FE621HW1

September 26, 2020

[1]:
```
import os
import time
import numpy as np
import pandas as pd
import datetime as dt
import matplotlib.pyplot as plt
import pandas_datareader as web
import pandas_market_calendars as calen
from numpy import log as ln
from scipy.stats import norm
from pandas import DataFrame
from yahoo_fin import stock_info as si
from yahoo_fin import options
from scipy import misc
```

1 Part 1. Data gathering component

1. Write a function (program) to connect to sources and download data from yahoo Finance.
2. With the function created in problem 1, download data on both options and equity for the following symbols:
    - AMAZ
    - SPY
    - VIX
3. Write a paragraph describing the symbols you are downloading data for explain what is the SPY and its purpose.
4. The followinf items will also need to be recorded:
    - The underlying equity or ETF price at the exact moment when the rest of the data is downloaded.
    - The short-term interest rate.
    - Time to Maturity

1.1 Download Data from Yahoo

[2]:
```python
def download_data(path, name_list):
    start = dt.datetime(2019,12,13)
    end = dt.datetime(2020,8,31)
    for name in name_list:
        data = web.DataReader(name,'yahoo',start,end)
        data.to_csv(path + name + '.csv')
```

1.2 Get Options Maturity

[207]:
```python
def get_maturi(name_list):
    maturi = []
    for name in name_list:
        data_option = options.get_expiration_dates(name)
        maturi.append(data_option)
    return(maturi)
```

1.3 Get Stock Live Price

[4]:
```python
def live_data(name_list):
    prices = []
    for name in name_list:
        price = si.get_live_price(name)
        prices.append(price)
    live_price = pd.DataFrame({'Code':name_list, 'Live_Price':prices})
    return(live_price)
```

1.4 Download Option Data

[5]:
```python
def download_options(maturi, name_list, path):
    for i in range(0,len(maturi)):
        list = maturi[i]
        name = name_list[i]
        for date in list:
            call = options.get_calls(name, date)
            call.to_csv(path + name + date + 'C.csv')
            put = options.get_puts(name, date)
            put.to_csv(path + name + date + 'P.csv')
```

[6]:
```python
if __name__ == "__main__":
    path = '/Users/yuechenjiang/Desktop/FE621/'
    name = input('Please enter stock codes and separate them with commas:\n')
    name_list = name.split(',')
    download_data(path, name_list)
    maturi = get_maturi(name_list)
```

```
    print(live_data(name_list))
    download_options(maturi, name_list, path)
```

```
Please enter stock codes and separate them with commas:
AMZN,SPY,^VIX
   Code   Live_Price
0  AMZN  3019.790039
1   SPY   323.420013
2  ^VIX    28.610001
```

[208]:
```
print((len(maturi[0]), len(maturi[1]), len(maturi[2])))
```

```
(18, 32, 10)
```

Use the function "download_options(maturi, name_list, path)" once a day to collect day by day option data.

Symbols	Describing
Contract Name	The name of each option whatever it belongs to index or stock.
Last Trade Day	The date of option was traded in most recently.
Strike price	The price level of each option which determines whether the option will be exercised.
Last Trade Price	The price of option was traded in very recent day.
Ask	The lowest price that some one wants to buy the option.
Bid	The highest price that someone would like to sell the option.
Change	The absolute change of price of the option price, which only has number when the latest trade updated.
Percentage Change	The ratio of the price changes, which indicates the difference divided by the origin price.
Volume of Trade	Number of options that has been traded during a specific period.
Open Interest	Accumulated numbers of the option that has not been exercised.
Implied Volatility	This ratio measures the uncertainty of an option and the market, which links to Stock price.

Symbols	Describing
Expire day	Expire day was shown in the name of each option and could be selected on websites. This date stands for the last trading day of exercising the options.

SPY: SPY500 is one kind of ETF which contains a basket of stocks that covered the characteristic stocks all over the market. The purpose of this setting is to avoid most of the risk in the stock market, to keep implied volatility in a certain range.

VIX: VIX is a number which gets the volatility from the S&P500 and give them weigh to reflect the volatility growth and dropping. VIX index option could be seen as a compensate of normal options. When VIX index going down, buyers would buy theoptions to make up the loss of VIX index option or the opposite. Thus. The purpose of VIXis till to prevent the risks that happened in the market.

Observation Result: Relationship between AMZN SPY and VIX
AMZN is a single but unique stock in American stock market, which is also belongs to the S&P 500. Thus the goes up and down depends on the progress if each ingredient stock.VIX is a weighed summation of the implied volatility of each stock in S&P 500. According to the observation, when AMZN and S&P 500 went up sometime, VIX would go down; when AMZN and S&P 500 went down sometime, VIX would go up.

2 Part 2. Analysis of the data

5. Using your choice of computer programming language implement the Black-Scholes formulas as a function of current stock price S_0, volatility σ, time to expiration $T-t$ (in years), strike price K and short-term interest rate r (annual). Please note that no toolbox function is allowed but you may use the normal(CDF) calculation.

6. Implement the Bisection method to find the root of arbitrary functions. Apply this method to calculate the implied volatility on the first day you downloaded (DATA1). For this purpose use as the option value the average of bid and ask price if they both exist (and if their corresponding volume is nonzero). Also use a tolerance level of 10^{-6} Report the implied volatility at the money (for the option with strike price closest to the traded stock price). You need to do it for both the stock and the ETF data you have (you do not need to do this for VIX). Then average all the implied volatilties for the options between in-the-money and out-of-the-money.

7. Implement the Newton method/Secant method or Muller method to find the root of arbitrary functions. You will need to discover the formula for the option's derivative with respect to the volatility σ. Apply these methods to the same options as in the previous problem. Compare the time it takes to get the root with the same level of accuracy.

2.1 BS Formula

[119]:
```
def bs_formula(S0,sigma,t,K,r,option_type):

    d1 = (ln(S0/K) + (r + (sigma**2)/2) * t)/(sigma * np.sqrt(t))
    d2 = d1 - (sigma * np.sqrt(t))

    if option_type==0:
        c = S0 * norm.cdf(d1) - K * np.exp(-r * t) * norm.cdf(d2)
        return(c)
    elif option_type==1:
        p = K * np.exp(-r * t) * norm.cdf(-d2) - S0 * norm.cdf(-d1)
        return(p)
```

2.2 Bisection method

[120]:
```
def bisection_method(S0, K, r, t, op, option_type):
    tol = 10**(-7)
    maxiter = 10000
    sigma_low = 0
    sigma_high = 1
    for i in range(0,maxiter):
        sigma = (sigma_low + sigma_high)/2
        price = bs_formula(S0,sigma,t,K,r,option_type)
        test = price - op

        if abs(test) <= tol:
            return(sigma)
        else:
            if test < 0.0:
                sigma_low = sigma
            else:
                sigma_high = sigma

    return(sigma)
```

2.3 Newton method

[336]:
```
def NewtonsMethod(S0, r, t, op, K, option_type):
    tol = 10**(-6)
    sigma=0.0
    while abs(bs_formula(S0,sigma,t,K,r,option_type) - op) > tol:
        if option_type==0:
            if bs_formula(S0,sigma,t,K,r,option_type) > op:
                sigma-=tol
            else:
                sigma+=tol
```

```
        else:
            if bs_formula(S0,sigma,t,K,r,option_type) < op:
                sigma-=tol
            else:
                sigma+=tol
    return(sigma)
```

[335]:
```
def NewtonsMethod(S0, r, t, op, K, option_type):
    tol = 10**(-6)
    max = 10000
    ts = np.sqrt(t)
    sigma = (op/S0)/(0.398 * ts)
    for i in range(0,max):
        price = bs_formula(S0,sigma,t,K,r,option_type)
        diff = op - price
        if abs(diff) < tol:
            return(sigma)
        else:
            d1 = (log(S0/X) + (r + 0.5 * sigma**2)*t)/(sigma*np.sqrt(t))
            nd1 = 1/(sqrt(2 * np.pi)) * np.exp(-d1**2/2)
            vege = S0 * ts * nd1
            sigma = sigma + diff/vega
```

[128]:
```
# this part substitute the test data to verify
# whether the data calculated by the bisection method and Newton iteration␣
↪method are the same
op = 1.875
S0 = 21
K = 20
r = 0.1
t = 0.25
print('The bisection method calculation call option result is:\n',␣
↪bisection_method(S0, K, r, t, op, 0))
print('The newtons method calculation call option result is:\n',␣
↪NewtonsMethod(S0, r, t, op, K, 0))
```

```
The bisection method calculation call option result is:
 0.23451292514801025
```

```
/Users/yuechenjiang/opt/anaconda3/lib/python3.7/site-
packages/ipykernel_launcher.py:3: RuntimeWarning: divide by zero encountered in
double_scalars
  This is separate from the ipykernel package so we can avoid doing imports
until
```

```
The newtons method calculation call option result is:
 0.23451300000021386
```

The calculation results of dichotomy and Newton's iteration method are very close.

