Project: Pricing Asian option with Binomial tree method

data source: \ https://finance.yahoo.com/quote/BTC-USD/history?p=BTC-USD; \
https://finance.yahoo.com/quote/ETH-USD/history?p=ETH-USD; \
https://www.deribit.com/main#/options?tab=BTC-2MAR21

In [12]:

```
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
from pandas_datareader import data as wb
import time
from scipy.stats import norm
```

1. Download underlying asset's price data, analyze the data, estimate log return mean, volatility, and other parameter values. consider two risk-free rates: ·r = 1% and r=5%

In [13]:

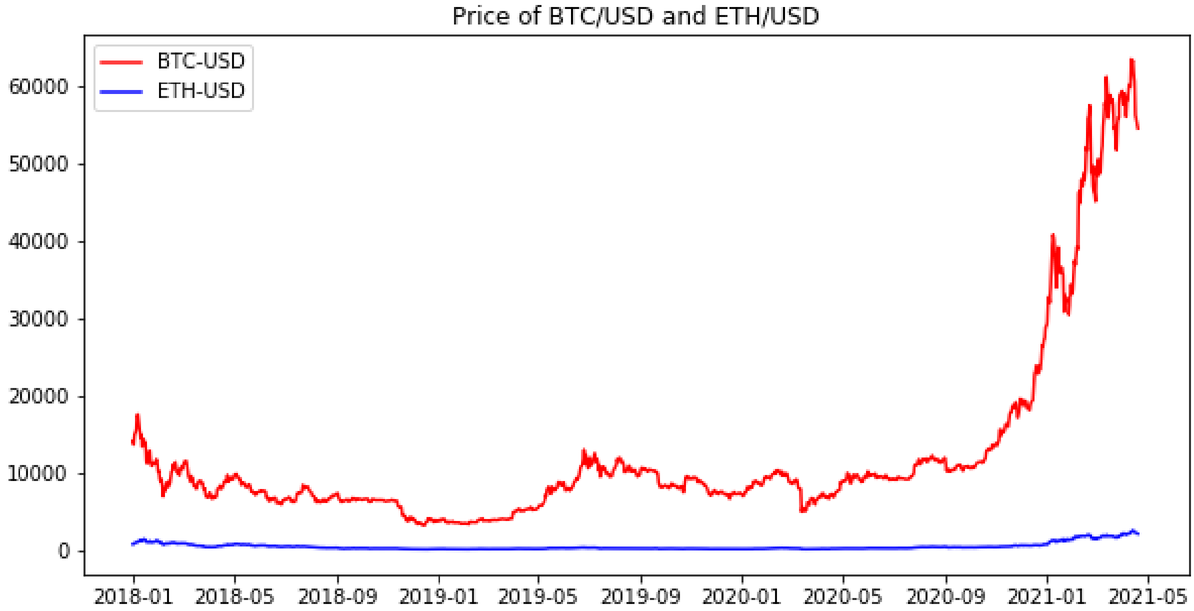
```
# Get data from yahoo source:
BTC=wb.DataReader('BTC-USD', data_source='yahoo',start='2018-1-1')
# BTC.info()
ETH=wb.DataReader('ETH-USD', data_source='yahoo',start='2018-1-1')
# ETH.info()
price_BTC = BTC['Adj Close']
price_ETH = ETH['Adj Close']
```

In [14]:

```
#%% visualize the price
plt.figure(figsize = (10,5))
plt.plot(price_BTC,color = "Red",label = "BTC-USD")
plt.plot(price_ETH,color = "Blue",label = "ETH-USD")
plt.legend()
plt.title("Price of BTC/USD and ETH/USD")
plt.show()
```

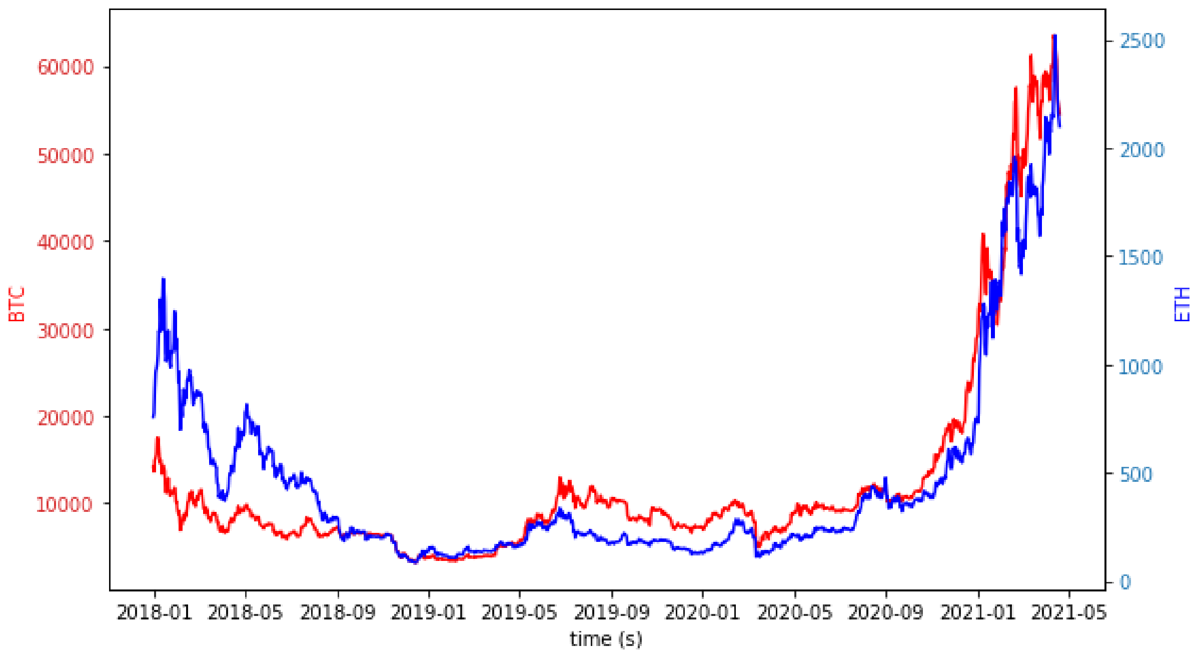
```
/Users/kenneth/anaconda3/lib/python3.7/site-packages/pandas/plotting/_
converter.py:129: FutureWarning: Using an implicitly registered dateti
me converter for a matplotlib plotting method. The converter was regis
tered by pandas on import. Future versions of pandas will require you
to explicitly register matplotlib converters.

To register the converters:
        >>> from pandas.plotting import register_matplotlib_converters
        >>> register_matplotlib_converters()
  warnings.warn(msg, FutureWarning)
```



In [15]:

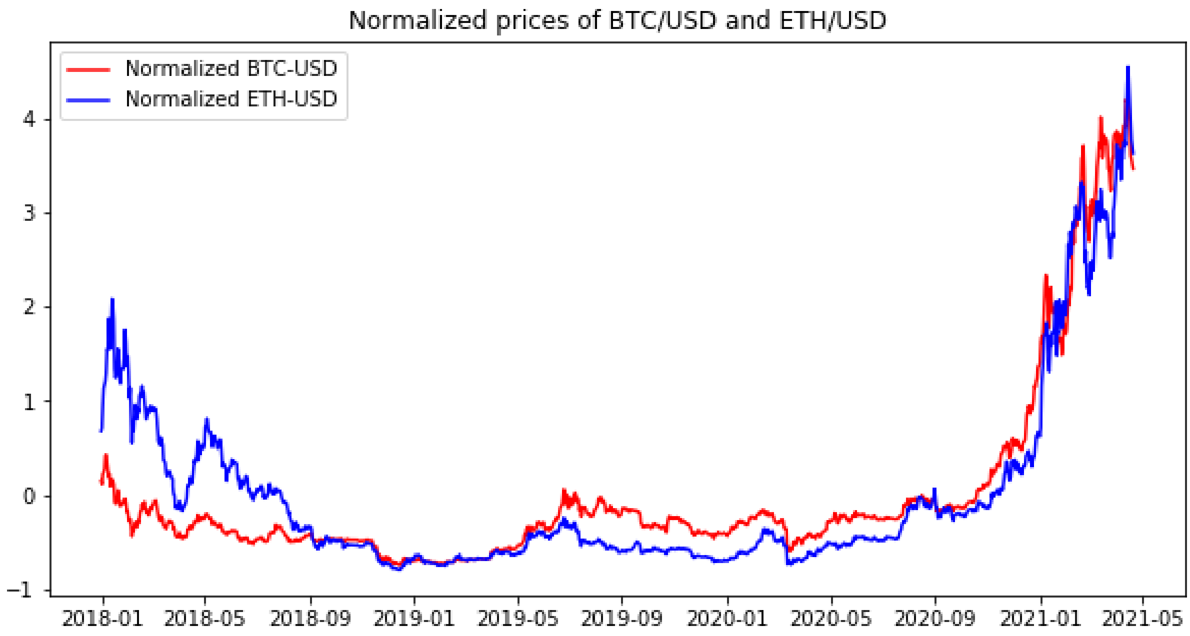
```
#separate 2 y-axis to compare the evolution of BTC and ETH prices
fig, ax1 = plt.subplots(figsize = (9,5))
color = 'tab:red'
ax1.set_xlabel('time (s)')
ax1.set_ylabel('BTC', color="Red")
ax1.plot( price_BTC, color="Red")
ax1.tick_params(axis='y', labelcolor=color)
ax2 = ax1.twinx()
color = 'tab:blue'
ax2.set_ylabel('ETH', color="Blue")
ax2.plot(price_ETH, color="Blue")
ax2.tick_params(axis='y', labelcolor=color)
fig.tight_layout()
plt.show()
```



In [16]:

```
#plot the normalized figures
plt.figure(figsize = (10,5))
plt.plot((price_BTC-np.mean(BTC['Adj Close']))/np.std(BTC['Adj Close']
plt.plot((price_ETH-np.mean(ETH['Adj Close']))/np.std(ETH['Adj Close']
```

```
plt.legend()
plt.title("Normalized prices of BTC/USD and ETH/USD")
plt.show()
```



Analyze data

In [17]:

```
#log return, volatility
log_ret_BTC = np.log(price_BTC).diff().iloc[1::]
log_ret_ETH = np.log(price_ETH).diff().iloc[1::]
print("average return of BTC: ", np.mean(log_ret_BTC))
print("average return of ETH: ", np.mean(log_ret_ETH))
print("volatility of BTC price: ", np.std(log_ret_BTC))
print("volatility of ETH price: ", np.std(log_ret_ETH))
```

```
average return of BTC:  0.0011222594068337663
average return of ETH:  0.0008487011314255292
volatility of BTC price:  0.040213226497934365
volatility of ETH price:  0.05148287132739567
```

In [18]:

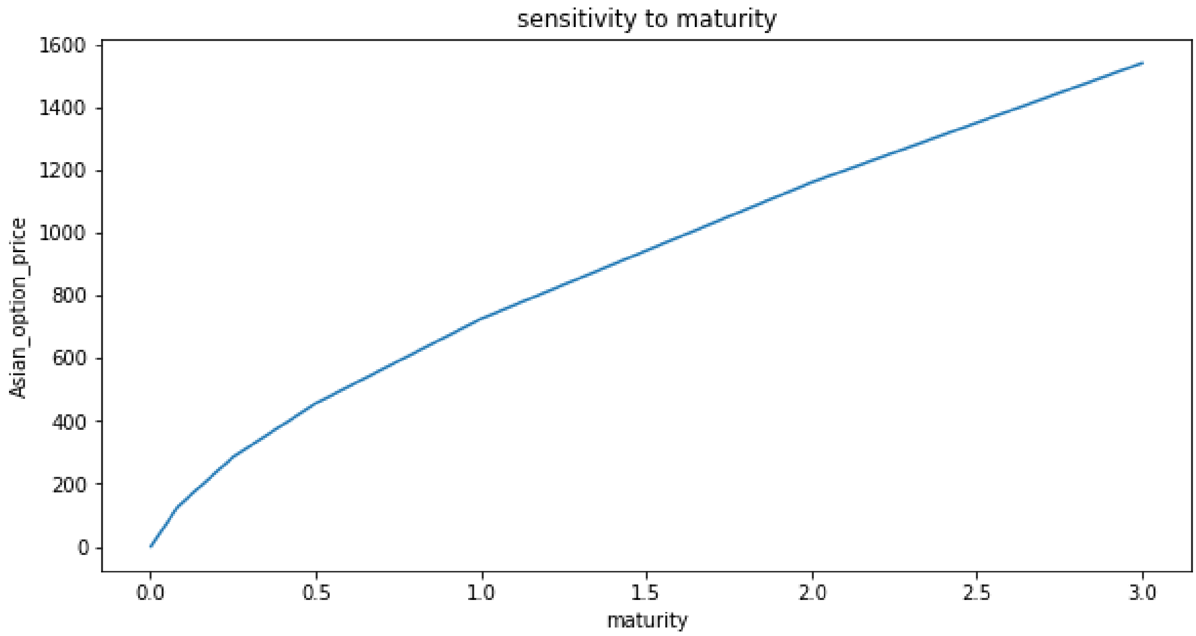
```
def BTM(strike_type,option_type,S0, K, r, sigma, T, N):
    deltaT = T/ N
    u = np.exp(sigma*np.sqrt(deltaT))
    d = 1 / u
    proba = (np.exp(r*deltaT) - d)/ (u - d)
    St=[S0]
    At=[S0]
    strike=[K]
    # Compute the leaves S_{N, j} and the average price A_{N, j}
    for i in range(N):
        St= [j* u for j in St]+[j * d for j in St]
        At+=At
        strike+=strike
        for x in range(len(At)):
            At[x]= At[x]+St[x]
    At=np.array(At)/(N+1)
    if strike_type == "fixed":
        if option_type == "C":
```

```
                payoff = np.maximum(At-np.array(strike), 0)
            else:
                payoff = np.maximum(np.array(strike)-At, 0)
        else:
            if option_type =="C":
                payoff = np.maximum(np.array(St)-At, 0)
            else:
                payoff = np.maximum(At-np.array(St), 0)
        #calculate backward the option prices
        option_price  = payoff
        for i in range(N):
            length = int(len(option_price)/2)
            option_price = proba*option_price[0:length]+(1-proba)*option_p
        return option_price[0]
```

Sensitivity to maturity

In [19]:

```
range_T=[1/365,1/12,1/4,1/2,1,2,3]
option_price = []
for i in range_T:
    Asian_option = BTM("fixed","C",S0=57830,K=58000,r=0.01,sigma=0.05,
    option_price.append(Asian_option)
plt.figure(figsize=(10,5))
plt.plot(range_T,option_price)
plt.xlabel("maturity")
plt.ylabel("Asian_option_price")
plt.title("sensitivity to maturity")
plt.show()
```



