[center,topright,bottomright,topleft,bottomleft,fullsc,halfleft,halfright] = ...
     dynamicFigureLocations(0.5);
figure('position',topright,'color','w');
DateChoice = '31-Mar-2016';%'24-Jun-2015';
iij = datenum(DateChoice);
MTX = zeros(nmat,1000);

for i=1:nmat
    idx = find(output.(codes{i}).TickTimes == iij);
    volCall = output.(codes{i}).volCall(idx,[1 25 50]);
    volPut = output.(codes{i}).volPut(idx,[1 25 50]);
    deltaCall = output.(codes{i}).deltaCall(idx,[1 25 50]);
    deltaPut = output.(codes{i}).deltaPut(idx,[1 25 50]);
    DeltaVol = [1+deltaPut deltaCall];
    DeltaVol(3) = [];
    EurVol = [volPut volCall];
    EurVol(3) = [];
    DeltaVol = fliplr(DeltaVol).*100;
    EurVol = fliplr(EurVol);
    iDelta = linspace(10,90,1000);
```


```
        deltaCall(j,:) = delta(2,:);
        volPut(j,:) = vol(1,:);
        volCall(j,:) = vol(2,:);
    end
    output.(codes{i}).deltaPut = deltaPut;
    output.(codes{i}).deltaCall = deltaCall;
    output.(codes{i}).volPut = volPut;
    output.(codes{i}).volCall = volCall;
    output.(codes{i}).TickTimes = dv;
    disp(['Completed: ',codes{i}]);
end


[center,topright,bottomright,topleft,bottomleft,fullsc,halfleft,halfright] = ...
     dynamicFigureLocations(0.5);
figure('position',topright,'color','w');
DateChoice = '31-Mar-2016';%'24-Jun-2015';
iij = datenum(DateChoice);
MTX = zeros(nmat,1000);

for i=1:nmat
    idx = find(output.(codes{i}).TickTimes == iij);
    volCall = output.(codes{i}).volCall(idx,[1 25 50]);
    volPut = output.(codes{i}).volPut(idx,[1 25 50]);
    deltaCall = output.(codes{i}).deltaCall(idx,[1 25 50]);
    deltaPut = output.(codes{i}).deltaPut(idx,[1 25 50]);
    DeltaVol = [1+deltaPut deltaCall];
    DeltaVol(3) = [];
    EurVol = [volPut volCall];
    EurVol(3) = [];
    DeltaVol = fliplr(DeltaVol).*100;
    EurVol = fliplr(EurVol);
    iDelta = linspace(10,90,1000);
```

```
    iEurVol = interp1(DeltaVol,EurVol,iDelta,"spline");
    MTX(i,:) = iEurVol;
    plot(iDelta,iEurVol,'linewidth',2);hold on
end
grid on;
legentries = strrep(codes,'m','');
G = legend(legentries);set(G,'interpreter','latex','fontsize',16);
G = title([CCY1,CCY2,' European Volatility Surface on ',DateChoice]);set(G,'interpreter','latex','fontsize',16);
G = xlabel('Call Delta');set(G,'interpreter','latex','fontsize',16);
G = ylabel('Implied Volatility');set(G,'interpreter','latex','fontsize',16);


figure('position',topleft,'color','w');
s = surf(iDelta,maturity,MTX);
s.EdgeColor = 'none';
G = title([CCY1,CCY2,' European Volatility Surface on ',DateChoice]);set(G,'interpreter','latex','fontsize',16);
G = xlabel('Delta');set(G,'interpreter','latex','fontsize',16);
G = ylabel('Maturity');set(G,'interpreter','latex','fontsize',16);
G = zlabel('Volatility');set(G,'interpreter','latex','fontsize',16);
```

USD/TWD 10 and 25 Delta Time Series:

```
clear;clc;close all
addpath(genpath("../../"));

CCY1 = 'USD';
CCY2 = 'TWD';


A = recoverOptionPriceData(CCY1,CCY2);
B = structureOptionData(A);


maturity = B.Maturities;
codes = B.Codes;
nmat = length(codes);