2.4 Calculat Volatility

[34]:
```
def open_file(path, data):
    names = []
    for file in os.listdir(path + data):
        if '.csv' in file:
            names.append(file)
    return(names)
```

[35]:
```
def add_column(path, data, names, price, day):
    nyse = calen.get_calendar('NYSE')

    start = time.time()
    for name in names:
        file = pd.read_csv(path + data + name)
        file['option price'] = 0.0
        file['moneyness'] = 'nan'
        file['bise_vol'] = 0.0
        file['newt_vol'] = 0.0
        file['S0'] = price

        for i in file.index:
            file['option price'][i] = (file['Bid'][i] + file['Ask'][i])/2

            if file['S0'][i]/file['Strike'][i] >= 0.95 and file['S0'][i]/
 ↪file['Strike'][i] <= 1.05:
                file['moneyness'][i] = 'at the money'
            elif file['S0'][i]/file['Strike'][i] > 1.05:
                file['moneyness'][i] = 'in the money'
            else:
                file['moneyness'][i] = 'out of money'
            file.to_csv(day + name, index = False)

    delta_time = (time.time() - start)
    print(delta_time)
```

[129]:
```
 if __name__ == "__main__":
        live_price = live_data(name_list)
        amzn_price = live_price.iloc[0,1]
        spy_price = live_price.iloc[1,1]
        vix_price = live_price.iloc[2,1]
        amzn_name = open_file(path, 'DAY1AMZN/')
        print('Time cost of add colum of AMZN DAY1:')
        add_column(path, 'DAY1AMZN/', amzn_name, amzn_price, 'day1')
        spy_name = open_file(path, 'DAY1SPY/')
        print('Time cost of add colum of SPY DAY1:')
        add_column(path, 'DAY1SPY/', spy_name, spy_price, 'day1')
```

```python
        # vix_name = open_file(path, 'DAY1VIX/')
        # print('Time cost of add colum of VIX DAY1:')
        # add_column(path, 'DAY1VIX/', vix_name, vix_price, 'day1')
        # amzn_name = open_file(path, 'DAY2AMZN/')
        # print('Time cost of add colum of AMZN DAY2:')
        # add_column(path, 'DAY1AMZN/', amzn_name, amzn_price, 'day2')
        # spy_name = open_file(path, 'DAY2SPY/')
        # print('Time cost of add colum of SPY DAY2:')
        # add_column(path, 'DAY1SPY/', spy_name, spy_price, 'day2')
        # vix_name = open_file(path, 'DAY2VIX/')
        # print('Time cost of add colum of VIX DAY2:')
        # add_column(path, 'DAY1VIX/', vix_name, vix_price, 'day2')
```

```
Time cost of add colum of AMZN DAY1:
```

```
/Users/yuechenjiang/opt/anaconda3/lib/python3.7/site-
packages/ipykernel_launcher.py:14: SettingWithCopyWarning:
A value is trying to be set on a copy of a slice from a DataFrame

See the caveats in the documentation: https://pandas.pydata.org/pandas-
docs/stable/user_guide/indexing.html#returning-a-view-versus-a-copy

/Users/yuechenjiang/opt/anaconda3/lib/python3.7/site-
packages/ipykernel_launcher.py:19: SettingWithCopyWarning:
A value is trying to be set on a copy of a slice from a DataFrame

See the caveats in the documentation: https://pandas.pydata.org/pandas-
docs/stable/user_guide/indexing.html#returning-a-view-versus-a-copy
/Users/yuechenjiang/opt/anaconda3/lib/python3.7/site-
packages/ipykernel_launcher.py:17: SettingWithCopyWarning:
A value is trying to be set on a copy of a slice from a DataFrame

See the caveats in the documentation: https://pandas.pydata.org/pandas-
docs/stable/user_guide/indexing.html#returning-a-view-versus-a-copy
/Users/yuechenjiang/opt/anaconda3/lib/python3.7/site-
packages/ipykernel_launcher.py:21: SettingWithCopyWarning:
A value is trying to be set on a copy of a slice from a DataFrame

See the caveats in the documentation: https://pandas.pydata.org/pandas-
docs/stable/user_guide/indexing.html#returning-a-view-versus-a-copy
```

```
26.19404172897339
Time cost of add colum of SPY DAY1:
26.573400735855103
```

8. Present a table reporting the implied volatility values obtained for every maturity, option type and stock. Also compile the average volatilities as described in the previous point. Comment on the observed difference in values obtained for AMZN and SPY. Compare with the current value of the VIX. Comment on what happens when the maturity increases. Comment on

what happen when the options become in the money respectively out of the money.

2.4.1 Biesection Volatility

[108]:
```
def bi_vol(path, data, names, dates, option_type):
    nyse = calen.get_calendar('NYSE')

    start = time.time()

    for name in names:
        file = pd.read_csv(path + data + name)
        for date in dates:
            schedule = nyse.schedule(start_date='2020-9-23', end_date=date)
            len(schedule)
            t = len(schedule)/252
            r = 1.58/100
            for i in file.index:
                S0 = file['S0'][i]
                K = file['Strike'][i]
                op = file['option price'][i]
                file['bise_vol'][i] = bisection_method(S0, K, r, t, op,␣
 ↪option_type)
                file.to_csv(path + data + name, index=False)

    delta_time = (time.time() - start)
    print(delta_time)
```

[130]:
```
# Due to the large amount of the data,
# this function is a test function.
# There is only one Call Option data of Time to maturity on April 16, 2021 in␣
 ↪the test folder.
# After the test program is correct, use Google Colab to calculate all the data.
 ↪
def bi_vol(path, data, names, option_type):
    nyse = calen.get_calendar('NYSE')

    start = time.time()

    for name in names:
        file = pd.read_csv(path + data + name)
        schedule = nyse.schedule(start_date='2020-9-23', end_date='2021-4-16')
        len(schedule)
        t = len(schedule)/252
        r = 1.58/100
        for i in file.index:
            S0 = file['S0'][i]
            K = file['Strike'][i]
```

```
            op = file['option price'][i]
            file['bise_vol'][i] = bisection_method(S0, K, r, t, op, option_type)
            file.to_csv(path + data + name, index=False)

    delta_time = (time.time() - start)
    print(delta_time)
```

2.4.2 Newton Volatility

[109]:
```
def nt_vol(path, data, names, dates, option_type):
    nyse = calen.get_calendar('NYSE')

    start = time.time()
    for name in names:
        file = pd.read_csv(path + data + name)
        for date in dates:
            schedule = nyse.schedule(start_date='2020-9-23', end_date=date)
            t = len(schedule)/252
            r = 1.58/100
            for i in file.index:
                S0 = file['S0'][i]
                K = file['Strike'][i]
                op = file['option price'][i]
                file['newt_vol'][i] = NewtonsMethod(S0, r, t, op, K,␣
 ↪option_type)
                file.to_csv(path + data + name,index=False)

    delta_time = (time.time() - start)
    print(delta_time)
```

[131]:
```
# Due to the large amount of the data,
# this function is a test function.
# There is only one Call Option data of Time to maturity on April 16, 2021 in␣
 ↪the test folder.
# After the test program is correct, use Google Colab to calculate all the data.

def nt_vol(path, data, names, option_type):
    nyse = calen.get_calendar('NYSE')

    start = time.time()
    for name in names:
        file = pd.read_csv(path + data + name)
        schedule = nyse.schedule(start_date='2020-9-23', end_date='2021-4-16')
        t = len(schedule)/252
        r = 1.58/100
        for i in file.index:
```

```
            S0 = file['S0'][i]
            K = file['Strike'][i]
            op = file['option price'][i]
            file['newt_vol'][i] = NewtonsMethod(S0, r, t, op, K, option_type)
            file.to_csv(path + data + name,index=False)

    delta_time = (time.time() - start)
    print(delta_time)
```

[99]:
```
def vol_at_the_money(path, data, names):
    for name in names:
        file = pd.read_csv(path + data + name)
        a = file[file['moneyness']=='at the money']
        a = a[['Contract Name','moneyness','Implied Volatility','bise_vol']]
        a.to_csv(path + data + 'vol_at_the_money.csv',index=False)
```