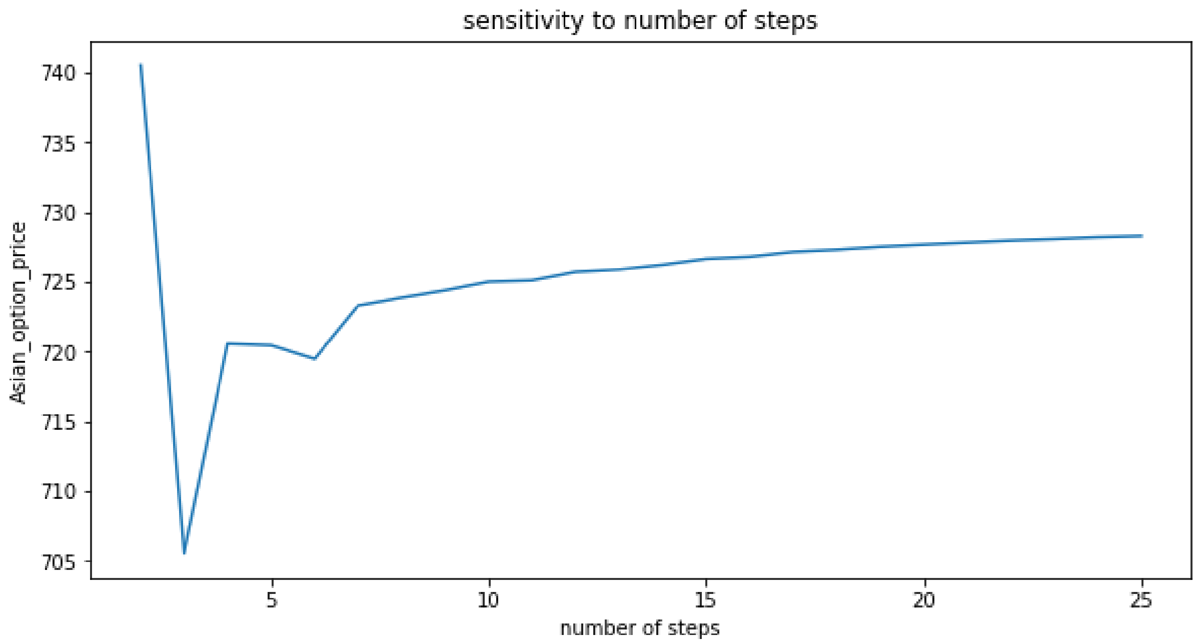
Sensitivity to number of steps

In [20]:

```
range_N=np.array([2,3,4,5,]+[6+j for j in range(20)])
option_price = []
for i in range_N:
    start_time = time.time()
    Asian_option = BTM("fixed","C",S0=57830,K=58000,r=0.01,sigma=0.05,
    option_price.append(Asian_option)
```

```
    print("---",i," steps took ","%s seconds ---" % round(time.time()
plt.figure(figsize=(10,5))
plt.plot(range_N,option_price)
plt.xlabel("number of steps")
plt.ylabel("Asian_option_price")
plt.title("sensitivity to number of steps")
plt.show()
```

```
--- 2  steps took  0.0 seconds ---
--- 3  steps took  0.0 seconds ---
--- 4  steps took  0.0 seconds ---
--- 5  steps took  0.0 seconds ---
--- 6  steps took  0.0 seconds ---
--- 7  steps took  0.0 seconds ---
--- 8  steps took  0.0 seconds ---
--- 9  steps took  0.0 seconds ---
--- 10  steps took  0.0 seconds ---
--- 11  steps took  0.0 seconds ---
--- 12  steps took  0.0 seconds ---
--- 13  steps took  0.01 seconds ---
--- 14  steps took  0.01 seconds ---
--- 15  steps took  0.05 seconds ---
--- 16  steps took  0.05 seconds ---
--- 17  steps took  0.08 seconds ---
--- 18  steps took  0.18 seconds ---
--- 19  steps took  0.59 seconds ---
--- 20  steps took  1.19 seconds ---
--- 21  steps took  1.82 seconds ---
--- 22  steps took  3.24 seconds ---
--- 23  steps took  5.97 seconds ---
--- 24  steps took  12.32 seconds ---
--- 25  steps took  29.79 seconds ---
```



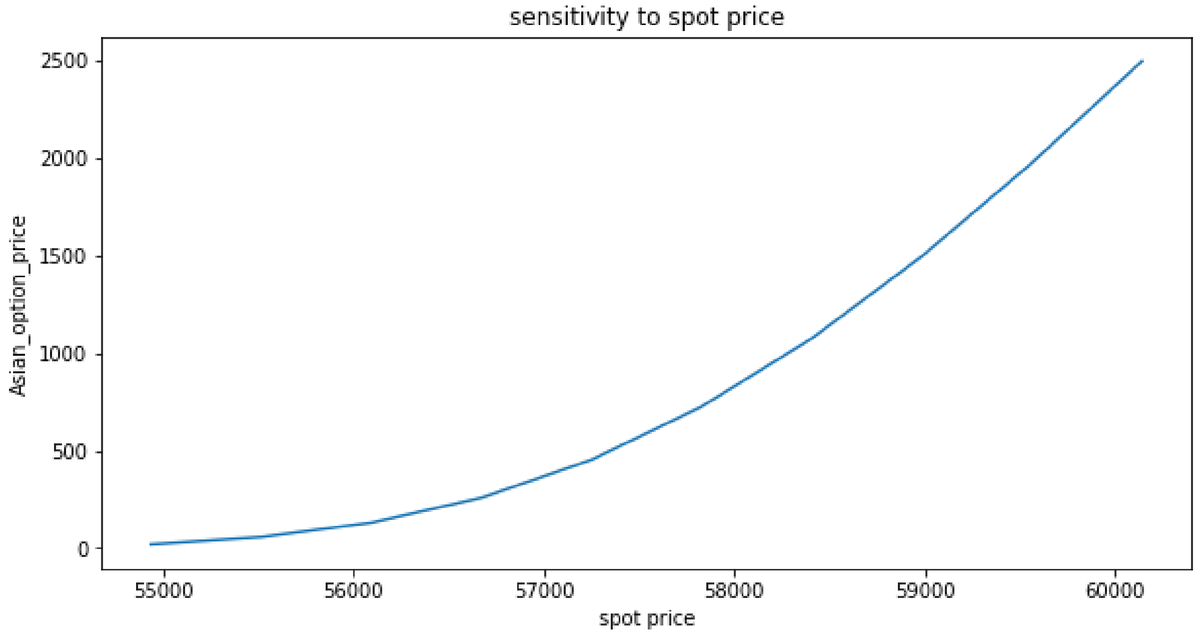
Sensitivity to spot and strike prices

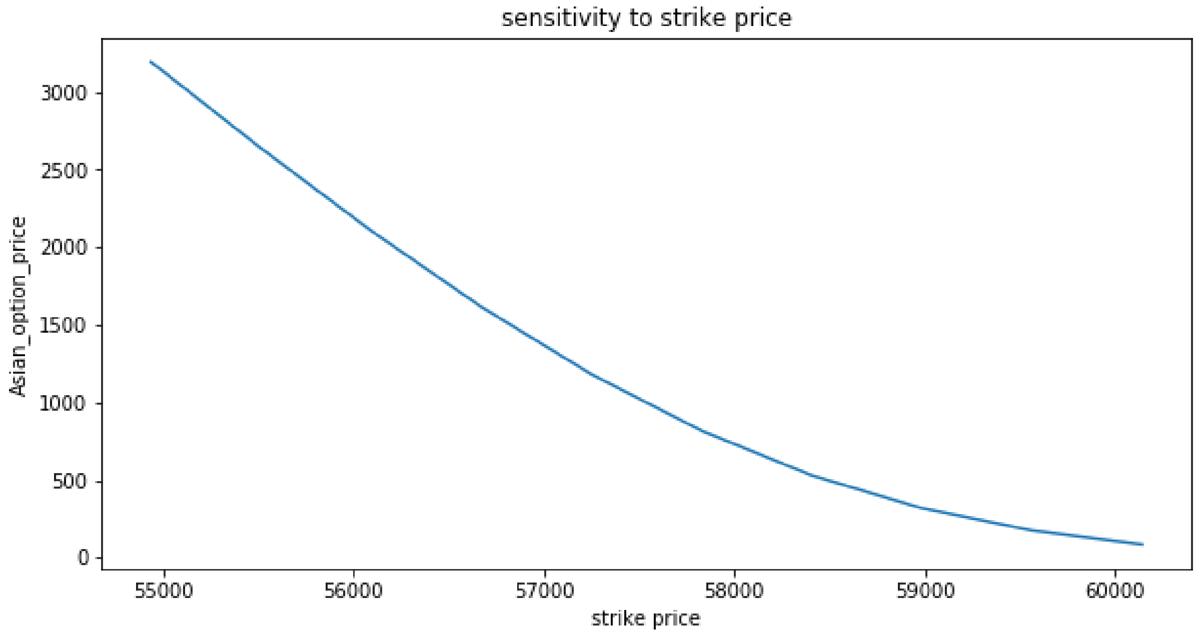
In [21]:

```
range_price=np.array([57830*(0.95+0.01*j) for j in range(10)])
option_price = []
for i in range_price:
    Asian_option = BTM("fixed","C",S0=i,K=58000,r=0.01,sigma=0.05,T=1,
    option_price.append(Asian_option)
plt.figure(figsize=(10,5))
```

```
plt.plot(range_price,option_price)
plt.xlabel("spot price")
plt.ylabel("Asian_option_price")
plt.title("sensitivity to spot price")
plt.show()

option_price = []
for i in range_price:
    Asian_option = BTM("fixed","C",S0=57830,K=i,r=0.01,sigma=0.05,T=1,
    option_price.append(Asian_option)
plt.figure(figsize=(10,5))
plt.plot(range_price,option_price)
plt.xlabel("strike price")
plt.ylabel("Asian_option_price")
plt.title("sensitivity to strike price")
plt.show()
```





Modified BTM

In [22]:

```
def HW_BTM(strike_type,option_type,S0,K,r,sigma,T,step,M):
    N=step
    deltaT=T/step
    u = np.exp(sigma*np.sqrt(deltaT))
    d = 1 / u
    proba = (np.exp(r*deltaT) - d)/ (u - d)
    #calculate average price at note (N,J)
    At=[]
    St=[]
    strike=np.array([K]*M)

    for J in range(N+1):
        At_max = np.array([(S0 * u**(j) * d**0) for j in range(N-J)]+[
        At_max = np.sum(At_max)/len(At_max)
        At_min = np.array([(S0 * d**(j) * u**0) for j in range(J+1)]+[
        At_min = np.sum(At_min)/len(At_min)
        diff=At_max-At_min
        At+=[[At_max-diff/(M-1)*k for k in range(M)]]
        St=np.array([S0* u**(N-J) * d**J]*M)
        if strike_type == "fixed":
            if option_type == "C":
                payoff = np.maximum(At-strike, 0)
            else:
                payoff = np.maximum(strike-At, 0)
        else:
            if option_type =="C":
                payoff = np.maximum(St-At, 0)
            else:
                payoff = np.maximum(At-St, 0)
    At=np.round(At,4)
    payoff=np.round(payoff,4)

    for N in range(step-1,-1,-1):
        At_backward=[]
        At_new=[]
        for J in range(N+1):
            At_max = np.array([(S0 * u**(j) * d**0) for j in range(N-J
            At_max = np.sum(At_max)/len(At_max)
            At_min = np.array([(S0 * d**(j) * u**0) for j in range(J+1
            At_min = np.sum(At_min)/len(At_min)
            diff= At_max-At_min
            At_backward+=[[At_max-diff/(M-1)*k for k in range(M)]]
            St_u=np.array([S0* u**(N+1-J) * d**J]*M)
            St_d=np.array([S0* u**(N-J) * d**(J+1)]*M)
            At_new.append(((N+1)*np.array(At_backward[J])+St_u)/(N+2))
            At_new.append(((N+1)*np.array(At_backward[J])+St_d)/(N+2))

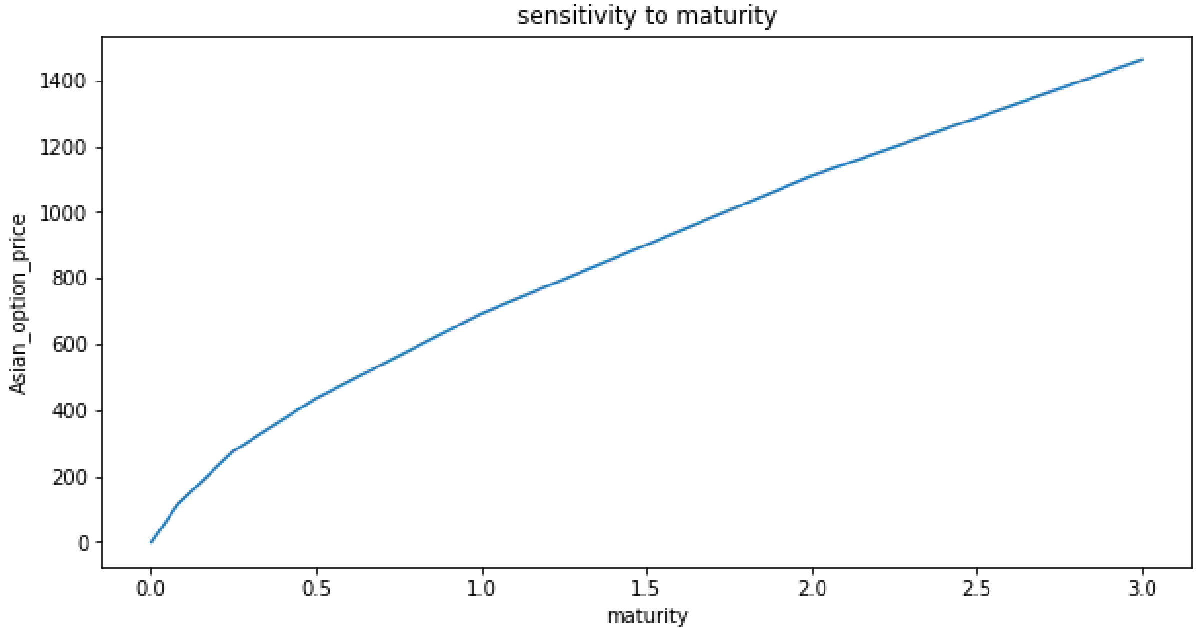
        At_backward=np.round(At_backward,4)
        At_new=np.round(At_new,4)
        payoff_new=At_new*0
        payoff_backward=At_backward*0
        for i in range(len(At_backward)):
            for j in range(len(At[i])):
                if At[i][j]==At_new[2*i][j]:
                    payoff_new[2*i][j]=payoff[i][j]
                else:
                    x=(At[i][j]-At_new[2*i][j])*payoff[i][j+1]
                    y=(At_new[2*i][j]-At[i][j+1])*payoff[i][j]
                    payoff_new[2*i][j]= (x+y)/(At[i][j]-At[i][j+1])
```

```
                    if At[i+1][j]==At_new[2*i+1][j]:
                        payoff_new[2*i+1][j]=payoff[i+1][j]
                    else:
                        x=(At[i+1][j-1]-At_new[2*i+1][j])*payoff[i+1][j]
                        y=(At_new[2*i+1][j]-At[i+1][j])*payoff[i+1][j-1]
                        payoff_new[2*i+1][j]= (x+y)/(At[i+1][j-1]-At[i+1][
                payoff_backward[i]=(payoff_new[2*i]*proba+payoff_new[2*i+
            At=At_backward
            payoff=np.round(payoff_backward,4)
        option_price = np.average(payoff)
        return option_price
```

Sensitivity to maturity

In [23]:

```
range_T=[1/365,1/12,1/4,1/2,1,2,3]
option_price = []
for i in range_T:
    Asian_option = HW_BTM("fixed","C",S0=57830,K=58000,r=0.01,sigma=0.
    option_price.append(Asian_option)
plt.figure(figsize=(10,5))
plt.plot(range_T,option_price)
plt.xlabel("maturity")
plt.ylabel("Asian_option_price")
plt.title("sensitivity to maturity")
plt.show()
```