DeltaType = 'spot';
pipsPer = 'per';


for i=1:nmat
    [dv,IA,IB] = unique(floor(B.OptionData.(codes{i}).TickTimes),'last');
    ndays = length(dv);
    quotes = B.OptionData.(codes{i}).Quotes(IA,:);
    r = log(1+B.OptionData.(codes{i}).YldCCY1(IA)./100);
    q = log(1+B.OptionData.(codes{i}).YldCCY2(IA)./100);
    S = B.OptionData.(codes{i}).SpotPrice(IA);
    T = maturity(i);
    deltaPut = zeros(ndays,50);
    deltaCall = zeros(ndays,50);
    volPut = zeros(ndays,50);
    volCall = zeros(ndays,50);
    for j=1:ndays
```

```
    for j=1:ndays
        [delta,vol,K] = drawSurface(quotes(j,:),r(j),q(j),T,S(j),DeltaType,pipsPer);
        deltaPut(j,:) = delta(1,:);
        deltaCall(j,:) = delta(2,:);
        volPut(j,:) = vol(1,:);
        volCall(j,:) = vol(2,:);
    end
    output.(codes{i}).deltaPut = deltaPut;
    output.(codes{i}).deltaCall = deltaCall;
    output.(codes{i}).volPut = volPut;
    output.(codes{i}).volCall = volCall;
    output.(codes{i}).TickTimes = dv;
    disp(['Completed: ',codes{i}]);
end
```

```
%% Doing Some Plotting

[center,topright,bottomright,topleft,bottomleft,fullsc,halfleft,halfright] = ...
    dynamicFigureLocations(0.9);
figure('position',center,'color','w');
nmat = length(B.Maturities);
% 10 Put
subplot(2,2,1);
for i=1:nmat
    x = output.(codes{i}).TickTimes;
    y = output.(codes{i}).volPut(:,10);
    plot(x,y);hold on;
end
axis tight;datetick('x','mm-yyyy');grid on
legentries = strrep(codes,'m','');
G = legend(legentries);set(G,'interpreter','latex','fontsize',16);
G = title([CCY1,CCY2,' 10 Delta Put Options']);set(G,'interpreter','latex','fontsize',16);
G = xlabel('Date');set(G,'interpreter','latex','fontsize',16);
```

```
G = xlabel('Date');set(G,'interpreter','latex','fontsize',16);
G = ylabel('Implied Volatility');set(G,'interpreter','latex','fontsize',16);
% 25 Put
subplot(2,2,2);
for i=1:nmat
    x = output.(codes{i}).TickTimes;
    y = output.(codes{i}).volPut(:,25);
    plot(x,y);hold on;
end
axis tight;datetick('x','mm-yyyy');grid on
legentries = strrep(codes,'m','');
G = legend(legentries);set(G,'interpreter','latex','fontsize',16);
G = title([CCY1,CCY2,' 25 Delta Put Options']);set(G,'interpreter','latex','fontsize',16);
G = xlabel('Date');set(G,'interpreter','latex','fontsize',16);
G = ylabel('Implied Volatility');set(G,'interpreter','latex','fontsize',16);
% 10 Call
subplot(2,2,3);
for i=1:nmat
    x = output.(codes{i}).TickTimes;
    y = output.(codes{i}).volCall(:,10);
    plot(x,y);hold on;
end
axis tight;datetick('x','mm-yyyy');grid on
legentries = strrep(codes,'m','');
G = legend(legentries);set(G,'interpreter','latex','fontsize',16);
G = title([CCY1,CCY2,' 10 Delta Call Options']);set(G,'interpreter','latex','fontsize',16);
G = xlabel('Date');set(G,'interpreter','latex','fontsize',16);
G = ylabel('Implied Volatility');set(G,'interpreter','latex','fontsize',16);
% 25 Call
subplot(2,2,4);
for i=1:nmat
    x = output.(codes{i}).TickTimes;
```

```
    y = output.(codes{i}).volCall(:,25);
    plot(x,y);hold on;
end
axis tight;datetick('x','mm-yyyy');grid on
legentries = strrep(codes,'m','');
G = legend(legentries);set(G,'interpreter','latex','fontsize',16);
G = title([CCY1,CCY2,' 25 Delta Call Options']);set(G,'interpreter','latex','fontsize',16);
G = xlabel('Date');set(G,'interpreter','latex','fontsize',16);
G = ylabel('Implied Volatility');set(G,'interpreter','latex','fontsize',16);
```

USD/TWD European Surface:

```
clear;clc;close all
addpath(genpath("../../"));

CCY1 = 'USD';
CCY2 = 'TWD';

A = recoverOptionPriceData(CCY1,CCY2);
B = structureOptionData(A);


maturity = B.Maturities;
codes = B.Codes;
nmat = length(codes);

DeltaType = 'spot';
pipsPer = 'per';


for i=1:nmat
    [dv,IA,IB] = unique(floor(B.OptionData.(codes{i}).TickTimes),'last');
    ndays = length(dv);
    quotes = B.OptionData.(codes{i}).Quotes(IA,:);
    r = log(1+B.OptionData.(codes{i}).YldCCY1(IA)./100);
    q = log(1+B.OptionData.(codes{i}).YldCCY2(IA)./100);
    S = B.OptionData.(codes{i}).SpotPrice(IA);
    T = maturity(i);
    deltaPut = zeros(ndays,50);
    deltaCall = zeros(ndays,50);
    volPut = zeros(ndays,50);
    volCall = zeros(ndays,50);
    for j=1:ndays
        [delta,vol,K] = drawSurface(quotes(j,:),r(j),q(j),T,S(j),DeltaType,pipsPer);
        deltaPut(j,:) = delta(1,:);
        deltaCall(j,:) = delta(2,:);
        volPut(j,:) = vol(1,:);
        volCall(j,:) = vol(2,:);
    end
    output.(codes{i}).deltaPut = deltaPut;
    output.(codes{i}).deltaCall = deltaCall;
    output.(codes{i}).volPut = volPut;
    output.(codes{i}).volCall = volCall;
    output.(codes{i}).TickTimes = dv;
    disp(['Completed: ',codes{i}]);
end


[center,topright,bottomright,topleft,bottomleft,fullsc,halfleft,halfright] = ...
     dynamicFigureLocations(0.5);
figure('position',topright,'color','w');
DateChoice = '10-Dec-2014';%'24-Jun-2015';
iij = datenum(DateChoice);
MTX = zeros(nmat,1000);

for i=1:nmat
    idx = find(output.(codes{i}).TickTimes == iij);
    volCall = output.(codes{i}).volCall(idx,[1 25 50]);
    volPut = output.(codes{i}).volPut(idx,[1 25 50]);
    deltaCall = output.(codes{i}).deltaCall(idx,[1 25 50]);
    deltaPut = output.(codes{i}).deltaPut(idx,[1 25 50]);
    DeltaVol = [1+deltaPut deltaCall];
    DeltaVol(3) = [];
    EurVol = [volPut volCall];
    EurVol(3) = [];
    DeltaVol = fliplr(DeltaVol).*100;
```

```
    iDelta = linspace(10,90,1000);
    iEurVol = interp1(DeltaVol,EurVol,iDelta,"spline");
    MTX(i,:) = iEurVol;
    plot(iDelta,iEurVol,'linewidth',2);hold on
end
grid on;
legentries = strrep(codes,'m','');
G = legend(legentries);set(G,'interpreter','latex','fontsize',16);
G = title([CCY1,CCY2,' European Volatility Surface on ',DateChoice]);set(G,'interpreter','latex','fontsize',16);
G = xlabel('Call Delta');set(G,'interpreter','latex','fontsize',16);
G = ylabel('Implied Volatility');set(G,'interpreter','latex','fontsize',16);


figure('position',topleft,'color','w');
s = surf(iDelta,maturity,MTX);
s.EdgeColor = 'none';
G = title([CCY1,CCY2,' European Volatility Surface on ',DateChoice]);set(G,'interpreter','latex','fontsize',16);
G = xlabel('Delta');set(G,'interpreter','latex','fontsize',16);
G = ylabel('Maturity');set(G,'interpreter','latex','fontsize',16);
G = zlabel('Volatility');set(G,'interpreter','latex','fontsize',16);
```

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