2.4.3 Average Volatility

[105]:
```
def ave_vol(path, data, names, code):
    ave_in = []
    ave_out = []

    for name in names:
        file = pd.read_csv(path + data + name)
        in_m = file[file['moneyness']=='in the money']
        in_col = in_m['bise_vol']
        ave_in.append(np.mean(in_col))
        out_m = file[file['moneyness']=='out of money']
        out_col = out_m['bise_vol']
        ave_out.append(np.mean(out_col))

    d={'contract':names,'ave_in':ave_in,'ave_out':ave_out}
    ave_vola=pd.DataFrame(data=d)
    ave_vola.to_csv(path + data + 'ave_vol.csv',index=False)
```

2.4.4 Test function and Calculate AMZN Call Options.

[137]:
```
# This part only run the test file to see if there is any bug in the function
# the bisection modle cost 26.359920024871826s
# the Newtons Method cost 0.57525706291198873s

if __name__ == "__main__":
    test = open_file(path, 'test')
    # at_amzn = open_file(path, 'at_amzn1c')
    # at_spy = open_file(path, 'at_spy1')
    # amzn_date = maturi[0]
```

```python
    # spy_date = maturi[1]
    print('bisection cost time:')
    bi_vol(path, 'test/', test, 0)
    # bi_vol(path, data, names, dates, option_type)
    # bi_vol(path, 'at_amzn1c/', at_amzn, amzn_date, 0)
    # bi_vol(path, 'at_spy1/', at_spy, spy_date, 'day1')
    print('newton cost time:')
    nt_vol(path, 'test/', test, 0)
    # nt_vol(path, 'at_amzn1/', at_amzn, amzn_date, 'day1')
    # nt_vol(path, 'at_spy1/', at_spy, spy_date, 'day1')
    vol_at_the_money(path, 'test/', test)
    # vol_at_the_money(path, 'at_amzn1/', at_amzn)
    # vol_at_the_money(path, 'at_spy1/', at_spy)
    ave_vol(path, 'test/', ['day1AMZNApril 16, 2021C.csv'], 'AMZN')
    # ave_vol(path, 'at_amzn1/', at_amzn, 'AMZN')
    # ave_vol(path, 'at_spy1/', at_spy, 'SPY')


# test successed
```

```
bisection cost time:
```

```
/Users/yuechenjiang/opt/anaconda3/lib/python3.7/site-
packages/ipykernel_launcher.py:3: RuntimeWarning: overflow encountered in
double_scalars
  This is separate from the ipykernel package so we can avoid doing imports
until
/Users/yuechenjiang/opt/anaconda3/lib/python3.7/site-
packages/ipykernel_launcher.py:3: RuntimeWarning: divide by zero encountered in
double_scalars
  This is separate from the ipykernel package so we can avoid doing imports
until
/Users/yuechenjiang/opt/anaconda3/lib/python3.7/site-
packages/ipykernel_launcher.py:20: SettingWithCopyWarning:
A value is trying to be set on a copy of a slice from a DataFrame

See the caveats in the documentation: https://pandas.pydata.org/pandas-
docs/stable/user_guide/indexing.html#returning-a-view-versus-a-copy
```

```
23.857665061950684
newton cost time:
```

```
/Users/yuechenjiang/opt/anaconda3/lib/python3.7/site-
packages/ipykernel_launcher.py:3: RuntimeWarning: divide by zero encountered in
double_scalars
  This is separate from the ipykernel package so we can avoid doing imports
until
/Users/yuechenjiang/opt/anaconda3/lib/python3.7/site-
packages/ipykernel_launcher.py:19: SettingWithCopyWarning:
```

```
A value is trying to be set on a copy of a slice from a DataFrame

See the caveats in the documentation: https://pandas.pydata.org/pandas-
docs/stable/user_guide/indexing.html#returning-a-view-versus-a-copy
```

```
0.5628271102905273
```

[ ]:
```
# After test we calculate the AMZN call options with different time to␣
↪maturity,
# others are finished in Google Colab.
if __name__ == "__main__":
    at_amzn = open_file(path, 'at_amzn1c')
    amzn_date = maturi[0]
    bi_vol(path, 'at_amzn1c/', at_amzn, amzn_date, 0)
    nt_vol(path, 'at_amzn1c/', at_amzn, amzn_date, 'day1')
    vol_at_the_money(path, 'at_amzn1c/', at_amzn)
    ave_vol(path, 'at_amzn1c/', at_amzn, 'AMZN')
```

When the transaction volume is large, the implied volatility calculated by the bisection and Newton iteration method is closer to the actual value. The efficiency of the Newton iteration method is higher than that of the dichotomy method, but there are cases where the iteration does not produce results, so The following volatility curve is drawn using the implied volatility calculated by dichotomy.

2.5 Put-Call parity

9. For each option in your table calculate the price of the different type (Call/Put) using the Put-Call parity. Compare the resulting values with the BID/ASK values for the corre- sponding option if they exist.

[225]:
```
def put_call(path, data, dates, code):
    nyse = calen.get_calendar('NYSE')

    call_names = []
    for file in os.listdir(path + data):
        if 'C.csv' in file:
            call_names.append(file)

    for name in call_names:
        file_call=pd.read_csv(path + data + name)
        file_call['Parity_call']=np.nan

    put_names = []
    for file in os.listdir(path + data):
        if 'P.csv' in file:
            put_names.append(file)

    for name in put_names:
```

```
        file_put=pd.read_csv(path + data + name)
        file_put['Parity_put']=np.nan

    for date in dates:
        schedule = nyse.schedule(start_date='2020-9-23', end_date=date)
        len(schedule)
        t=len(schedule)/252
        r=1.58/100
        for i in range(min(len(file_call),len(file_put))):
            K=file_call['Strike'][i]
            S0=file_call['S0'][i]
            file_call['Parity_call'][i]=max(file_put['option price'][i]+S0-K*np.
↪exp(-r*t),0)
            file_put['Parity_put'][i]=max(file_call['option price'][i]+K*np.
↪exp(-r*t)-S0,0)
            c={'Contract Name':file_call['Contract Name'],'Bid':
↪file_call['Bid'],'Ask':file_call['Ask'], 'option price':file_call['option␣
↪price'],'Parity call':file_call['Parity_call']}
            callfile=pd.DataFrame(data=c)
            callfile.to_csv(code + 'Parity_call_' + date + '.csv', index=False)
            p={'Contract Name':file_put['Contract Name'],'Bid':
↪file_put['Bid'],'Ask':file_put['Ask'],'option price':file_put['option␣
↪price'],'Parity put':file_put['Parity_put']}
            putfile=pd.DataFrame(data=p)
            putfile.to_csv(code + 'Parity_put_' + date + '.csv', index=False)
```

[229]:
```
if __name__ == "__main__":
    put_call(path, 'at_amzn1/', maturi[0], 'AMZN')
    put_call(path, 'at_spy1/', maturi[1], 'SPY')
```

```
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docs/stable/user_guide/indexing.html#returning-a-view-versus-a-copy
/Users/yuechenjiang/opt/anaconda3/lib/python3.7/site-
packages/ipykernel_launcher.py:31: SettingWithCopyWarning:
A value is trying to be set on a copy of a slice from a DataFrame

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```

```
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```

```
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```

```
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See the caveats in the documentation: https://pandas.pydata.org/pandas-
docs/stable/user_guide/indexing.html#returning-a-view-versus-a-copy
```

There are part of the file of put-call parity table. All files see zip file.

[230]:
```
call_amzn = pd.read_csv('AMZNParity_call_September 25, 2020.csv')
call_amzn
```

[230]:
```
           Contract Name  Bid  Ask  option price  Parity call
0   AMZN210716C01520000  0.0  0.0           0.0  1500.075917
1   AMZN210716C01800000  0.0  0.0           0.0  1220.128579
2   AMZN210716C01860000  0.0  0.0           0.0  1160.139863
3   AMZN210716C01940000  0.0  0.0           0.0  1080.154910
4   AMZN210716C01980000  0.0  0.0           0.0  1040.162433
..                   …    …    …             …            …
56  AMZN210716C05050000  0.0  0.0           0.0     0.000000
57  AMZN210716C05100000  0.0  0.0           0.0     0.000000
58  AMZN210716C05200000  0.0  0.0           0.0     0.000000
59  AMZN210716C05250000  0.0  0.0           0.0     0.000000
60  AMZN210716C05300000  0.0  0.0           0.0     0.000000

[61 rows x 5 columns]
```

[233]:
```
put_amzn = pd.read_csv('AMZNParity_put_September 25, 2020.csv')
put_amzn
```

[233]:
```
           Contract Name  Bid  Ask  option price  Parity put
0   AMZN210820P01500000  0.0  0.0           0.0         0.0
1   AMZN210820P01600000  0.0  0.0           0.0         0.0
2   AMZN210820P01620000  0.0  0.0           0.0         0.0
3   AMZN210820P01640000  0.0  0.0           0.0         0.0
4   AMZN210820P01660000  0.0  0.0           0.0         0.0
..                   …    …    …             …          …
67  AMZN210820P04500000  0.0  0.0           0.0         NaN
68  AMZN210820P04600000  0.0  0.0           0.0         NaN
69  AMZN210820P05000000  0.0  0.0           0.0         NaN
70  AMZN210820P05100000  0.0  0.0           0.0         NaN
71  AMZN210820P05200000  0.0  0.0           0.0         NaN