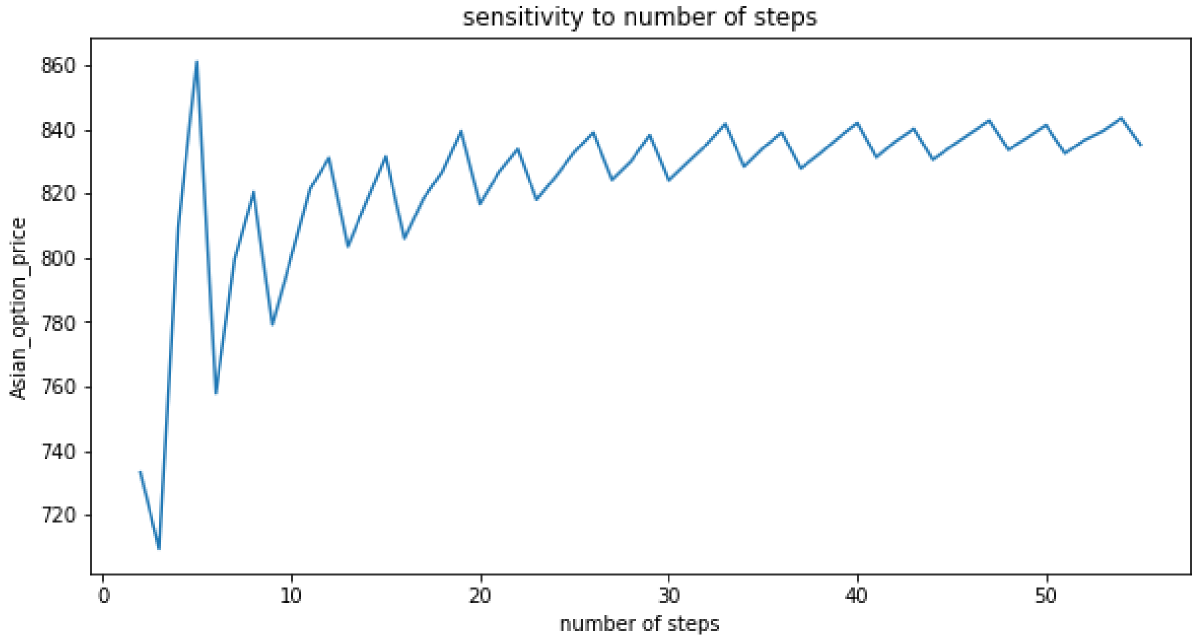
Sensitivity to number of steps

In [24]:

```
range_N=np.array([2,3,4,5,]+[6+j for j in range(50)])
option_price = []
for i in range_N:
    start_time = time.time()
    Asian_option = HW_BTM("fixed","C",S0=57830,K=58000,r=0.01,sigma=0.
    option_price.append(Asian_option)
    print("---",i," steps took ","%s seconds ---" % round(time.time()
plt.figure(figsize=(10,5))
plt.plot(range_N,option_price)
```

```
plt.xlabel("number of steps")
plt.ylabel("Asian_option_price")
plt.title("sensitivity to number of steps")
plt.show()
```

```
--- 2  steps took  0.0 seconds ---
--- 3  steps took  0.0 seconds ---
--- 4  steps took  0.0 seconds ---
--- 5  steps took  0.0 seconds ---
--- 6  steps took  0.0 seconds ---
--- 7  steps took  0.0 seconds ---
--- 8  steps took  0.0 seconds ---
--- 9  steps took  0.01 seconds ---
--- 10  steps took  0.01 seconds ---
--- 11  steps took  0.01 seconds ---
--- 12  steps took  0.01 seconds ---
--- 13  steps took  0.01 seconds ---
--- 14  steps took  0.01 seconds ---
--- 15  steps took  0.02 seconds ---
--- 16  steps took  0.02 seconds ---
--- 17  steps took  0.02 seconds ---
--- 18  steps took  0.02 seconds ---
--- 19  steps took  0.02 seconds ---
--- 20  steps took  0.05 seconds ---
--- 21  steps took  0.04 seconds ---
--- 22  steps took  0.04 seconds ---
--- 23  steps took  0.05 seconds ---
--- 24  steps took  0.05 seconds ---
--- 25  steps took  0.05 seconds ---
--- 26  steps took  0.06 seconds ---
--- 27  steps took  0.07 seconds ---
--- 28  steps took  0.07 seconds ---
--- 29  steps took  0.08 seconds ---
--- 30  steps took  0.08 seconds ---
--- 31  steps took  0.08 seconds ---
--- 32  steps took  0.1 seconds ---
--- 33  steps took  0.1 seconds ---
--- 34  steps took  0.11 seconds ---
--- 35  steps took  0.13 seconds ---
--- 36  steps took  0.14 seconds ---
--- 37  steps took  0.15 seconds ---
--- 38  steps took  0.15 seconds ---
--- 39  steps took  0.15 seconds ---
--- 40  steps took  0.16 seconds ---
--- 41  steps took  0.18 seconds ---
--- 42  steps took  0.19 seconds ---
--- 43  steps took  0.19 seconds ---
--- 44  steps took  0.22 seconds ---
--- 45  steps took  0.22 seconds ---
--- 46  steps took  0.24 seconds ---
--- 47  steps took  0.25 seconds ---
--- 48  steps took  0.28 seconds ---
--- 49  steps took  0.28 seconds ---
--- 50  steps took  0.3 seconds ---
--- 51  steps took  0.31 seconds ---
--- 52  steps took  0.33 seconds ---
--- 53  steps took  0.35 seconds ---
--- 54  steps took  0.36 seconds ---
--- 55  steps took  0.39 seconds ---
```

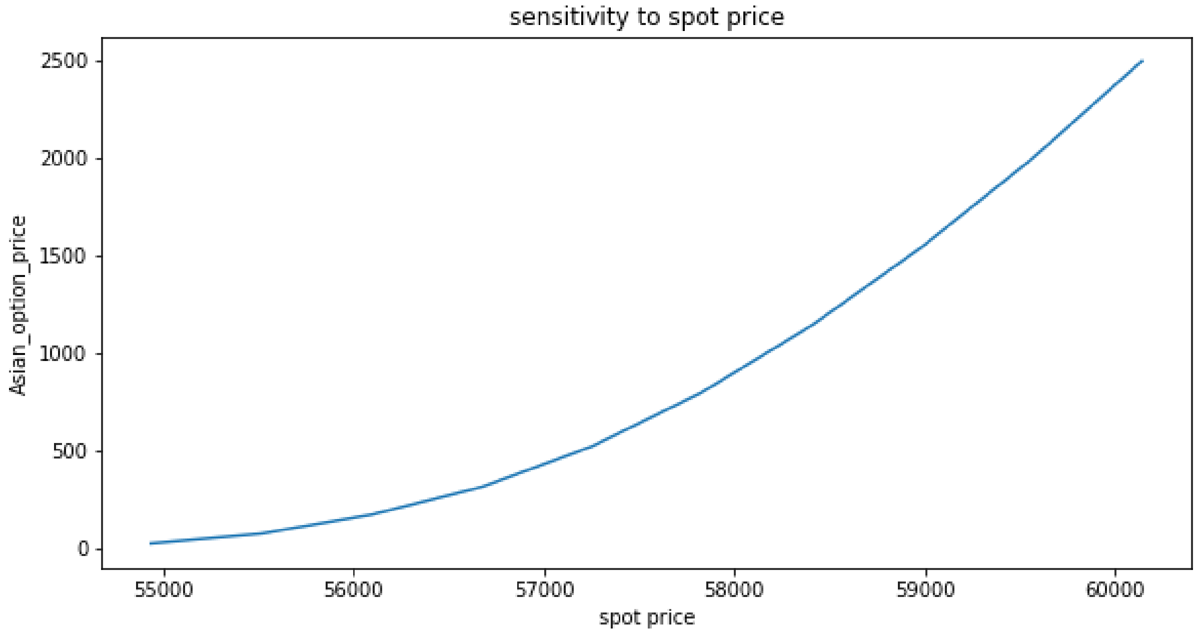


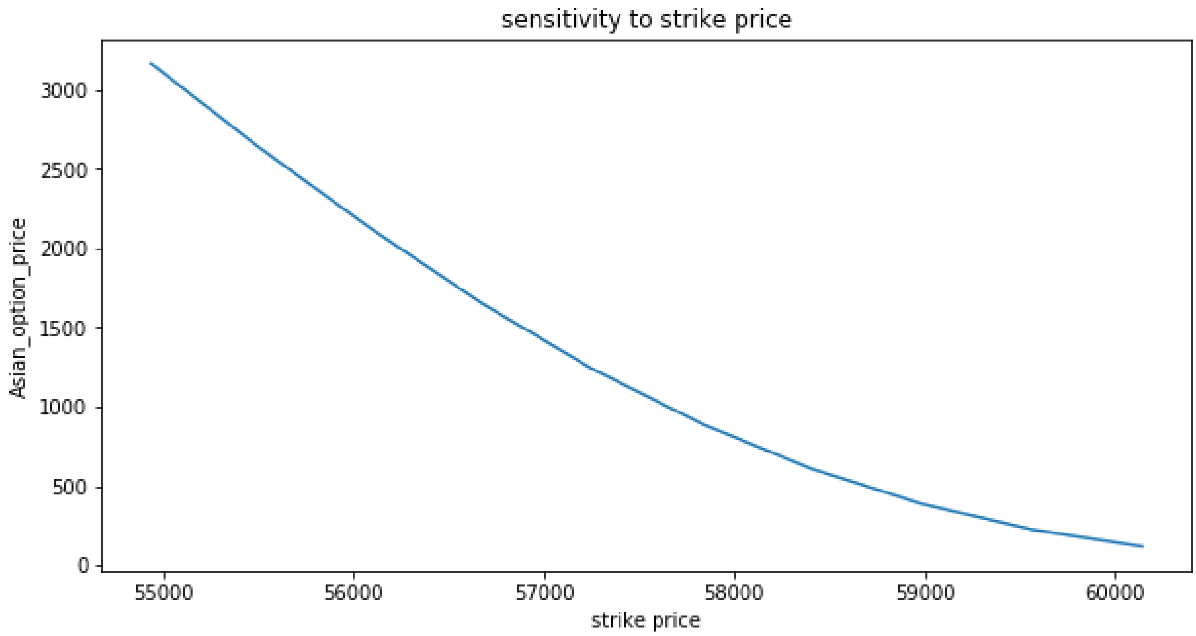
Sensitivity to spot and strike prices

In [25]:

```
range_price=np.array([57830*(0.95+0.01*j)  for j in range(10)])
option_price = []
for i in range_price:
    Asian_option = HW_BTM("fixed","C",S0=i,K=58000,r=0.01,sigma=0.05,T
    option_price.append(Asian_option)
plt.figure(figsize=(10,5))
plt.plot(range_price,option_price)
plt.xlabel("spot price")
plt.ylabel("Asian_option_price")
plt.title("sensitivity to spot price")
plt.show()

option_price = []
for i in range_price:
    Asian_option = HW_BTM("fixed","C",S0=57830,K=i,r=0.01,sigma=0.05,T
    option_price.append(Asian_option)
plt.figure(figsize=(10,5))
plt.plot(range_price,option_price)
plt.xlabel("strike price")
plt.ylabel("Asian_option_price")
plt.title("sensitivity to strike price")
plt.show()
```





Black-Schole formula for European options:

In [26]:

```
def BS_option_price(t,St,K,T,r,sigma,Type):
    d1=(np.log(St/K)+(r+0.5*sigma**2)*(T-t))/sigma*np.sqrt(T-t)
    d2=d1-sigma*np.sqrt(T-t)

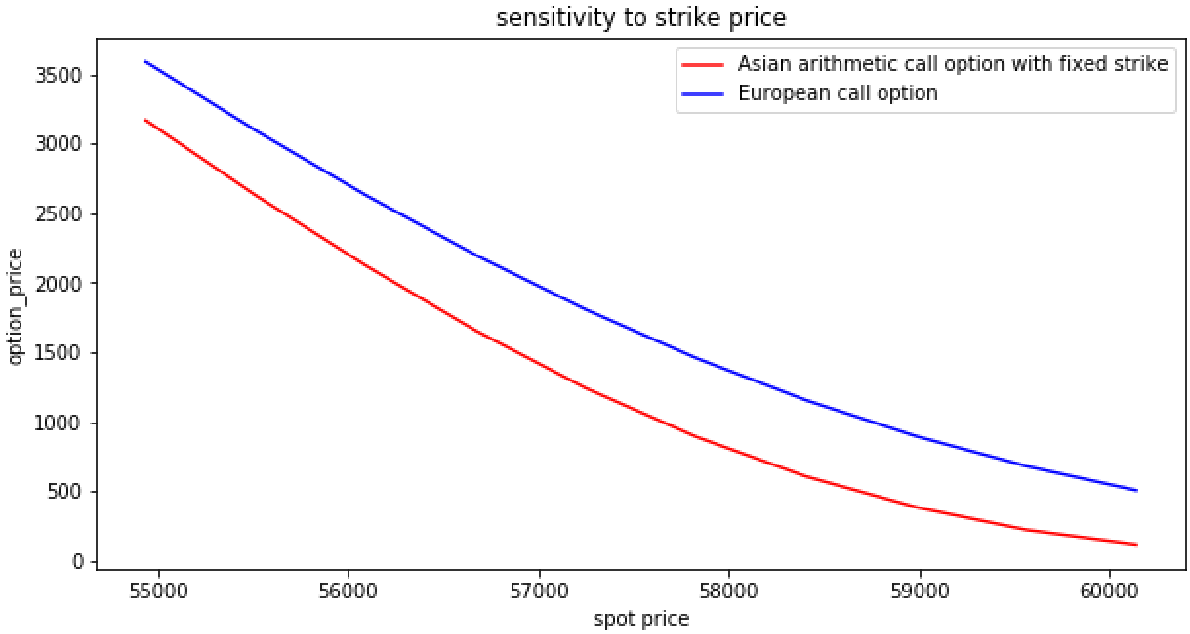
    if Type == 'call':
        option_price=St*norm.cdf(d1)-K*np.exp(-r*(T-t))*norm.cdf(d2)

    elif Type == 'put':
        option_price=K*np.exp(-r*(T-t))*norm.cdf(-d2)-St*norm.cdf(-d1)
    return option_price
```

In [27]:

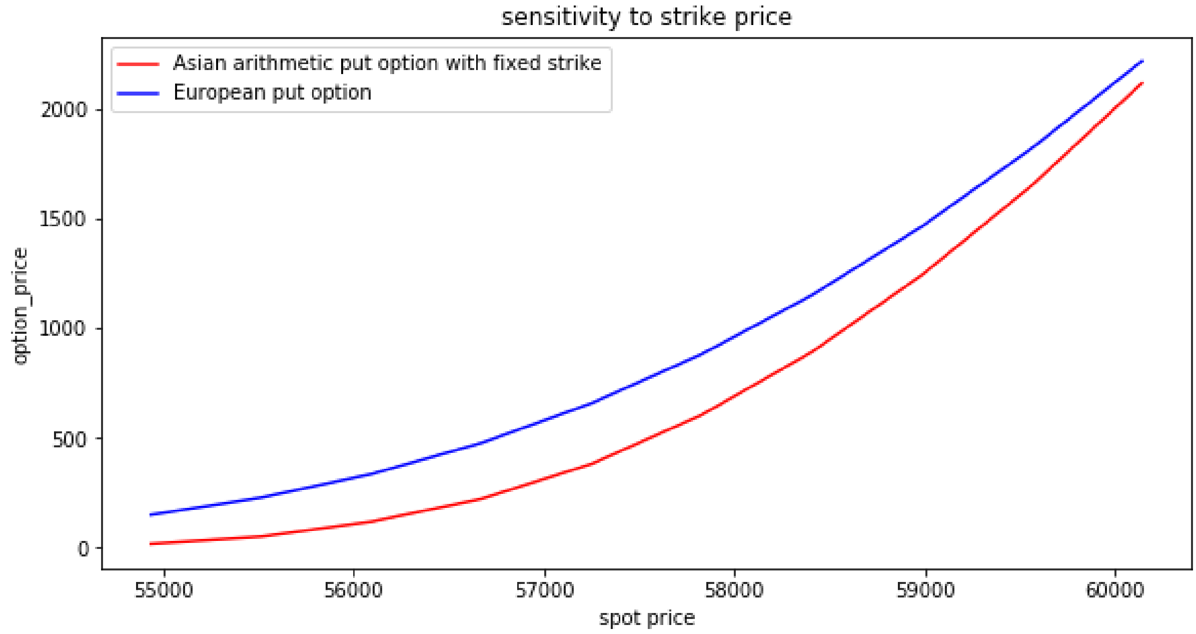
```
range_price=np.array([57830*(0.95+0.01*j)  for j in range(10)])
option1 = []
option2 = []
for i in range_price:
    Asian_option = HW_BTM("fixed","C",S0=57830,K=i,r=0.01,sigma=0.05,T
```

```
    European_option = BS_option_price(t=0,St=57830,K=i,T=1,r=0.01,sigm
    option1.append(Asian_option)
    option2.append(European_option)
plt.figure(figsize=(10,5))
plt.plot(range_price,option1,color="Red",label="Asian arithmetic call
plt.plot(range_price,option2,color="Blue",label="European call option'
plt.xlabel("spot price")
plt.ylabel("option_price")
plt.legend()
plt.title("sensitivity to strike price")
plt.show()
```