[72 rows x 5 columns]
```

[234]:
```
call_amzn = pd.read_csv('SPYParity_call_September 30, 2020.csv')
call_amzn
```

[234]:

```
          Contract Name     Bid     Ask  option price  Parity call
0    SPY210618C00100000    0.00    0.00         0.000   228.767623
1    SPY210618C00110000  214.40  215.71       215.055   218.771384
2    SPY210618C00115000    0.00    0.00         0.000   213.773265
3    SPY210618C00120000    0.00    0.00         0.000   208.775145
4    SPY210618C00125000  199.61  200.81       200.210   203.777026
..                  …       …       …             …            …
156  SPY210618C00510000    0.00    0.00         0.000          NaN
157  SPY210618C00515000    0.00    0.00         0.000          NaN
158  SPY210618C00520000    0.00    0.00         0.000          NaN
159  SPY210618C00525000    0.00    0.00         0.000          NaN
160  SPY210618C00530000    0.00    0.00         0.000          NaN

[161 rows x 5 columns]
```

[235]:

```python
put_spy = pd.read_csv('SPYParity_put_September 30, 2020.csv')
put_spy
```

[235]:

```
         Contract Name  Bid  Ask  option price  Parity put
0   SPY201019P00210000  0.0  0.0           0.0    0.000000
1   SPY201019P00215000  0.0  0.0           0.0    0.000000
2   SPY201019P00220000  0.0  0.0           0.0    0.000000
3   SPY201019P00225000  0.0  0.0           0.0    0.000000
4   SPY201019P00230000  0.0  0.0           0.0    0.000000
5   SPY201019P00235000  0.0  0.0           0.0    0.000000
6   SPY201019P00240000  0.0  0.0           0.0    0.000000
7   SPY201019P00245000  0.0  0.0           0.0    0.000000
8   SPY201019P00250000  0.0  0.0           0.0    0.000000
9   SPY201019P00255000  0.0  0.0           0.0    0.000000
10  SPY201019P00260000  0.0  0.0           0.0    0.000000
11  SPY201019P00270000  0.0  0.0           0.0    0.000000
12  SPY201019P00275000  0.0  0.0           0.0    0.000000
13  SPY201019P00280000  0.0  0.0           0.0   21.929168
14  SPY201019P00285000  0.0  0.0           0.0    0.000000
15  SPY201019P00290000  0.0  0.0           0.0    0.000000
16  SPY201019P00295000  0.0  0.0           0.0    0.000000
17  SPY201019P00300000  0.0  0.0           0.0    0.000000
18  SPY201019P00305000  0.0  0.0           0.0    0.000000
19  SPY201019P00310000  0.0  0.0           0.0    0.000000
20  SPY201019P00315000  0.0  0.0           0.0    0.000000
21  SPY201019P00320000  0.0  0.0           0.0    0.000000
22  SPY201019P00325000  0.0  0.0           0.0    0.000000
23  SPY201019P00326000  0.0  0.0           0.0    0.000000
24  SPY201019P00327000  0.0  0.0           0.0    0.000000
25  SPY201019P00328000  0.0  0.0           0.0    0.000000
26  SPY201019P00329000  0.0  0.0           0.0    0.000000
27  SPY201019P00330000  0.0  0.0           0.0    0.000000
```

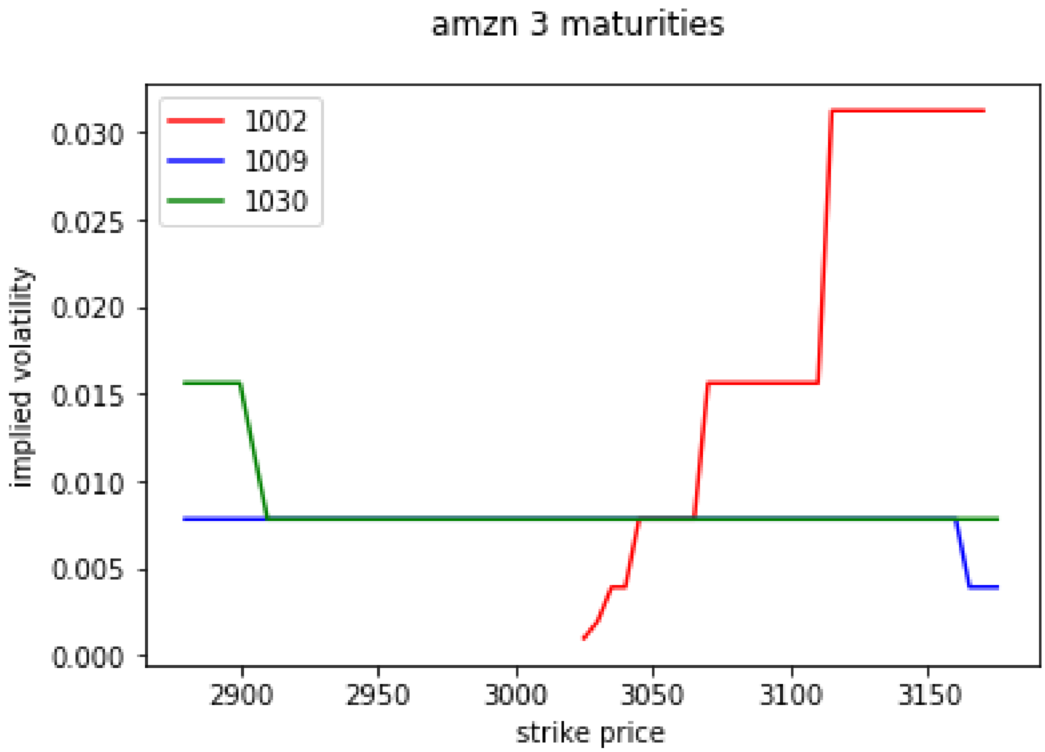
```
28  SPY201019P00331000  0.0  0.0           0.0    0.000000
29  SPY201019P00332000  0.0  0.0           0.0    0.000000
30  SPY201019P00333000  0.0  0.0           0.0    0.000000
31  SPY201019P00334000  0.0  0.0           0.0    0.000000
32  SPY201019P00335000  0.0  0.0           0.0   20.533813
33  SPY201019P00336000  0.0  0.0           0.0    0.000000
34  SPY201019P00337000  0.0  0.0           0.0    0.000000
35  SPY201019P00338000  0.0  0.0           0.0    8.747308
36  SPY201019P00339000  0.0  0.0           0.0    0.000000
37  SPY201019P00340000  0.0  0.0           0.0    5.796180
38  SPY201019P00341000  0.0  0.0           0.0    5.895804
39  SPY201019P00342000  0.0  0.0           0.0    0.000000
40  SPY201019P00343000  0.0  0.0           0.0   18.574299
41  SPY201019P00344000  0.0  0.0           0.0    0.000000
42  SPY201019P00345000  0.0  0.0           0.0    0.000000
43  SPY201019P00347000  0.0  0.0           0.0    0.000000
44  SPY201019P00349000  0.0  0.0           0.0    0.000000
45  SPY201019P00350000  0.0  0.0           0.0    0.000000
46  SPY201019P00360000  0.0  0.0           0.0   16.810538
47  SPY201019P00370000  0.0  0.0           0.0    0.000000
```

2.6 Volatility Smile close to time to maturity options

10. Consider the implied volatility values obtained in the previous parts. Create a 2 dimensional plot of implied volatilities versus strike K for the closest to maturity options. What do you observe? Plot all implied volatilities for the three different maturities on the same plot, where you use a different color for each maturity. In total there should be 3 sets of points plotted with different color.

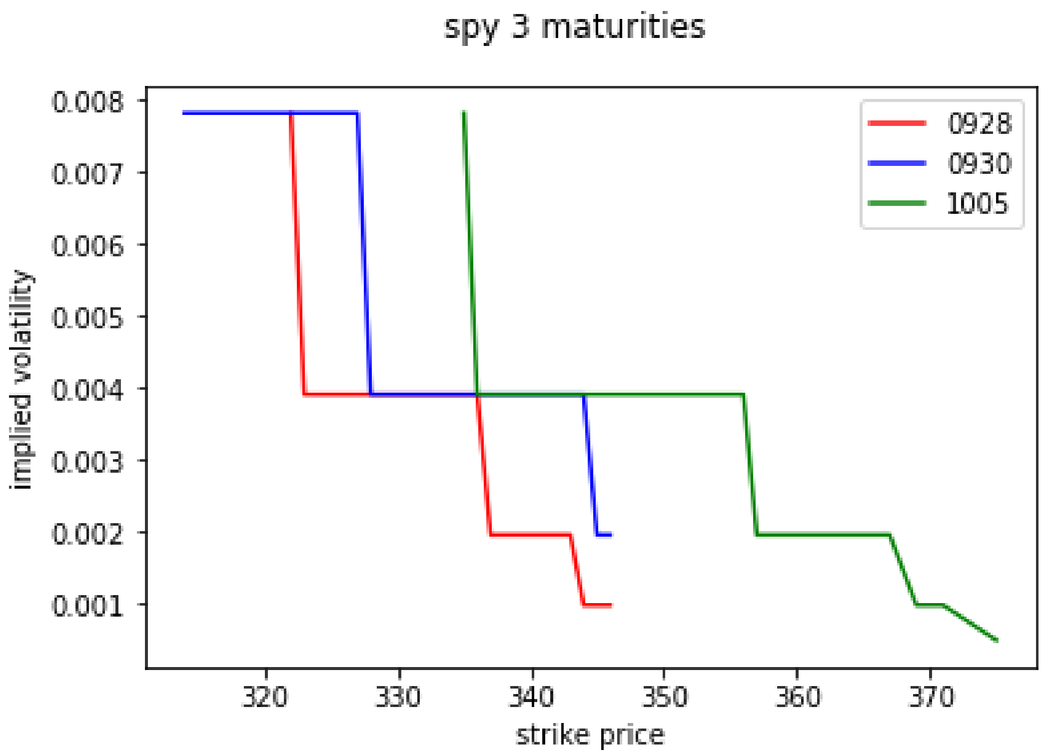
[200]:
```
#Plot all implied volatilities for the three different maturities on the same␣
↪plot