In [28]:

```
option1 = []
option2 = []
for i in range_price:
    Asian_option = HW_BTM("fixed","P",S0=57830,K=i,r=0.01,sigma=0.05,T
    European_option = BS_option_price(t=0,St=57830,K=i,T=1,r=0.01,sigm
    option1.append(Asian_option)
    option2.append(European_option)
plt.figure(figsize=(10,5))
plt.plot(range_price,option1,color="Red",label="Asian arithmetic put c
plt.plot(range_price,option2,color="Blue",label="European put option")
plt.xlabel("spot price")
plt.ylabel("option_price")
plt.legend()
plt.title("sensitivity to strike price")
plt.show()
```



In [ ]:

In [ ]:

In [ ]:

In [ ]:

In [ ]:

In [29]:

```
def vanilla_option_delta(t, St, K, T, r, sigma, Type, epsilon = 0.01):
    return ((BS_option_price(t, St+epsilon, K, T, r, sigma, Type) - BS

def asian_option_delta(strike_type, option_type, S0, K, r, sigma, T, s
    return ((HW_BTM(strike_type, option_type, S0+epsilon, K, r, sigma,
```

In [30]:

```
def vanilla_option_gamma(t, St, K, T, r, sigma, Type, epsilon = 0.01):
    return ((vanilla_option_delta(t, St+epsilon, K, T, r, sigma, Type,

def asian_option_gamma(strike_type, option_type, S0, K, r, sigma, T, s
    return ((asian_option_delta(strike_type, option_type, S0+epsilon,
```

In [93]:

```
def vanilla_option_vega(t, St, K, T, r, sigma, Type, epsilon = 0.01):
    return ((BS_option_price(t, St, K, T, r, sigma+epsilon, Type) - BS

def asian_option_vega(strike_type, option_type, S0, K, r, sigma, T, st
    return ((HW_BTM(strike_type, option_type, S0, K, r, sigma+epsilon,


# HW_BTM(strike_type,option_type,S0,K,r,sigma,T,step,M)
```

In [118…

```
def vanilla_option_theta(t, St, K, T, r, sigma, Type, epsilon = 0.01):
    return ((BS_option_price(t, St, K, T-epsilon, r, sigma, Type) - BS

def asian_option_theta(strike_type, option_type, S0, K, r, sigma, T, s
    return ((HW_BTM(strike_type, option_type, S0, K, r, sigma, T-epsil
```

In [98]:

```
def vanilla_option_rho(t, St, K, T, r, sigma, Type, epsilon = 0.01):
    return ((BS_option_price(t, St, K, T, r+epsilon, sigma, Type) - BS

def asian_option_rho(strike_type, option_type, S0, K, r, sigma, T, ste
    return ((HW_BTM(strike_type, option_type, S0, K, r+epsilon, sigma,
```

In [ ]:

In [ ]:

In [ ]:

In [ ]:

Compare the Greeks of Asian option and Vanilla option for Bitcoin

In [117…

```
# Delta comparason:
range_price=np.array([57830*(0.95+0.01*j)  for j in range(10)])
vanilla_delta = []
asian_delta = []
for i in range_price:

    Vanilla_option = vanilla_option_delta(t=0,St=i,K=58000,T=1,r=0.01,
    vanilla_delta.append(Vanilla_option)

    Asian_option = asian_option_delta("fixed","C",S0=i,K=58000,r=0.01,
    asian_delta.append(Asian_option)



plt.figure(figsize=(10,5))
plt.plot(range_price,vanilla_delta,label='vanilla_option')
plt.plot(range_price,asian_delta,label='asian_option')

plt.xlabel("spot price")
plt.ylabel("delta")
plt.title("sensitivity to spot price")
plt.legend()
```

```
range_price=np.array([57830*(0.95+0.01*j)  for j in range(10)])
vanilla_delta = []
asian_delta = []
for i in range_price:

    Vanilla_option = vanilla_option_delta(t=0,St=57830,K=i,T=1,r=0.01,
    vanilla_delta.append(Vanilla_option)

    Asian_option = asian_option_delta("fixed","C",S0=57830,K=i,r=0.01,
    asian_delta.append(Asian_option)



plt.figure(figsize=(10,5))
plt.plot(range_price,vanilla_delta,label='vanilla_option')
plt.plot(range_price,asian_delta,label='asian_option')

plt.xlabel("strike price")
plt.ylabel("delta")
plt.title("sensitivity to strike price")
plt.legend()
```

```
range_price=np.array([57830*(0.95+0.01*j)  for j in range(10)])

vanilla_price= []
asian_price = []
vanilla_delta = []
asian_delta = []

for i in range_price:

    Vanilla_option = vanilla_option_delta(t=0,St=57830,K=i,T=1,r=0.01,
    vanilla_delta.append(Vanilla_option)

    Vanilla_option = BS_option_price(t=0,St=57830,K=i,T=1,r=0.01,sigma
    vanilla_price.append(Vanilla_option)


    Asian_option = asian_option_delta("fixed","C",S0=57830,K=i,r=0.01,
    asian_delta.append(Asian_option)

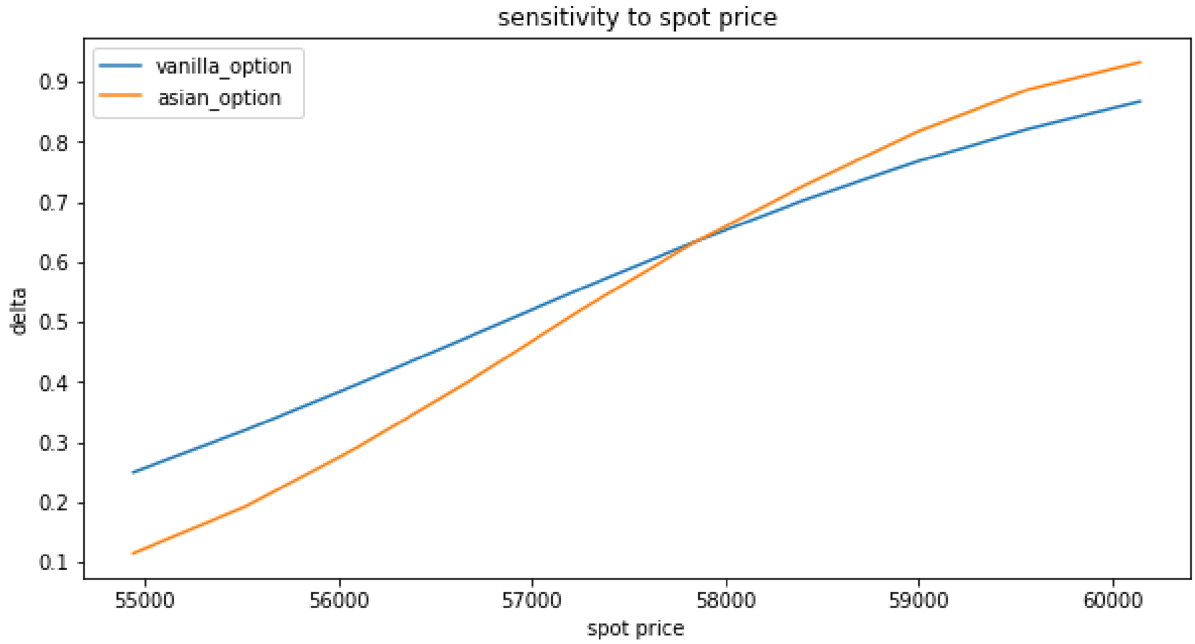
    Asian_option = HW_BTM("fixed","C",S0=57830,K=i,r=0.01,sigma=0.05,T
    asian_price.append(Asian_option)

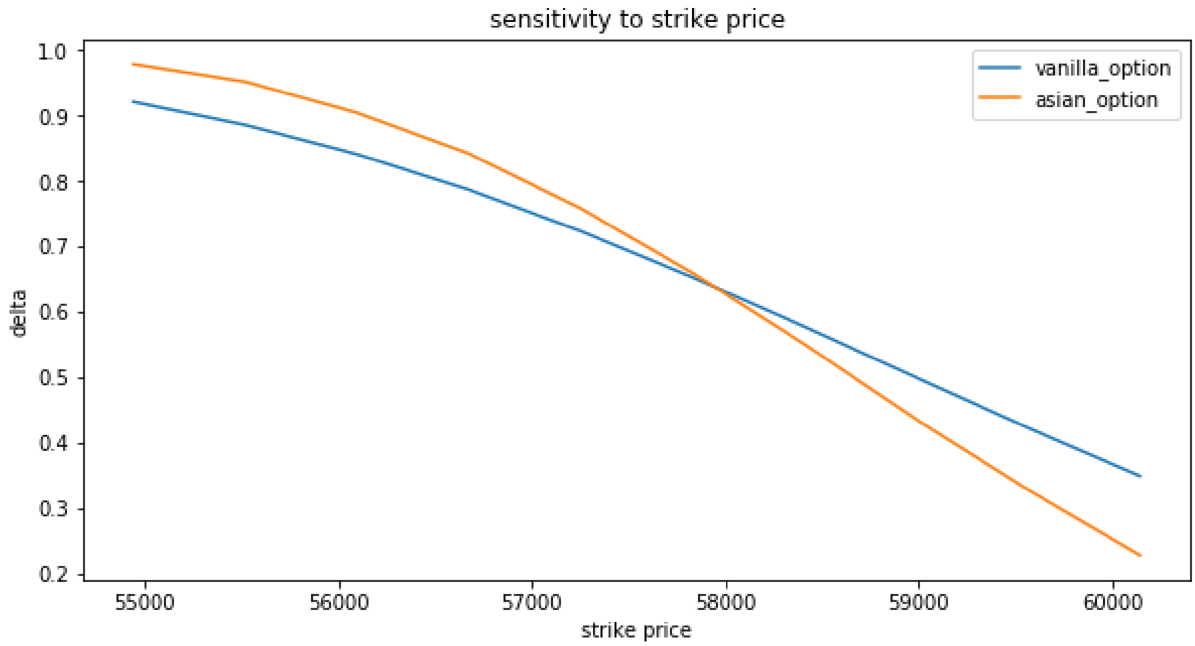


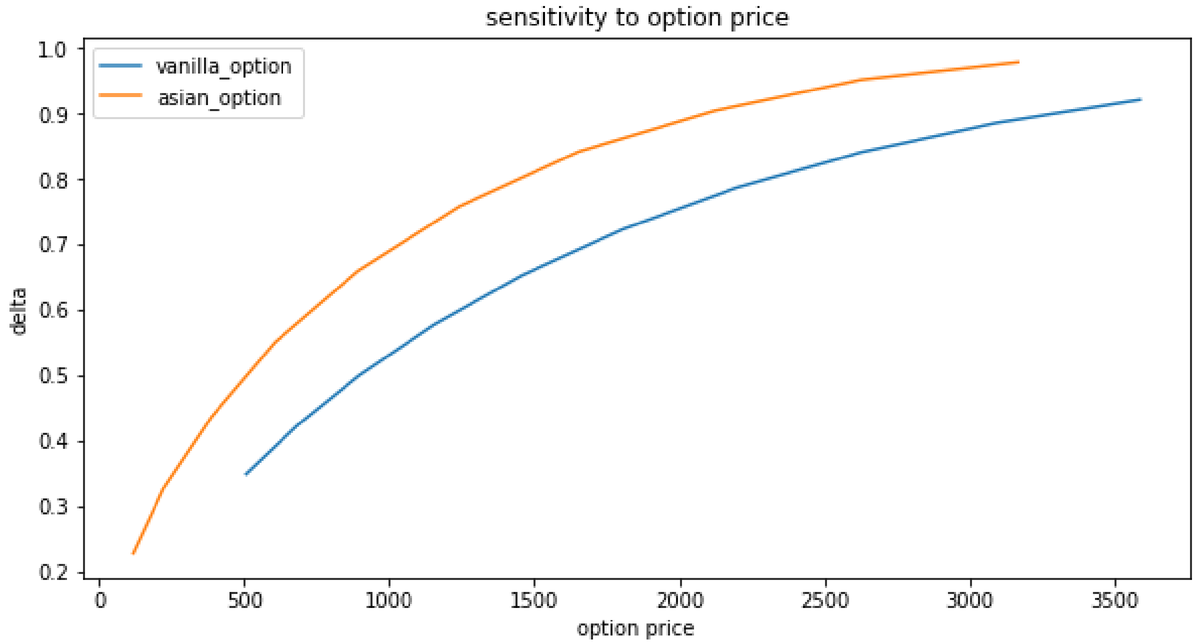
plt.figure(figsize=(10,5))
plt.plot(vanilla_price,vanilla_delta,label='vanilla_option')
plt.plot(asian_price,asian_delta,label='asian_option')

plt.xlabel("option price")
plt.ylabel("delta")
plt.title("sensitivity to option price")
plt.legend()
```