file=pd.read_csv('day1AMZNOctober 2, 2020C.csv')
a=file.dropna(how='any',subset=['bise_vol'])
plt.plot(a['Strike'],a['bise_vol'],'r')

file=pd.read_csv('day1AMZNOctober 9, 2020C.csv')
a=file.dropna(how='any',subset=['bise_vol'])
plt.plot(a['Strike'],a['bise_vol'],'b')

file=pd.read_csv('day1AMZNOctober 30, 2020C.csv')
a=file.dropna(how='any',subset=['bise_vol'])
plt.plot(a['Strike'],a['bise_vol'],'g')

plt.legend(labels=['1002','1009','1030'])
```

```
plt.xlabel('strike price')
plt.ylabel('implied volatility')
plt.suptitle('amzn 3 maturities')

plt.show()
```



[204]:
```
##spy 3 maturities plot

file=pd.read_csv('day1SPYSeptember 28, 2020C.csv')
a=file.dropna(how='any',subset=['bise_vol'])
plt.plot(a['Strike'],a['bise_vol'],'r')

file=pd.read_csv('day1SPYSeptember 30, 2020C.csv')
a=file.dropna(how='any',subset=['bise_vol'])
plt.plot(a['Strike'],a['bise_vol'],'b')

file=pd.read_csv('day1SPYOctober 5, 2020C.csv')
a=file.dropna(how='any',subset=['bise_vol'])
plt.plot(a['Strike'],a['bise_vol'],'g')

plt.legend(labels=['0928','0930','1005'])
```

```
plt.xlabel('strike price')
plt.ylabel('implied volatility')
plt.suptitle('spy 3 maturities')

plt.show()
```



2.7 Greek of Amzn and SPY

11. (Greeks) Calculate the derivatives of the call option price with respect to S (Delta), and σ (Vega) and the second derivative with respect to S (Gamma). First use the Black Scholes formula then approximate these derivatives using an approximation of the partial derivatives. Compare the numbers obtained by the two methods. Output a table containing all derivatives thus calculated.

[264]:
```
def N1(x):
    return  np.exp(-x**2/2)/(np.sqrt(2*np.pi))



def delta_bs(d1,sigma):
    return norm.cdf(d1)

def vega_bs(d1,sigma):
```

```
    return S0*np.sqrt(t)*N1(d1)

def gamma_bs(d1,sigma):
    return N1(d1)/(S0*sigma*np.sqrt(t))

def delta_numeri(S0,sigma):
    return (bs_formula(S0+0.
 ↪01,sigma,t,K,r,option_type)-bs_formula(S0,sigma,t,K,r,option_type))/0.01

def vega_numeri(sigma):
    return (bs_formula(S0,sigma+0.
 ↪0001,t,K,r,option_type)-bs_formula(S0,sigma,t,K,r,option_type))/0.0001

def gamma_numeri(S0,sigma):
    return (delta_numeri(S0+0.01,sigma)-delta_numeri(S0,sigma))/0.01
```

[270]:
```
def greek(path, data, dates, code):
    nyse = calen.get_calendar('NYSE')

    names = []
    for file in os.listdir(path + data):
        if 'C.csv' in file:
            names.append(file)

    for name in names:
        file = pd.read_csv(path + data + name)
        file=file.dropna(how='any',subset=['bise_vol'])
        file['delta_bs']=np.nan
        file['delta_numeri']=np.nan
        file['vega_bs']=np.nan
        file['vega_numeri']=np.nan
        file['gamma_bs']=np.nan
        file['gamma_numeri']=np.nan

    for date in dates:
        schedule = nyse.schedule(start_date='2020-2-10', end_date=date)
        len(schedule)
        t=len(schedule)/252
        r=1.58/100
        option_type=0

    for i in file.index:
        K=file['Strike'][i]
        S0=file['S0'][i]
        sigma=file['bise_vol'][i]

        d1=(ln(S0/K)+(r+(sigma**2)/2)*t)/(sigma*np.sqrt(t))
```

```
        d2=d1-(sigma*np.sqrt(t))

        file['delta_bs'][i]=delta_bs(d1,sigma)
        file['delta_numeri'][i]=delta_numeri(S0, sigma)
        file['vega_bs'][i]=vega_bs(d1,sigma)
        file['vega_numeri'][i]=vega_numeri(sigma)
        file['gamma_bs'][i]=gamma_bs(d1,sigma)
        file['gamma_numeri'][i]=gamma_numeri(S0,sigma)
        d={'Contract Name':file['Contract Name'],'Strike':file['Strike'],'S0':
↪file['S0'],'option price':file['option price'],'bise_vol':
↪file['bise_vol'],'delta_bs':file['delta_bs'],'delta_numeri':
↪file['delta_numeri'],'vega_bs':file['vega_bs'],'vega_numeri':
↪file['vega_numeri'],'gamma_bs':file['gamma_bs'],'gamma_numeri':
↪file['gamma_numeri']}
        file=pd.DataFrame(data=d)
        file.to_csv('Greek'+ code + date + '.csv',index=False)
```

[274]:
```
if __name__ == "__main__":
    greek(path, 'at_amzn1/', maturi[0], 'AMZN')
    greek(path, 'at_spy1/', maturi[1], 'SPY')
```

```
/Users/yuechenjiang/opt/anaconda3/lib/python3.7/site-
packages/ipykernel_launcher.py:31: RuntimeWarning: divide by zero encountered in
double_scalars
/Users/yuechenjiang/opt/anaconda3/lib/python3.7/site-
packages/ipykernel_launcher.py:34: SettingWithCopyWarning:
A value is trying to be set on a copy of a slice from a DataFrame

See the caveats in the documentation: https://pandas.pydata.org/pandas-
docs/stable/user_guide/indexing.html#returning-a-view-versus-a-copy
/Users/yuechenjiang/opt/anaconda3/lib/python3.7/site-
packages/ipykernel_launcher.py:3: RuntimeWarning: divide by zero encountered in
double_scalars
  This is separate from the ipykernel package so we can avoid doing imports
until
/Users/yuechenjiang/opt/anaconda3/lib/python3.7/site-
packages/ipykernel_launcher.py:35: SettingWithCopyWarning:
A value is trying to be set on a copy of a slice from a DataFrame

See the caveats in the documentation: https://pandas.pydata.org/pandas-
docs/stable/user_guide/indexing.html#returning-a-view-versus-a-copy
/Users/yuechenjiang/opt/anaconda3/lib/python3.7/site-
packages/ipykernel_launcher.py:36: SettingWithCopyWarning:
A value is trying to be set on a copy of a slice from a DataFrame

See the caveats in the documentation: https://pandas.pydata.org/pandas-
docs/stable/user_guide/indexing.html#returning-a-view-versus-a-copy
```

```
/Users/yuechenjiang/opt/anaconda3/lib/python3.7/site-
packages/ipykernel_launcher.py:37: SettingWithCopyWarning:
A value is trying to be set on a copy of a slice from a DataFrame

See the caveats in the documentation: https://pandas.pydata.org/pandas-
docs/stable/user_guide/indexing.html#returning-a-view-versus-a-copy
/Users/yuechenjiang/opt/anaconda3/lib/python3.7/site-
packages/ipykernel_launcher.py:28: RuntimeWarning: invalid value encountered in
double_scalars
/Users/yuechenjiang/opt/anaconda3/lib/python3.7/site-
packages/ipykernel_launcher.py:38: SettingWithCopyWarning:
A value is trying to be set on a copy of a slice from a DataFrame

See the caveats in the documentation: https://pandas.pydata.org/pandas-
docs/stable/user_guide/indexing.html#returning-a-view-versus-a-copy
/Users/yuechenjiang/opt/anaconda3/lib/python3.7/site-
packages/ipykernel_launcher.py:39: SettingWithCopyWarning:
A value is trying to be set on a copy of a slice from a DataFrame

See the caveats in the documentation: https://pandas.pydata.org/pandas-
docs/stable/user_guide/indexing.html#returning-a-view-versus-a-copy
/Users/yuechenjiang/opt/anaconda3/lib/python3.7/site-
packages/ipykernel_launcher.py:31: RuntimeWarning: divide by zero encountered in
double_scalars
/Users/yuechenjiang/opt/anaconda3/lib/python3.7/site-
packages/ipykernel_launcher.py:34: SettingWithCopyWarning:
A value is trying to be set on a copy of a slice from a DataFrame

See the caveats in the documentation: https://pandas.pydata.org/pandas-
docs/stable/user_guide/indexing.html#returning-a-view-versus-a-copy
/Users/yuechenjiang/opt/anaconda3/lib/python3.7/site-
packages/ipykernel_launcher.py:3: RuntimeWarning: divide by zero encountered in
double_scalars
  This is separate from the ipykernel package so we can avoid doing imports
until
/Users/yuechenjiang/opt/anaconda3/lib/python3.7/site-
packages/ipykernel_launcher.py:35: SettingWithCopyWarning:
A value is trying to be set on a copy of a slice from a DataFrame

See the caveats in the documentation: https://pandas.pydata.org/pandas-
docs/stable/user_guide/indexing.html#returning-a-view-versus-a-copy
/Users/yuechenjiang/opt/anaconda3/lib/python3.7/site-
packages/ipykernel_launcher.py:36: SettingWithCopyWarning:
A value is trying to be set on a copy of a slice from a DataFrame

See the caveats in the documentation: https://pandas.pydata.org/pandas-
docs/stable/user_guide/indexing.html#returning-a-view-versus-a-copy
/Users/yuechenjiang/opt/anaconda3/lib/python3.7/site-
```

```
packages/ipykernel_launcher.py:37: SettingWithCopyWarning:
A value is trying to be set on a copy of a slice from a DataFrame

See the caveats in the documentation: https://pandas.pydata.org/pandas-
docs/stable/user_guide/indexing.html#returning-a-view-versus-a-copy
/Users/yuechenjiang/opt/anaconda3/lib/python3.7/site-
packages/ipykernel_launcher.py:28: RuntimeWarning: invalid value encountered in
double_scalars
/Users/yuechenjiang/opt/anaconda3/lib/python3.7/site-
packages/ipykernel_launcher.py:38: SettingWithCopyWarning:
A value is trying to be set on a copy of a slice from a DataFrame

See the caveats in the documentation: https://pandas.pydata.org/pandas-
docs/stable/user_guide/indexing.html#returning-a-view-versus-a-copy
/Users/yuechenjiang/opt/anaconda3/lib/python3.7/site-
packages/ipykernel_launcher.py:39: SettingWithCopyWarning:
A value is trying to be set on a copy of a slice from a DataFrame

See the caveats in the documentation: https://pandas.pydata.org/pandas-
docs/stable/user_guide/indexing.html#returning-a-view-versus-a-copy
```

There are part of the file of put-call parity table. All files see zip file.

[273]:
```
greek_amzn = pd.read_csv('GreekAMZNJanuary 20, 2023.csv')
greek_amzn
```

[273]:
```
          Contract Name  Strike           S0  option price  bise_vol  \
0   AMZN210716C01520000  1520.0  3019.790039           0.0       0.0
1   AMZN210716C01800000  1800.0  3019.790039           0.0       0.0
2   AMZN210716C01860000  1860.0  3019.790039           0.0       0.0
3   AMZN210716C01940000  1940.0  3019.790039           0.0       0.0
4   AMZN210716C01980000  1980.0  3019.790039           0.0       0.0
..                  …       …            …            …         …
56  AMZN210716C05050000  5050.0  3019.790039           0.0       0.0
57  AMZN210716C05100000  5100.0  3019.790039           0.0       0.0
58  AMZN210716C05200000  5200.0  3019.790039           0.0       0.0
59  AMZN210716C05250000  5250.0  3019.790039           0.0       0.0
60  AMZN210716C05300000  5300.0  3019.790039           0.0       0.0

    delta_bs  delta_numeri  vega_bs  vega_numeri  gamma_bs  gamma_numeri
0        1.0          -1.0      0.0          0.0       NaN           0.0
1        1.0          -1.0      0.0          0.0       NaN           0.0
2        1.0          -1.0      0.0          0.0       NaN           0.0
3        1.0          -1.0      0.0          0.0       NaN           0.0
4        1.0          -1.0      0.0          0.0       NaN           0.0
..         …             …        …            …         …             …
56       0.0          -1.0      0.0          0.0       NaN           0.0
57       0.0          -1.0      0.0          0.0       NaN           0.0
```

```
58        0.0          -1.0     0.0          0.0       NaN           0.0
59        0.0          -1.0     0.0          0.0       NaN           0.0
60        0.0          -1.0     0.0          0.0       NaN           0.0

[61 rows x 11 columns]
```

[275]:

```
greek_spy = pd.read_csv('GreekSPYJanuary 20, 2023.csv')
greek_spy
```

[275]:

```
          Contract Name  Strike          S0  option price  bise_vol  delta_bs  \
0    SPY210618C00100000   100.0  328.730011         0.000       0.0       1.0
1    SPY210618C00110000   110.0  328.730011       215.055       0.0       1.0
2    SPY210618C00115000   115.0  328.730011         0.000       0.0       1.0
3    SPY210618C00120000   120.0  328.730011         0.000       0.0       1.0
4    SPY210618C00125000   125.0  328.730011       200.210       0.0       1.0
..                  …     …         …          …       …        …
156  SPY210618C00510000   510.0  328.730011         0.000       0.0       0.0
157  SPY210618C00515000   515.0  328.730011         0.000       0.0       0.0
158  SPY210618C00520000   520.0  328.730011         0.000       0.0       0.0
159  SPY210618C00525000   525.0  328.730011         0.000       0.0       0.0
160  SPY210618C00530000   530.0  328.730011         0.000       0.0       0.0

     delta_numeri  vega_bs  vega_numeri  gamma_bs  gamma_numeri
0            -1.0      0.0          0.0       NaN  4.547474e-09
1            -1.0      0.0          0.0       NaN  4.547474e-09
2            -1.0      0.0          0.0       NaN  4.547474e-09
3            -1.0      0.0          0.0       NaN  4.547474e-09
4            -1.0      0.0          0.0       NaN  4.547474e-09
..            …      …          …       …           …
156          -1.0      0.0          0.0       NaN  4.547474e-09
157          -1.0      0.0          0.0       NaN  4.547474e-09
158          -1.0      0.0          0.0       NaN  4.547474e-09
159          -1.0      0.0          0.0       NaN  4.547474e-09
160          -1.0      0.0          0.0       NaN  4.547474e-09

[161 rows x 11 columns]
```

12. Next we will use the second dataset DATA2. For each strike price in the data use the Stock price for the same day, the implied volatility you calculated from DATA1 and the current short-term interest rate (corresponding to the day on which DATA2 was gathered). Use the Black-Scholes formula, to calculate the option price.

[299]:

```
def bs_price(path, data1, data2, names1, names2, dates, price, option_type):
    nyse = calen.get_calendar('NYSE')

    for name in names1:
        file1=pd.read_csv(path + data1 + name)
```

```
        file1=file1.dropna(how='any',subset=['bise_vol'])
        for name in names2:
            file2=pd.read_csv(path + data2 + name)

            file2['S0'] = price
            file2['option price']=np.nan

            for date in dates:
                schedule = nyse.schedule(start_date='2020-9-23', end_date=date)
                len(schedule)
                t=len(schedule)/252
                r=1.58/100
                for i in file2.index:
                    K=file2['Strike'][i]
                    file2['option price'][i]=(file2['Bid'][i]+file2['Ask'][i])/2
                    sigma=file1['bise_vol'][i]
                    file2['option␣
↪price'][i]=bs_formula(price,sigma,t,K,r,option_type)

                    file2=file2.dropna(how='any',subset=['option price'])
                    d={'Contract Name':file2['Contract Name'],'Strike':
↪file2['Strike'],'S0':file2['S0'],'Bid':file2['Bid'],'Ask':
↪file2['Ask'],'option price':file2['option price']}
                    file2=pd.DataFrame(data=d)
                    file2.to_csv('bs_price_amzn_' + name,index=False)
```

There are part of the file of put-call parity table. All files see zip file.

[333]:
```
amzn = pd.read_csv('bs_price_amzn.csv')
amzn
```

[333]:

	Contract Name	Strike	S0	Bid	Ask	option price
0	AMZN200925C03075000	3075	3095.129883	13.70	14.40	8.640000e-220
1	AMZN200925C03080000	3080	3095.129883	11.35	12.35	7.210000e-128
2	AMZN200925C03085000	3085	3095.129883	11.20	12.10	3.460000e-61
3	AMZN200925C03090000	3090	3095.129883	10.30	10.85	1.650000e-19
4	AMZN200925C03095000	3095	3095.129883	8.65	9.35	4.711331e-02
..	…	…	…	…	…	…
137	AMZN200925C04600000	4600	3095.129883	0.00	0.01	1.504005e+03
138	AMZN200925C04700000	4700	3095.129883	0.00	0.01	1.603986e+03
139	AMZN200925C04800000	4800	3095.129883	0.00	0.01	1.703967e+03
140	AMZN200925C04900000	4900	3095.129883	0.00	0.00	1.803949e+03
141	AMZN200925C05000000	5000	3095.129883	0.00	0.01	1.903930e+03

[142 rows x 6 columns]

[334]:
```
spy = pd.read_csv('bs_price_spy.csv')
spy
```

[334]:
```
          Contract Name  Strike           S0     Bid     Ask   option price
0    SPY200930C00185000   185.0  3095.129883  155.01  155.38  7.978912e-147
1    SPY200930C00190000   190.0  3095.129883  133.71  134.17   0.000000e+00
2    SPY200930C00195000   195.0  3095.129883  136.04  137.07  1.949545e-141
3    SPY200930C00199000   199.0  3095.129883  125.92  126.67  4.993843e-144
4    SPY200930C00200000   200.0  3095.129883  123.55  124.00   0.000000e+00
..                  …      …           …     …     …            …
189  SPY200930C00405000   405.0  3095.129883    0.00    0.01   0.000000e+00
190  SPY200930C00410000   410.0  3095.129883    0.00    0.01   0.000000e+00
191  SPY200930C00415000   415.0  3095.129883    0.00    0.01   0.000000e+00
192  SPY200930C00420000   420.0  3095.129883    0.00    0.01   0.000000e+00
193  SPY200930C00425000   425.0  3095.129883    0.00    0.01   0.000000e+00

[194 rows x 6 columns]
```

3 Part 3. Numerical Integration of real-valued functions.

Consider the real-valued function:

$$f(x)\begin{cases}\dfrac{sin(x)}{x}, & for\ x\ \neq\ 0,\\ 1, & for\ x\ =\ 0.\end{cases}$$

Note that we can actually calculate this integral as: $\int_{-\infty}^{\infty} f(x)dx = \pi$

[17]:
```
def f(x):
    if x !=0:
        return np.sin(x)/x
    else:
        return 1
```

1. Implement the trapezoidal and the Simpson's quadrature rules to numerically approximate the indefinite integral above.

[18]:
```
#trapezoidal
def trapezoidal(a,N):
    dx = 2 * a / N
    integ = (f(-a) + f(a)) * dx/2
    for i in range(1,N):
        integ+=dx * f(-a + i * dx)
    return(integ)
```

[19]:
```
def simpson(a,N):
     dx = 2 * a / N
     even_item = 0
```

```
    odd_item = 0
    for j in range(1,int(N/2)):
        even_item+=f(-a + 2 * j * 2 * a/N)

    for j in range(1,int(N/2) + 1):
        odd_item+=f(-a + (2 * j - 1) * 2 * a/N)


    integ = even_item * 4 * dx/3 + odd_item * 2 * dx/3 + f(-a) * dx/3 + f(a) *␣
↪dx/3

    return(integ)
```

2. Compute the truncation error for the numerical algorithms implemented in 1. for a particular α R and \$ N\$ N. That is,create a functiono f α and N that will output $I_N - \pi$, where $I_{N,\alpha}$ is the numerical approximation of the integral. Study the changes in the approximation as N and α increase as well as the difference between the two quadrature approximations. Please write your observations.

Observation: Truncation error will decrease when α or N increase. And when fix α and increase N, simpson error is larger than that of trapezoidal method. (See image below)

[20]:
```
def trape_error(a,N):
    return(trapezoidal(a,N) - np.pi)

#fix a and increase N
def fix_trape_N(a):
    numbers=[]
    list=[]
    for n in range(1,500):
        N=1000*n
        numbers.append(N)
        list.append(trape_error(a,N))
    data = pd.DataFrame({'Numbers':numbers, 'Trape_Error':list})
    return(data)
```

[21]:
```
def simpson_error(a,N):
    return(simpson(a,N) - np.pi)

#fix a and increase N
def fix_simpson_N(a):
    numbers=[]
    list=[]
    for n in range(1,500):
        N=1000*n
        numbers.append(N)
        list.append(simpson_error(a,N))
    data = pd.DataFrame({'Numbers':numbers, 'Simpson_Error':list})
```