Out[117… <matplotlib.legend.Legend at 0x1338b8748>







In [125…

```
# Gamma comparason:
range_price=np.array([57830*(0.95+0.01*j)  for j in range(10)])
vanilla_gamma = []
asian_gamma = []
for i in range_price:

    Vanilla_option = vanilla_option_gamma(t=0,St=i,K=58000,T=1,r=0.01,
    vanilla_gamma.append(Vanilla_option)

    Asian_option = asian_option_gamma("fixed","C",S0=i,K=58000,r=0.01,
    asian_gamma.append(Asian_option)



plt.figure(figsize=(10,5))
plt.plot(range_price,vanilla_gamma,label='vanilla_option')
plt.plot(range_price,asian_gamma,label='asian_option')

plt.xlabel("spot price")
plt.ylabel("gamma")
plt.title("sensitivity to spot price")
plt.legend()




range_price=np.array([57830*(0.95+0.01*j)  for j in range(10)])
vanilla_gamma = []
asian_gamma = []
for i in range_price:

    Vanilla_option = vanilla_option_gamma(t=0,St=57830,K=i,T=1,r=0.01,
    vanilla_gamma.append(Vanilla_option)

    Asian_option = asian_option_gamma("fixed","C",S0=57830,K=i,r=0.01,
    asian_gamma.append(Asian_option)
```

```
plt.figure(figsize=(10,5))
plt.plot(range_price,vanilla_gamma,label='vanilla_option')
plt.plot(range_price,asian_gamma,label='asian_option')

plt.xlabel("strike price")
plt.ylabel("gamma")
plt.title("sensitivity to strike price")
plt.legend()





range_price=np.array([57830*(0.95+0.01*j)  for j in range(10)])

vanilla_price= []
asian_price = []
vanilla_gamma = []
asian_gamma = []

for i in range_price:

    Vanilla_option = vanilla_option_gamma(t=0,St=57830,K=i,T=1,r=0.01,
    vanilla_gamma.append(Vanilla_option)

    Vanilla_option = BS_option_price(t=0,St=57830,K=i,T=1,r=0.01,sigma
    vanilla_price.append(Vanilla_option)


    Asian_option = asian_option_gamma("fixed","C",S0=57830,K=i,r=0.01,
    asian_gamma.append(Asian_option)

    Asian_option = HW_BTM("fixed","C",S0=57830,K=i,r=0.01,sigma=0.05,T
    asian_price.append(Asian_option)

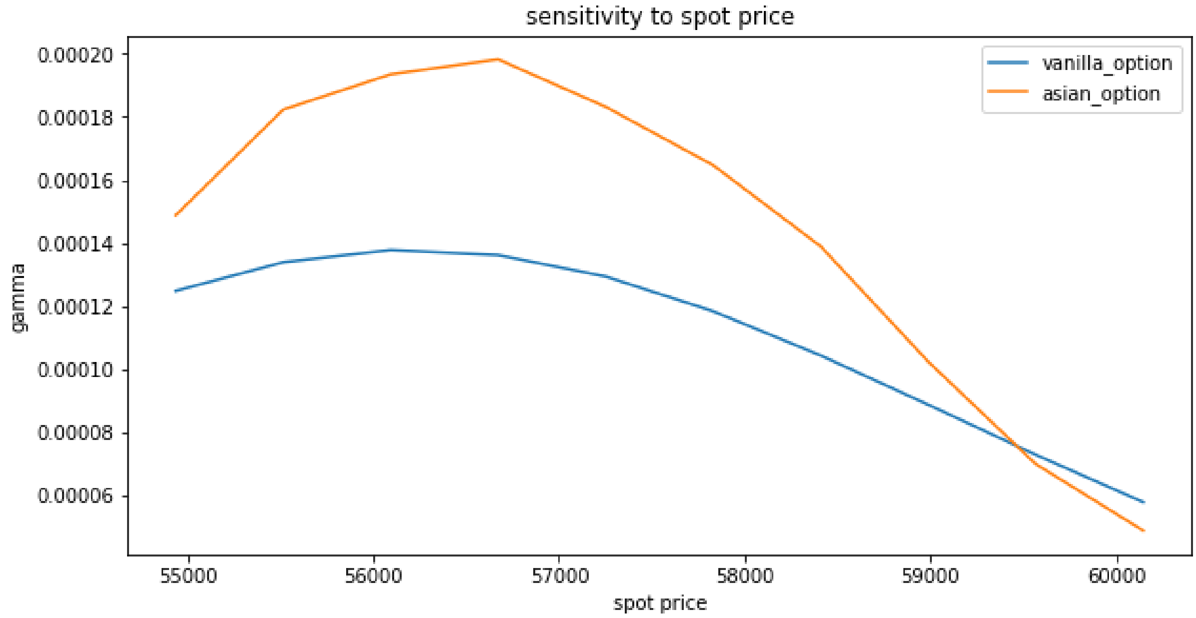


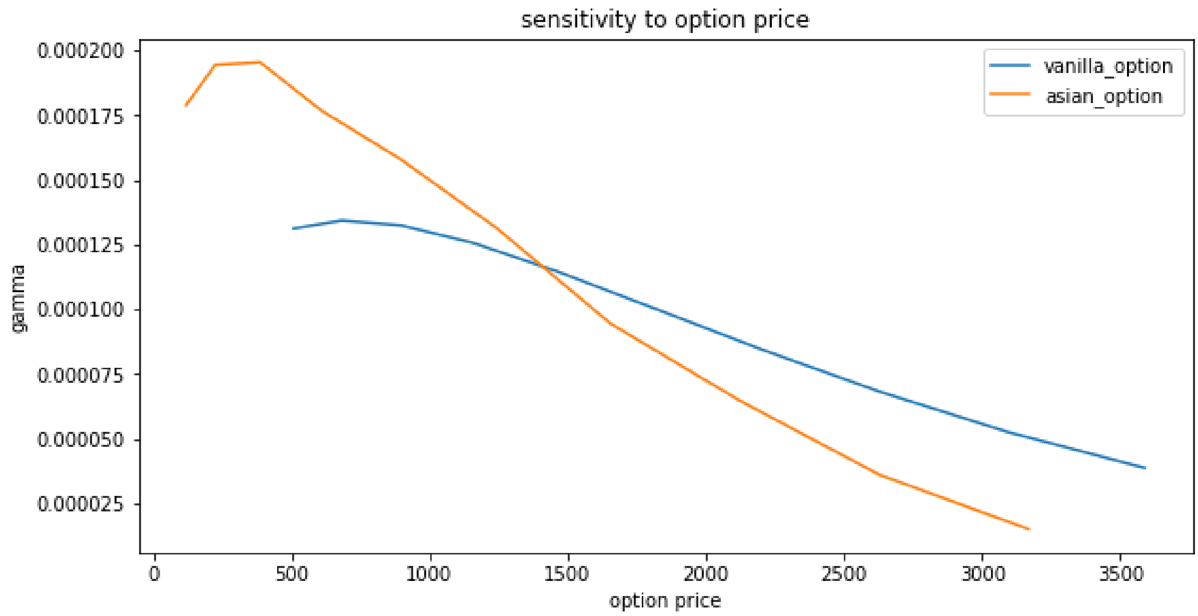
plt.figure(figsize=(10,5))
plt.plot(vanilla_price,vanilla_gamma,label='vanilla_option')
plt.plot(asian_price,asian_gamma,label='asian_option')

plt.xlabel("option price")
plt.ylabel("gamma")
plt.title("sensitivity to option price")
plt.legend()
```

Out[125…

```
<matplotlib.legend.Legend at 0x135433f98>
```





In [85]:

```
# Vega comparason:
range_price=np.array([57830*(0.95+0.01*j)  for j in range(10)])
vanilla_vega = []
```

```
asian_vega = []
for i in range_price:

    Vanilla_option = vanilla_option_vega(t=0,St=i,K=58000,T=1,r=0.01,s
    vanilla_vega.append(Vanilla_option)

    Asian_option = asian_option_vega("fixed","C",S0=i,K=58000,r=0.01,s
    asian_vega.append(Asian_option)



plt.figure(figsize=(10,5))
plt.plot(range_price,vanilla_vega,label='vanilla_option')
plt.plot(range_price,asian_vega,label='asian_option')

plt.xlabel("spot price")
plt.ylabel("vega")
plt.title("sensitivity to spot price")
plt.legend()




range_price=np.array([57830*(0.95+0.01*j)  for j in range(10)])
vanilla_vega = []
asian_vega = []
for i in range_price:

    Vanilla_option = vanilla_option_vega(t=0,St=57830,K=i,T=1,r=0.01,s
    vanilla_vega.append(Vanilla_option)

    Asian_option = asian_option_vega("fixed","C",S0=57830,K=i,r=0.01,s
    asian_vega.append(Asian_option)



plt.figure(figsize=(10,5))
plt.plot(range_price,vanilla_vega,label='vanilla_option')
plt.plot(range_price,asian_vega,label='asian_option')

plt.xlabel("strike price")
plt.ylabel("vega")
plt.title("sensitivity to strike price")
plt.legend()




range_price=np.array([57830*(0.95+0.01*j)  for j in range(10)])

vanilla_price= []
asian_price = []
vanilla_vega = []
asian_vega = []

for i in range_price:

    Vanilla_option = vanilla_option_vega(t=0,St=57830,K=i,T=1,r=0.01,s
    vanilla_vega.append(Vanilla_option)
```

```
    Vanilla_option = BS_option_price(t=0,St=57830,K=i,T=1,r=0.01,sigma
    vanilla_price.append(Vanilla_option)


    Asian_option = asian_option_vega("fixed","C",S0=57830,K=i,r=0.01,s
    asian_vega.append(Asian_option)

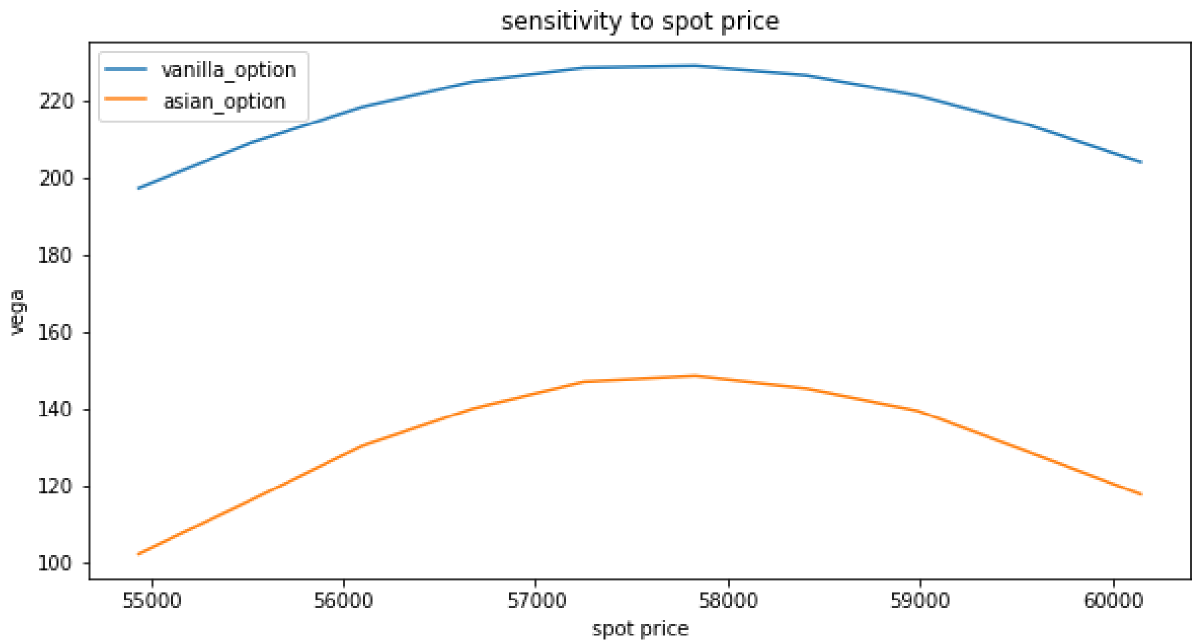
    Asian_option = HW_BTM("fixed","C",S0=57830,K=i,r=0.01,sigma=0.05,T
    asian_price.append(Asian_option)

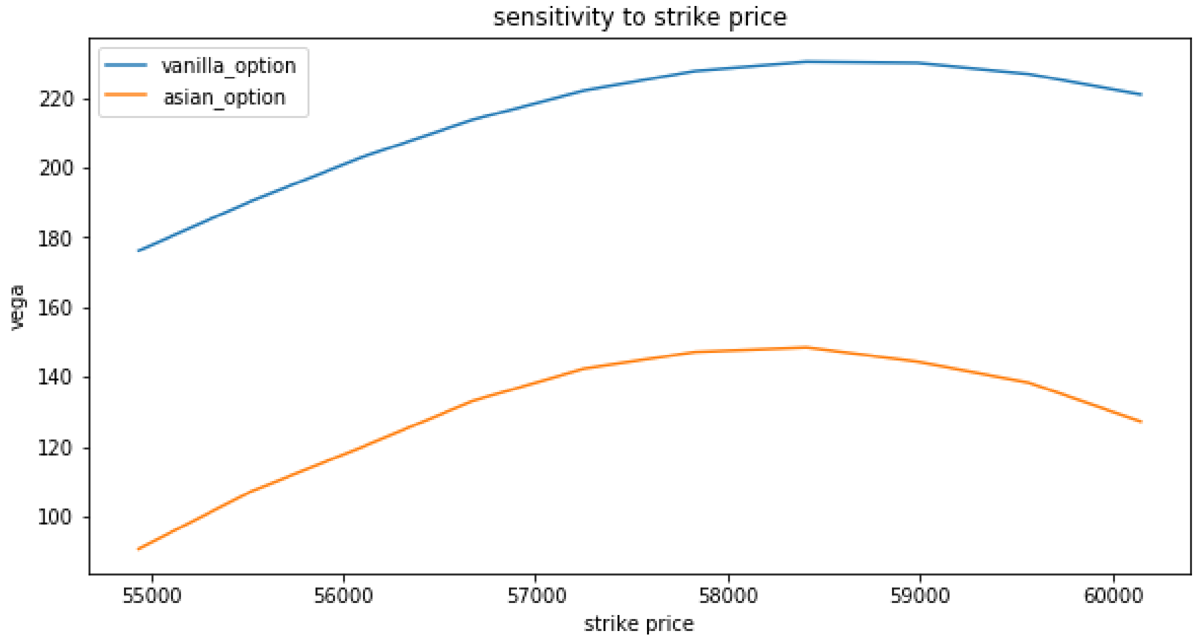


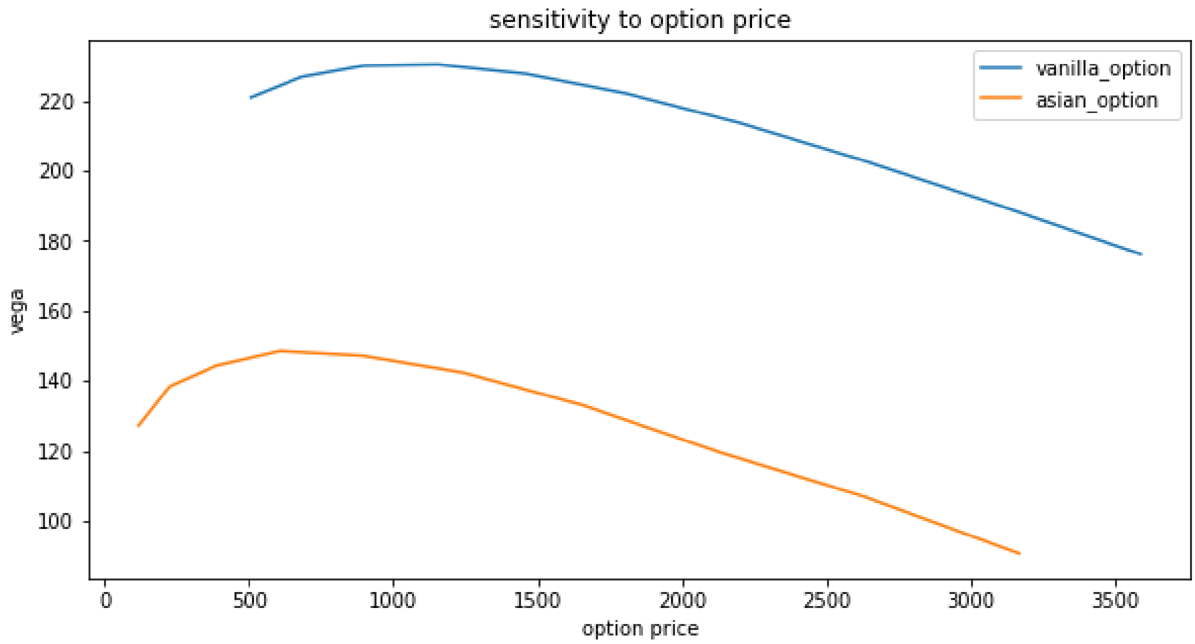
plt.figure(figsize=(10,5))
plt.plot(vanilla_price,vanilla_vega,label='vanilla_option')
plt.plot(asian_price,asian_vega,label='asian_option')

plt.xlabel("option price")
plt.ylabel("vega")
plt.title("sensitivity to option price")
plt.legend()
```

Out[85]: <matplotlib.legend.Legend at 0x12fd63ba8>







In [119…

```
# Theta comparason:
range_price=np.array([57830*(0.95+0.01*j)  for j in range(10)])
vanilla_theta = []
asian_theta = []
for i in range_price:

    Vanilla_option = vanilla_option_theta(t=0,St=i,K=58000,T=1,r=0.01,
    vanilla_theta.append(Vanilla_option)

    Asian_option = asian_option_theta("fixed","C",S0=i,K=58000,r=0.01,
    asian_theta.append(Asian_option)



plt.figure(figsize=(10,5))
plt.plot(range_price,vanilla_theta,label='vanilla_option')
plt.plot(range_price,asian_theta,label='asian_option')

plt.xlabel("spot price")
plt.ylabel("theta")
```

```
plt.title("sensitivity to spot price")
plt.legend()



range_price=np.array([57830*(0.95+0.01*j)  for j in range(10)])
vanilla_theta = []
asian_theta = []
for i in range_price:

    Vanilla_option = vanilla_option_theta(t=0,St=57830,K=i,T=1,r=0.01,
    vanilla_theta.append(Vanilla_option)

    Asian_option = asian_option_theta("fixed","C",S0=57830,K=i,r=0.01,
    asian_theta.append(Asian_option)



plt.figure(figsize=(10,5))
plt.plot(range_price,vanilla_theta,label='vanilla_option')
plt.plot(range_price,asian_theta,label='asian_option')

plt.xlabel("strike price")
plt.ylabel("theta")
plt.title("sensitivity to strike price")
plt.legend()





range_price=np.array([57830*(0.95+0.01*j)  for j in range(10)])

vanilla_price= []
asian_price = []
vanilla_theta = []
asian_theta = []

for i in range_price:

    Vanilla_option = vanilla_option_theta(t=0,St=57830,K=i,T=1,r=0.01,
    vanilla_theta.append(Vanilla_option)

    Vanilla_option = BS_option_price(t=0,St=57830,K=i,T=1,r=0.01,sigma
    vanilla_price.append(Vanilla_option)


    Asian_option = asian_option_theta("fixed","C",S0=57830,K=i,r=0.01,
    asian_theta.append(Asian_option)

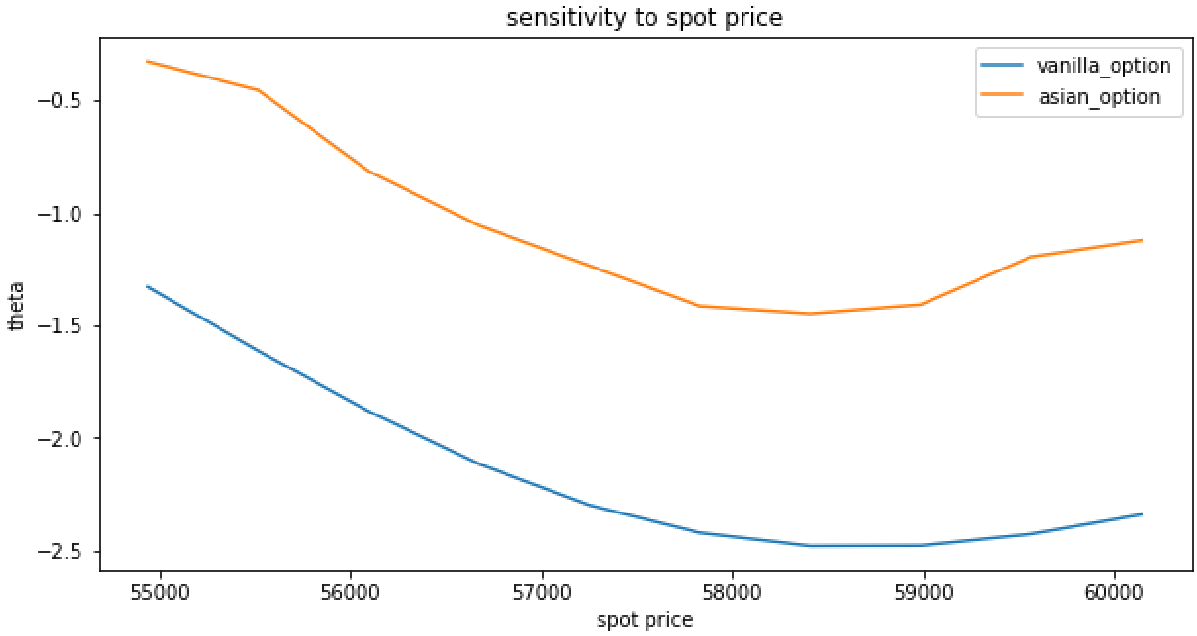
    Asian_option = HW_BTM("fixed","C",S0=57830,K=i,r=0.01,sigma=0.05,T
    asian_price.append(Asian_option)

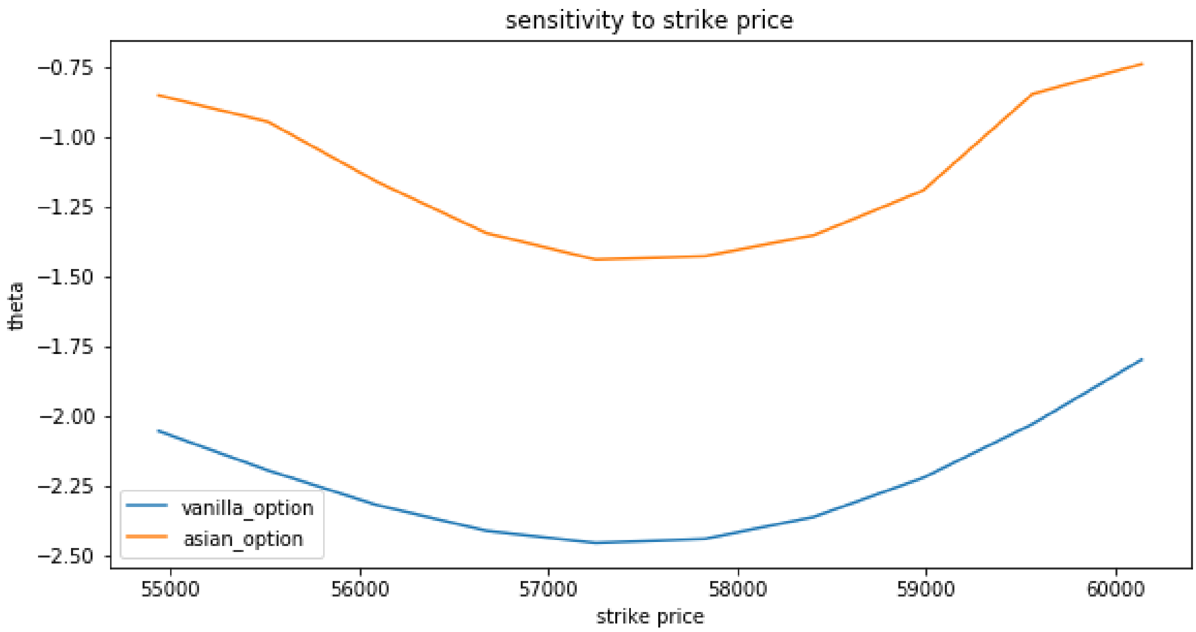


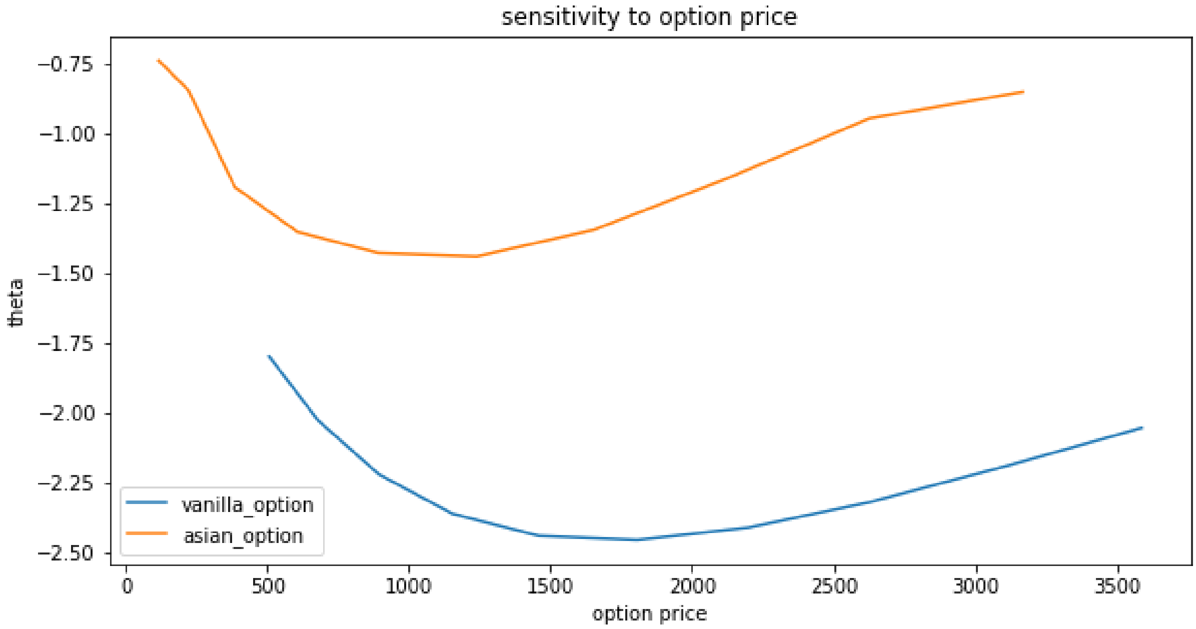
plt.figure(figsize=(10,5))
plt.plot(vanilla_price,vanilla_theta,label='vanilla_option')
plt.plot(asian_price,asian_theta,label='asian_option')
```

```
plt.xlabel("option price")
plt.ylabel("theta")
plt.title("sensitivity to option price")
plt.legend()
```

Out[119… <matplotlib.legend.Legend at 0x133853f28>







In [106…

```
# Rho comparason:
range_price=np.array([57830*(0.95+0.01*j)  for j in range(10)])
vanilla_rho = []
asian_rho = []
for i in range_price:

    Vanilla_option = vanilla_option_rho(t=0,St=i,K=58000,T=1,r=0.01,si
    vanilla_rho.append(Vanilla_option)

    Asian_option = asian_option_rho("fixed","C",S0=i,K=58000,r=0.01,si
    asian_rho.append(Asian_option)



plt.figure(figsize=(10,5))
plt.plot(range_price,vanilla_rho,label='vanilla_option')
plt.plot(range_price,asian_rho,label='asian_option')

plt.xlabel("spot price")
plt.ylabel("rho")
plt.title("sensitivity to spot price")
plt.legend()




range_price=np.array([57830*(0.95+0.01*j)  for j in range(10)])
vanilla_rho = []
asian_rho = []
for i in range_price:

    Vanilla_option = vanilla_option_rho(t=0,St=57830,K=i,T=1,r=0.01,si
    vanilla_rho.append(Vanilla_option)

    Asian_option = asian_option_rho("fixed","C",S0=57830,K=i,r=0.01,si
    asian_rho.append(Asian_option)
```

```
plt.figure(figsize=(10,5))
plt.plot(range_price,vanilla_rho,label='vanilla_option')
plt.plot(range_price,asian_rho,label='asian_option')

plt.xlabel("strike price")
plt.ylabel("rho")
plt.title("sensitivity to strike price")
plt.legend()
```

```
range_price=np.array([57830*(0.95+0.01*j)  for j in range(10)])

vanilla_price= []
asian_price = []
vanilla_rho = []
asian_rho = []

for i in range_price:

    Vanilla_option = vanilla_option_rho(t=0,St=57830,K=i,T=1,r=0.01,si
    vanilla_rho.append(Vanilla_option)

    Vanilla_option = BS_option_price(t=0,St=57830,K=i,T=1,r=0.01,sigma
    vanilla_price.append(Vanilla_option)


    Asian_option = asian_option_rho("fixed","C",S0=57830,K=i,r=0.01,si
    asian_rho.append(Asian_option)

    Asian_option = HW_BTM("fixed","C",S0=57830,K=i,r=0.01,sigma=0.05,T
    asian_price.append(Asian_option)

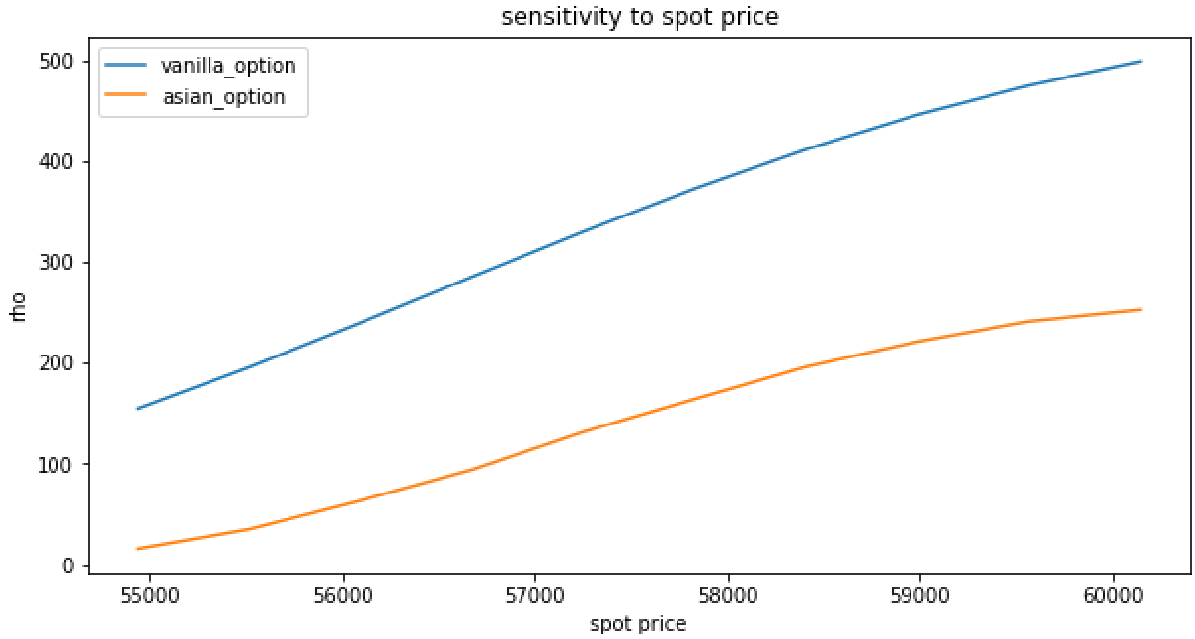


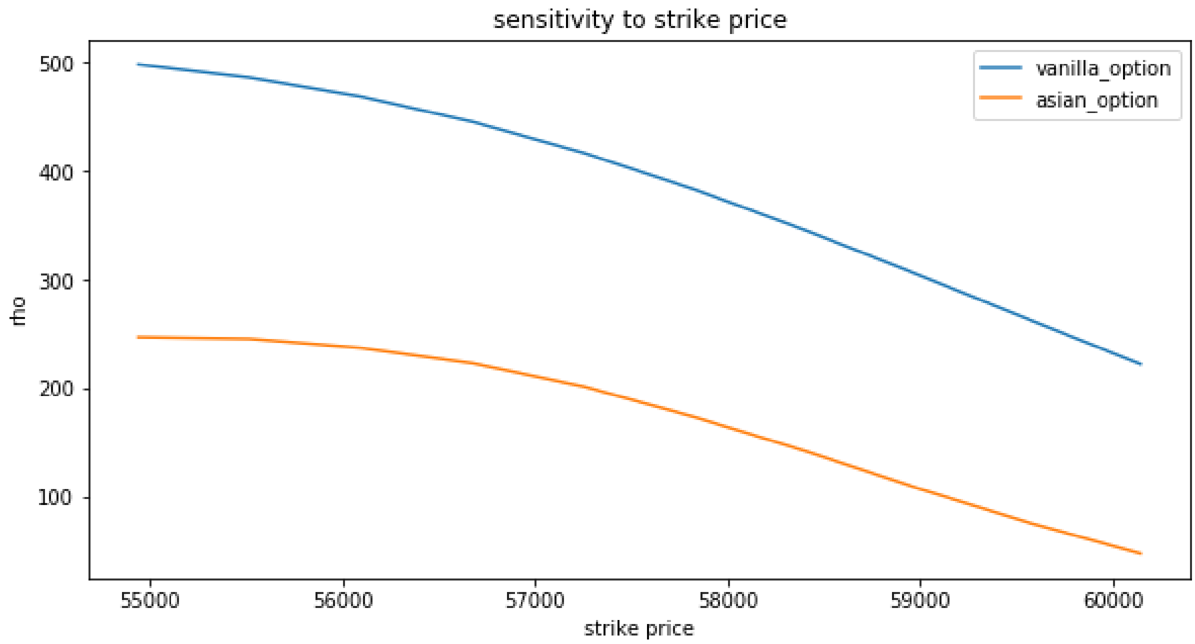
plt.figure(figsize=(10,5))
plt.plot(vanilla_price,vanilla_rho,label='vanilla_option')
plt.plot(asian_price,asian_rho,label='asian_option')

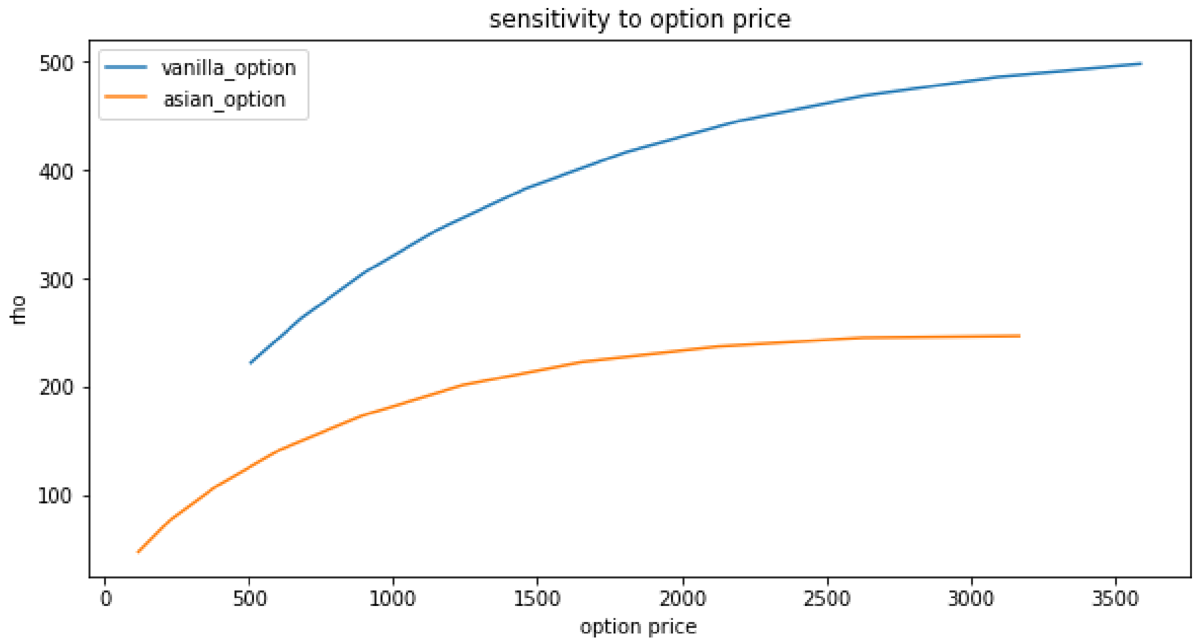
plt.xlabel("option price")
plt.ylabel("rho")
plt.title("sensitivity to option price")
plt.legend()
```