```
    return(data)
```

[22]:
```
#fix N and increase a
def fix_trape_a(N):
    numbers=[]
    list=[]
    for i in range(1,500):
        a=1000*i
        numbers.append(a)
        list.append(trape_error(a,N))
    data = pd.DataFrame({'Inte_Interval':numbers, 'Trape_Error':list})
    return(data)
```

[23]:
```
#fix N and increase a
def fix_trape_a(N):
    numbers=[]
    list=[]
    for i in range(1,500):
        a=1000*i
        numbers.append(a)
        list.append(simpson_error(a,N))
    data = pd.DataFrame({'Inte_Interval':numbers, 'Simpson_Error':list})
    return(data)
```

3. In a typical scenario we do not know the true value of the integral. Thus, to ensure the convergence of the numerical algorithms we pick a small tolerance value ξ and we check at every iteration $k = 1, 2, \cdots$ if the following condition holds:

$$|I_k - I_{k-1}| < \xi,$$

where I_k is the value of the integral at step k. When the condition holds,, the algorithm stops.Evaluate the number of steps until the algorithms from a) reach convergence for $\xi = 10^{-4}$. what do you observe?

[24]:
```
def trape_time(a, tol, k):
    while True:
        delta=abs(trapezoidal(a,k+1)-trapezoidal(a,k))
        if delta<tol:
            return(k+1)
            break
        k+=1
```

[25]:
```
def simp_time(a, tol, k):
    while True:
        delta = abs(simpson(a,k+1)-simpson(a,k))
        if delta<tol:
            return(k+1)
            break
```

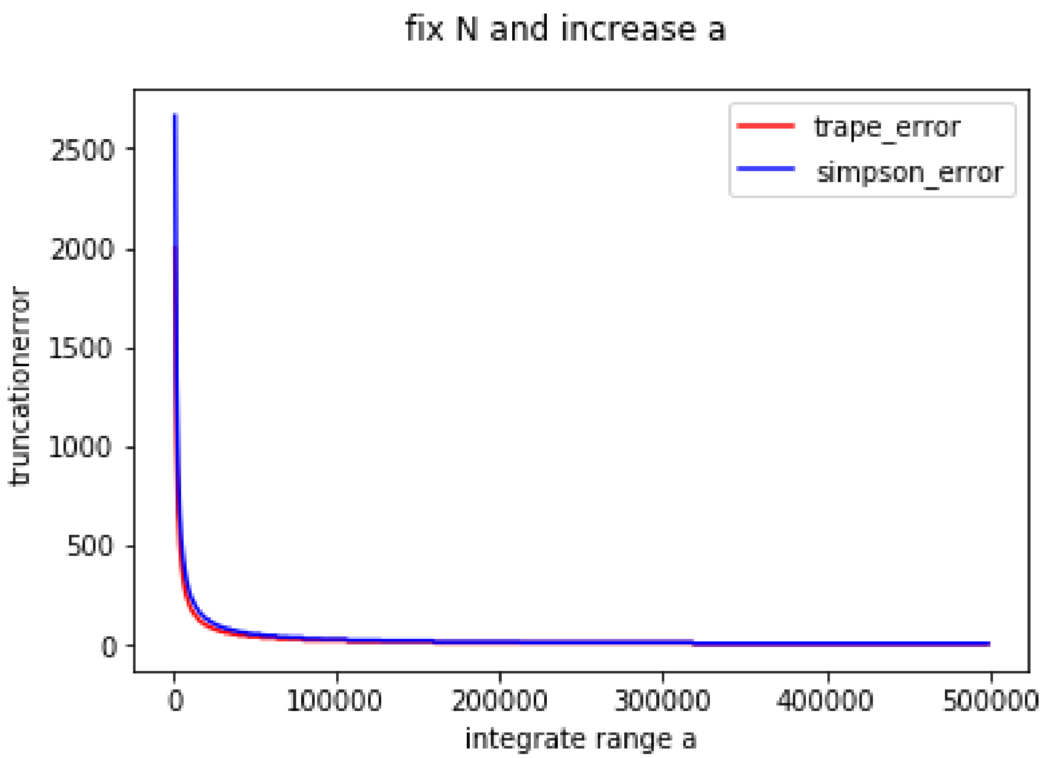
```
        k+=1
```

[26]:
```
if __name__ == "__main__":
    print('Trapezoidal’s quadrature rules:',trapezoidal(10**6,3000000))
    print('Simpson’s quadrature rules:', simpson(10**6,1000000))
    print('Times of trape is:', trape_time(10**6, 10**(-4), 318380))
    print('Times of simpson is', simp_time(10**6, 10**(-4), 640660))
    a = fix_trape_N(10**6)
    b = fix_simpson_N(10**6)
    c = fix_trape_a(500000)
    d = fix_trape_a(500000)
```

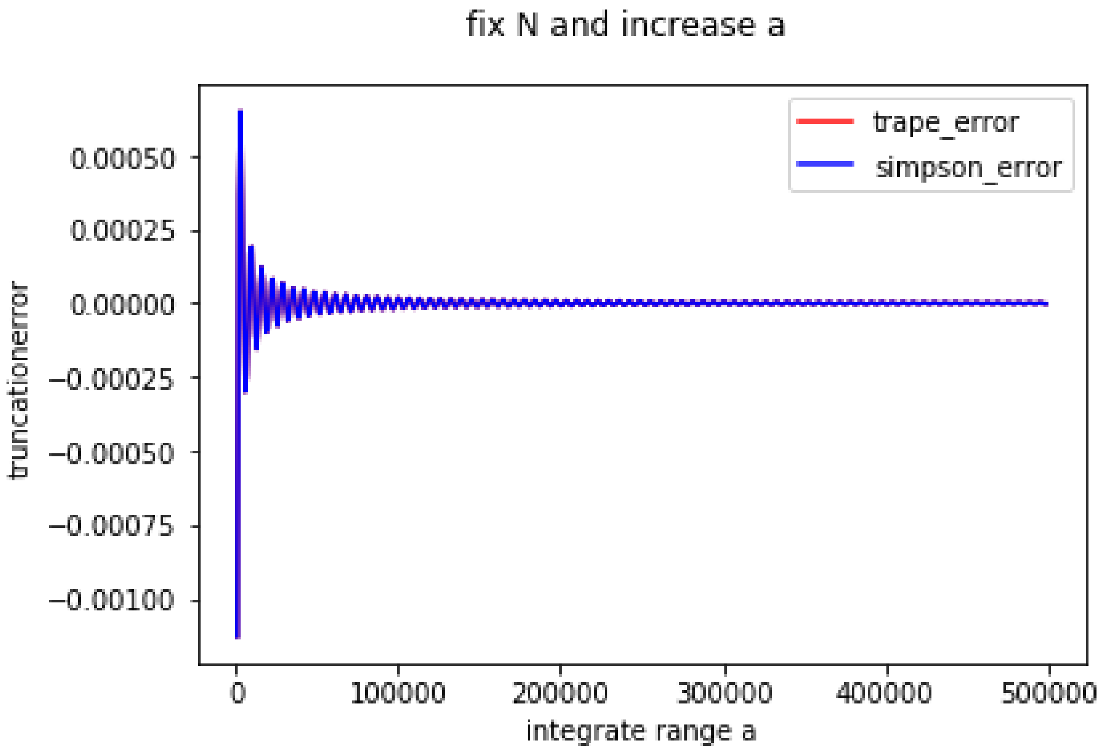
```
Trapezoidal’s quadrature rules: 3.1415908499948566
Simpson’s quadrature rules: 3.1415928898896732
Times of trape is: 318388
Times of simpson is 640668
```

So, simpson converge slower than that of trape.

[27]:
```
plt.plot(a.iloc[:,0],a.iloc[:,1],'r')
plt.plot(b.iloc[:,0],b.iloc[:,1],'b')

plt.legend(labels=['trape_error','simpson_error'])


plt.xlabel('integrate range a')
plt.ylabel('truncationerror')
plt.suptitle('fix N and increase a')

plt.show()
```



[28]:
```
plt.plot(c.iloc[:,0],c.iloc[:,1],'r')
plt.plot(d.iloc[:,0],d.iloc[:,1],'b')

plt.legend(labels=['trape_error','simpson_error'])


plt.xlabel('integrate range a')
plt.ylabel('truncationerror')
plt.suptitle('fix N and increase a')

plt.show()
```



4 Part4. Condider the following functions

1. The integration of $f_1(x, y)$ is 2.25
   The integration of $f_2(x, y)$ is $(e - 1) \times (e^3 - 1) = 32.79433128149753$

[29]:
```
-(np.exp(1)-1)*(np.exp(3)-1)
```

[29]: -32.79433128149753

2. Calculate the numerical integral of the f1 and f2 by applying the trape- zoidal rule for double integral

[30]:
```
def f1(x,y):
    return x*y

def f2(x,y):
    return np.exp(x+y)
```

[31]:
```
def trape_double(f,n,m):
    dx = 1/(n + 1)
    dy = 3/(m + 1)
    result=0
```

```
    def x(i):
        return i * dx
    def y(j):
        return j * dy

    for i in range(n + 1):
        for j in range(m + 1):
            result+=f(x(i),y(j)) + f(x(i),y(j + 1)) + f(x(i + 1), y(j)) + f(x(i␣
↪+ 1), y(j + 1)) + 2 * (f((x(i) + x(i + 1))/2, y(j)) + f((x(i) + x(i + 1))/
↪2,y(j + 1)) + f(x(i),(y(j) + y(j + 1))/2) + f(x(j + 1), (y(j) + y(j + 1))/
↪2)) + 4 * f((x(i) + x(i + 1))/2, (y(j) + y(j + 1))/2)

    return (dx * dy * result/16)
```

```
[32]: if __name__ == "__main__":
    m1 = 30
    n1 = 10

    m2 = 90
    n2 = 30

    m3 = 270
    n3 = 90

    m4 = 300
    n4 = 100

    m_list = [m1,m2,m3,m4]
    n_list = [n1,n2,n3,n4]
    approx_f1_list = [trape_double(f1,n1,m1), trape_double(f1,n2,m2),␣
↪trape_double(f1,n3,m3), trape_double(f1,n4,m4)]
    erro_f1_list = [trape_double(f1,n1,m1) - 2.25, trape_double(f1,n2,m2) - 2.
↪25, trape_double(f1,n3,m3) - 2.25, trape_double(f1,n4,m4) - 2.25]

    approx_f2_list = [trape_double(f2,n1,m1), trape_double(f2,n2,m2),␣
↪trape_double(f2,n3,m3), trape_double(f2,n4,m4)]
    erro_f2_list = [trape_double(f2,n1,m1) - (np.exp(1) - 1) * (np.exp(3) - 1),␣
↪trape_double(f2,n2,m2) - (np.exp(1) - 1) * (np.exp(3) - 1),␣
↪trape_double(f2,n3,m3) - (np.exp(1) - 1) * (np.exp(3) - 1),␣
↪trape_double(f2,n4,m4) - (np.exp(1) - 1) * (np.exp(3) - 1)]

    form = pd.DataFrame({'n':n_list, 'm':m_list, 'approx_f1':approx_f1_list,␣
↪'erro_f1':erro_f1_list, 'approx_f2':approx_f2_list, 'erro_f2':erro_f2_list})
    print(form)
```

```
     n    m  approx_f1   erro_f1  approx_f2    erro_f2
0   10   30   3.025293  0.775293  51.106606  18.312274
```

1	30	90	3.069523	0.819523	52.846132	20.051801
2	90	270	3.085504	0.835504	53.502354	20.708022
3	100	300	3.086321	0.836321	53.536295	20.741963

After calculated four approximation result and errors. We can observe from the result from above that the approximation method for double integration has lager error than that of single integration.