Out[106…

```
<matplotlib.legend.Legend at 0x1338f2c18>
```


sensitivity to spot price
vanilla_option
asian_option
rho
500
400
300
200
100
0
55000
56000
57000
58000
59000
60000
spot price


sensitivity to strike price
vanilla_option
asian_option
rho
500
400
300
200
100
55000
56000
57000
58000
59000
60000
strike price


sensitivity to option price
vanilla_option
asian_option
rho
500
400
300
200
100
0
500
1000
1500
2000
2500
3000
3500
option price

In [ ]:

Compare the Greeks of Asian option and Vanilla option for ETH

In [112…

```
# Delta comparason:
range_price=np.array([2100*(0.95+0.01*j)  for j in range(10)])
vanilla_delta = []
asian_delta = []
for i in range_price:

    Vanilla_option = vanilla_option_delta(t=0,St=i,K=2100,T=1,r=0.01,s
    vanilla_delta.append(Vanilla_option)

    Asian_option = asian_option_delta("fixed","C",S0=i,K=2100,r=0.01,s
    asian_delta.append(Asian_option)



plt.figure(figsize=(10,5))
plt.plot(range_price,vanilla_delta,label='vanilla_option')
plt.plot(range_price,asian_delta,label='asian_option')

plt.xlabel("spot price")
plt.ylabel("delta")
plt.title("sensitivity to spot price")
plt.legend()




range_price=np.array([2100*(0.95+0.01*j)  for j in range(10)])
vanilla_delta = []
asian_delta = []
for i in range_price:

    Vanilla_option = vanilla_option_delta(t=0,St=2100,K=i,T=1,r=0.01,s
    vanilla_delta.append(Vanilla_option)

    Asian_option = asian_option_delta("fixed","C",S0=2100,K=i,r=0.01,s
    asian_delta.append(Asian_option)



plt.figure(figsize=(10,5))
plt.plot(range_price,vanilla_delta,label='vanilla_option')
plt.plot(range_price,asian_delta,label='asian_option')

plt.xlabel("strike price")
plt.ylabel("delta")
plt.title("sensitivity to strike price")
plt.legend()




range_price=np.array([2100*(0.95+0.01*j)  for j in range(10)])
```

```
vanilla_price= []
asian_price = []
vanilla_delta = []
asian_delta = []

for i in range_price:

    Vanilla_option = vanilla_option_delta(t=0,St=2100,K=i,T=1,r=0.01,s
    vanilla_delta.append(Vanilla_option)

    Vanilla_option = BS_option_price(t=0,St=2100,K=i,T=1,r=0.01,sigma=
    vanilla_price.append(Vanilla_option)


    Asian_option = asian_option_delta("fixed","C",S0=2100,K=i,r=0.01,s
    asian_delta.append(Asian_option)

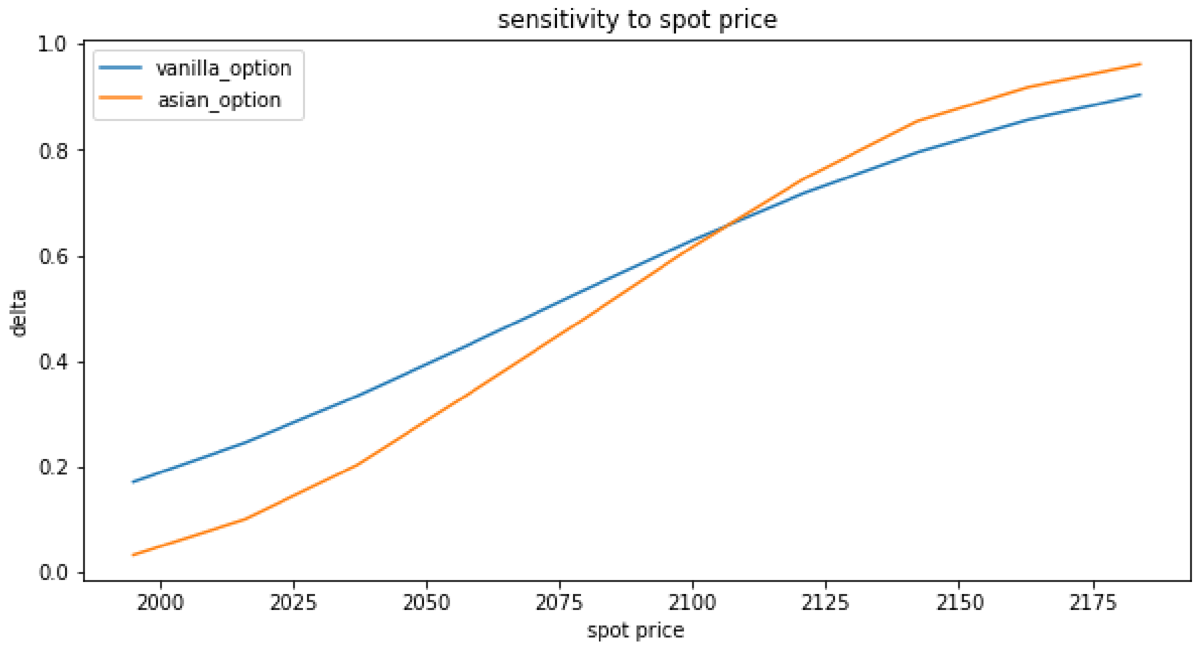
    Asian_option = HW_BTM("fixed","C",S0=2100,K=i,r=0.01,sigma=0.04,T=
    asian_price.append(Asian_option)

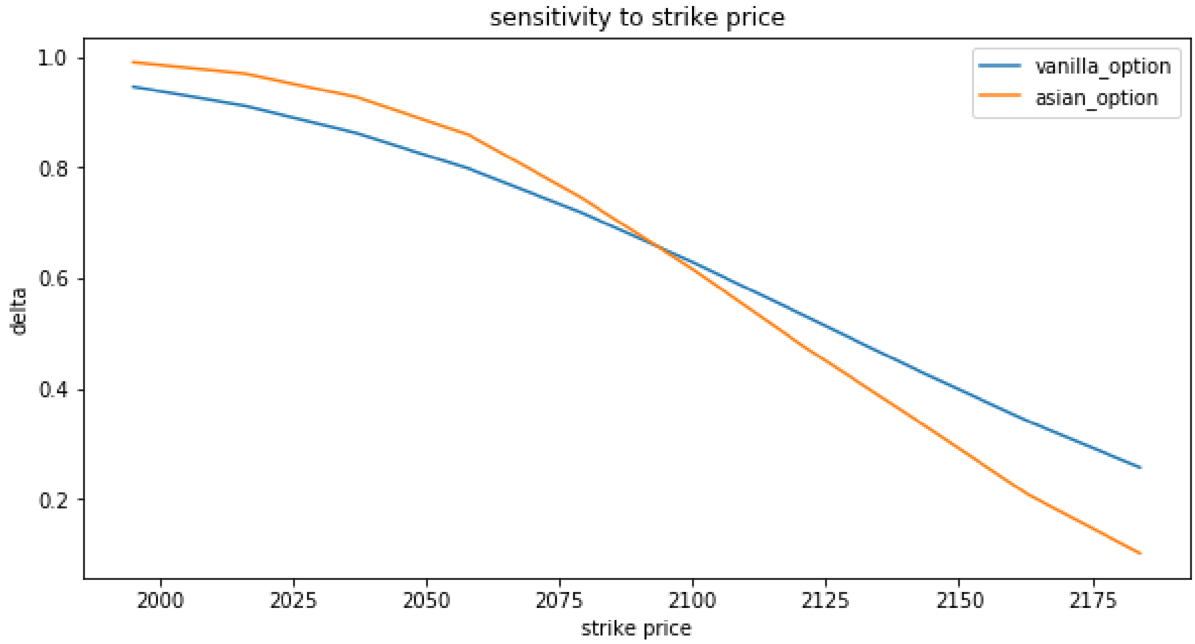


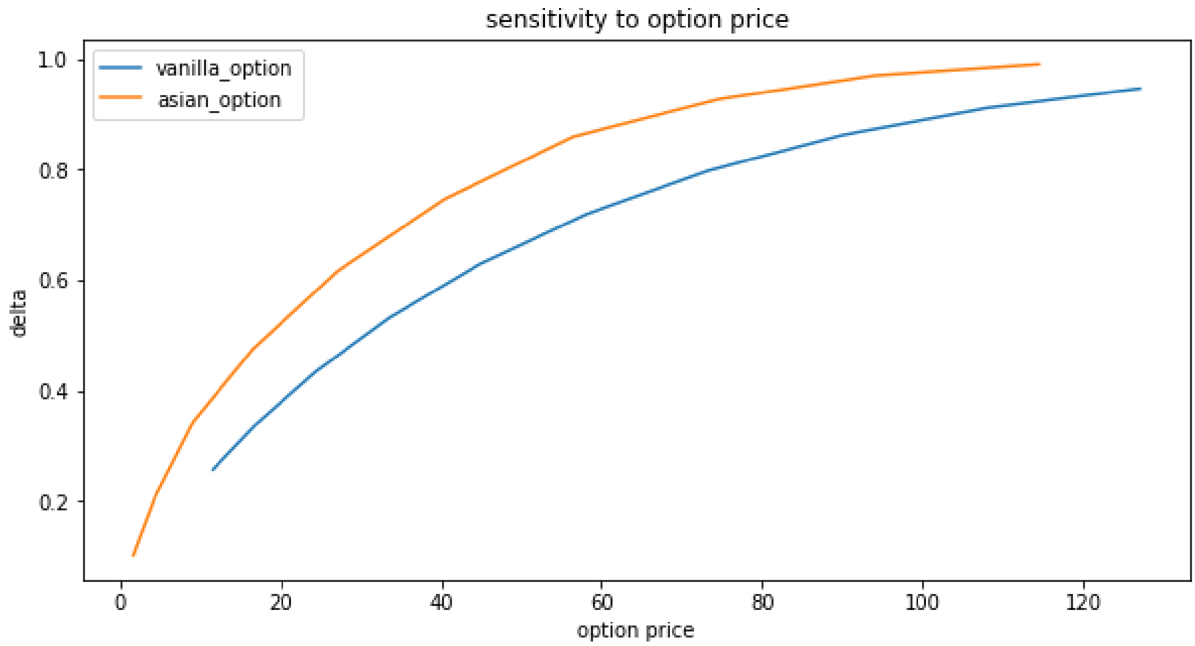
plt.figure(figsize=(10,5))
plt.plot(vanilla_price,vanilla_delta,label='vanilla_option')
plt.plot(asian_price,asian_delta,label='asian_option')

plt.xlabel("option price")
plt.ylabel("delta")
plt.title("sensitivity to option price")
plt.legend()
```

Out[112… <matplotlib.legend.Legend at 0x1341c3e10>







In [122…

```
# Gamma comparason:
range_price=np.array([2100*(0.95+0.01*j)  for j in range(10)])
vanilla_gamma = []
asian_gamma = []
for i in range_price:

    Vanilla_option = vanilla_option_gamma(t=0,St=i,K=2100,T=1,r=0.01,s
    vanilla_gamma.append(Vanilla_option)

    Asian_option = asian_option_gamma("fixed","C",S0=i,K=2100,r=0.01,s
    asian_gamma.append(Asian_option)



plt.figure(figsize=(10,5))
plt.plot(range_price,vanilla_gamma,label='vanilla_option')
plt.plot(range_price,asian_gamma,label='asian_option')

plt.xlabel("spot price")
plt.ylabel("gamma")
```

```
plt.title("sensitivity to spot price")
plt.legend()



range_price=np.array([2100*(0.95+0.01*j)  for j in range(10)])
vanilla_gamma = []
asian_gamma = []
for i in range_price:

    Vanilla_option = vanilla_option_gamma(t=0,St=2100,K=i,T=1,r=0.01,s
    vanilla_gamma.append(Vanilla_option)

    Asian_option = asian_option_gamma("fixed","C",S0=2100,K=i,r=0.01,s
    asian_gamma.append(Asian_option)



plt.figure(figsize=(10,5))
plt.plot(range_price,vanilla_gamma,label='vanilla_option')
plt.plot(range_price,asian_gamma,label='asian_option')

plt.xlabel("strike price")
plt.ylabel("gamma")
plt.title("sensitivity to strike price")
plt.legend()




range_price=np.array([2100*(0.95+0.01*j)  for j in range(10)])

vanilla_price= []
asian_price = []
vanilla_gamma = []
asian_gamma = []

for i in range_price:

    Vanilla_option = vanilla_option_gamma(t=0,St=2100,K=i,T=1,r=0.01,s
    vanilla_gamma.append(Vanilla_option)

    Vanilla_option = BS_option_price(t=0,St=2100,K=i,T=1,r=0.01,sigma=
    vanilla_price.append(Vanilla_option)


    Asian_option = asian_option_gamma("fixed","C",S0=2100,K=i,r=0.01,s
    asian_gamma.append(Asian_option)

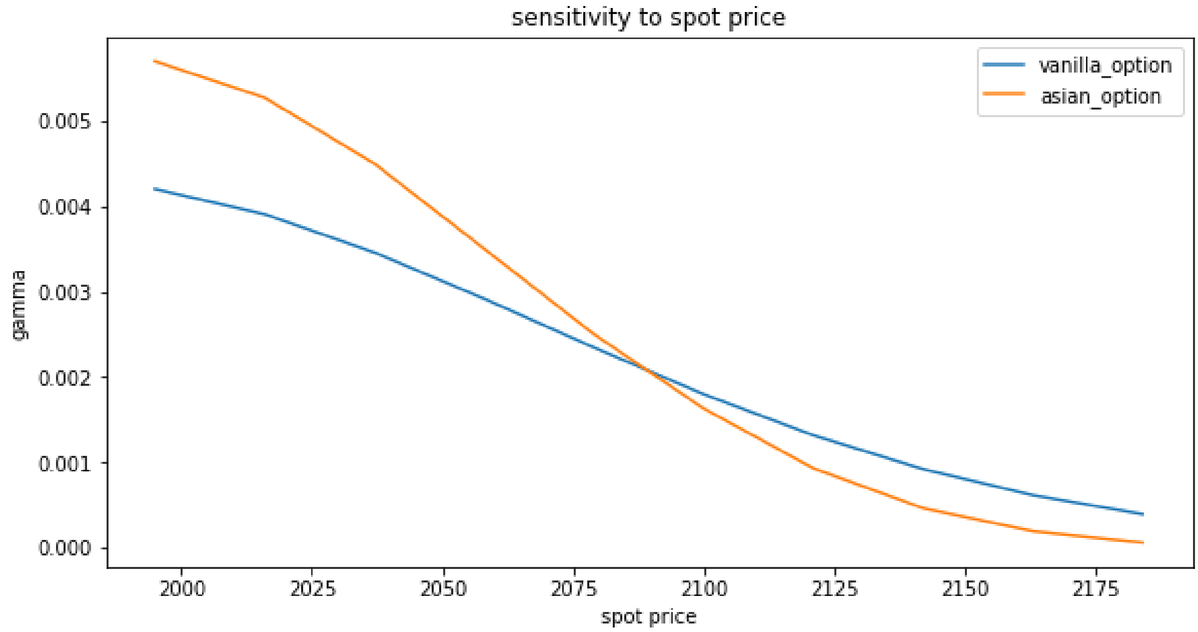
    Asian_option = HW_BTM("fixed","C",S0=2100,K=i,r=0.01,sigma=0.04,T=
    asian_price.append(Asian_option)

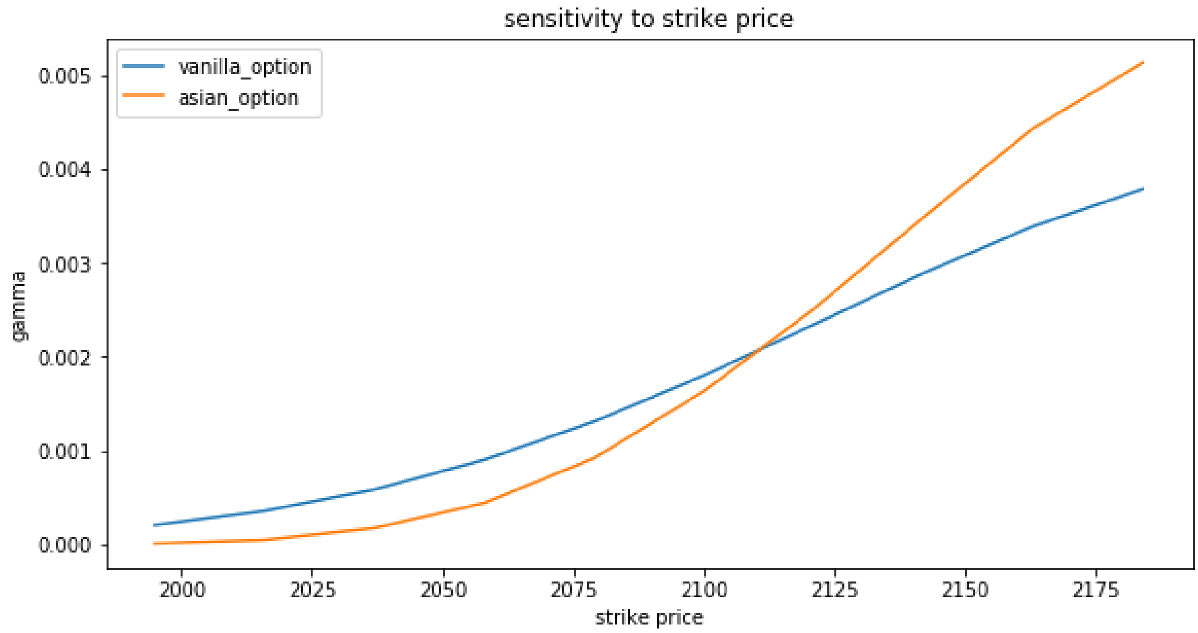


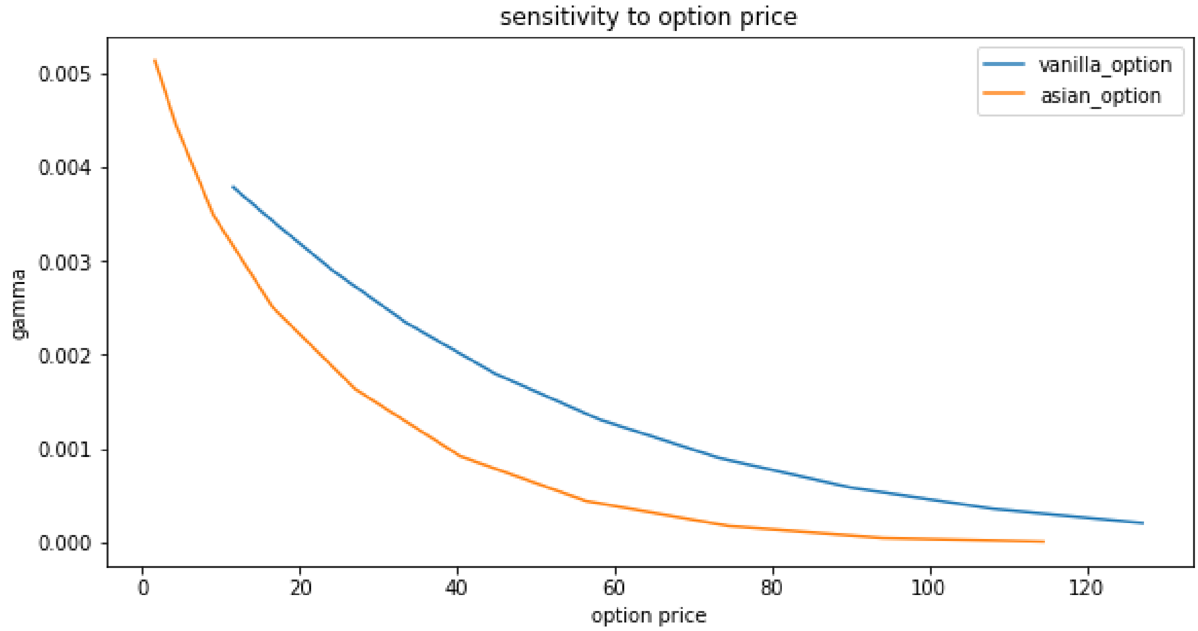
plt.figure(figsize=(10,5))
plt.plot(vanilla_price,vanilla_gamma,label='vanilla_option')
plt.plot(asian_price,asian_gamma,label='asian_option')
```

```
plt.xlabel("option price")
plt.ylabel("gamma")
plt.title("sensitivity to option price")
plt.legend()
```

Out[122… <matplotlib.legend.Legend at 0x132decb70>







In [114…

```
# Vega comparason:
range_price=np.array([2100*(0.95+0.01*j)  for j in range(10)])
vanilla_vega = []
asian_vega = []
for i in range_price:

    Vanilla_option = vanilla_option_vega(t=0,St=i,K=2100,T=1,r=0.01,si
    vanilla_vega.append(Vanilla_option)

    Asian_option = asian_option_vega("fixed","C",S0=i,K=2100,r=0.01,si
    asian_vega.append(Asian_option)



plt.figure(figsize=(10,5))
plt.plot(range_price,vanilla_vega,label='vanilla_option')
plt.plot(range_price,asian_vega,label='asian_option')

plt.xlabel("spot price")
plt.ylabel("vega")
plt.title("sensitivity to spot price")
plt.legend()




range_price=np.array([2100*(0.95+0.01*j)  for j in range(10)])
vanilla_vega = []
asian_vega = []
for i in range_price:

    Vanilla_option = vanilla_option_vega(t=0,St=2100,K=i,T=1,r=0.01,si
    vanilla_vega.append(Vanilla_option)

    Asian_option = asian_option_vega("fixed","C",S0=2100,K=i,r=0.01,si
    asian_vega.append(Asian_option)
```

```
plt.figure(figsize=(10,5))
plt.plot(range_price,vanilla_vega,label='vanilla_option')
plt.plot(range_price,asian_vega,label='asian_option')

plt.xlabel("strike price")
plt.ylabel("vega")
plt.title("sensitivity to strike price")
plt.legend()





range_price=np.array([2100*(0.95+0.01*j)  for j in range(10)])

vanilla_price= []
asian_price = []
vanilla_vega = []
asian_vega = []

for i in range_price:

    Vanilla_option = vanilla_option_vega(t=0,St=2100,K=i,T=1,r=0.01,si
    vanilla_vega.append(Vanilla_option)

    Vanilla_option = BS_option_price(t=0,St=2100,K=i,T=1,r=0.01,sigma=
    vanilla_price.append(Vanilla_option)


    Asian_option = asian_option_vega("fixed","C",S0=2100,K=i,r=0.01,si
    asian_vega.append(Asian_option)

    Asian_option = HW_BTM("fixed","C",S0=2100,K=i,r=0.01,sigma=0.04,T=
    asian_price.append(Asian_option)

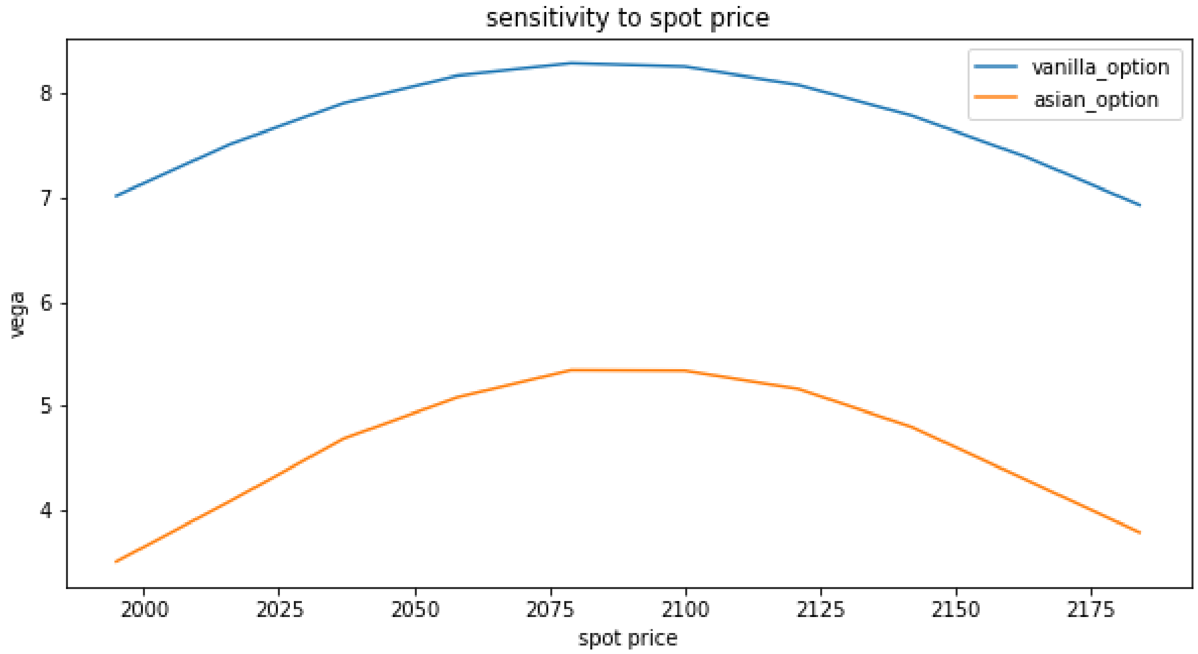


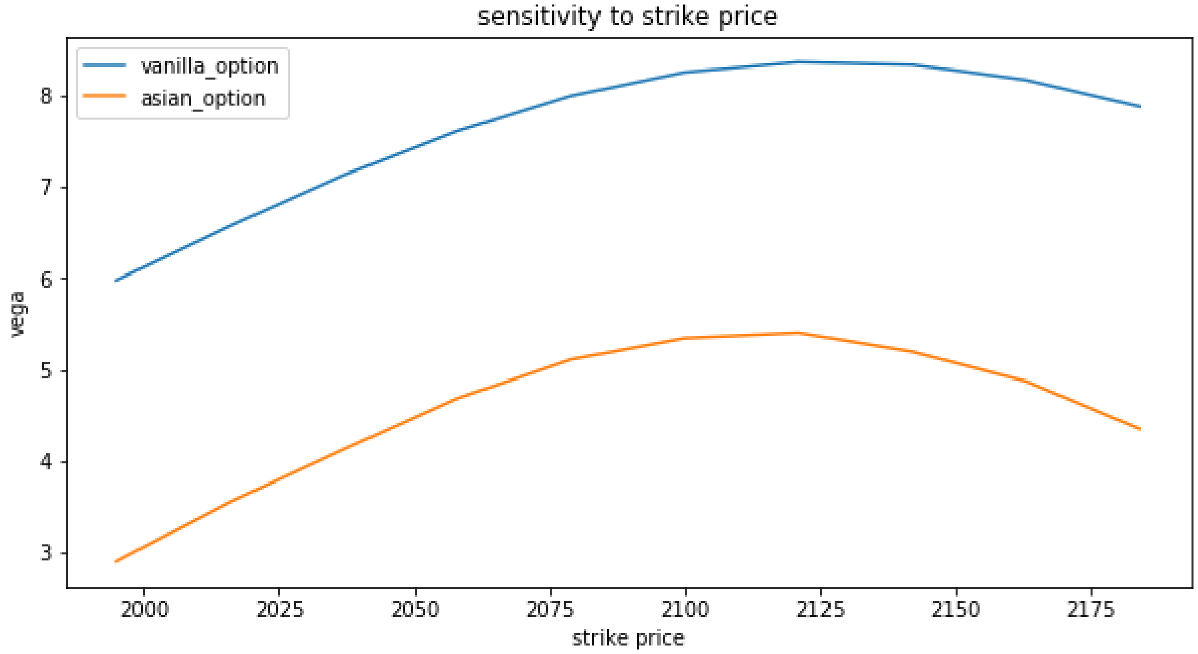
plt.figure(figsize=(10,5))
plt.plot(vanilla_price,vanilla_vega,label='vanilla_option')
plt.plot(asian_price,asian_vega,label='asian_option')

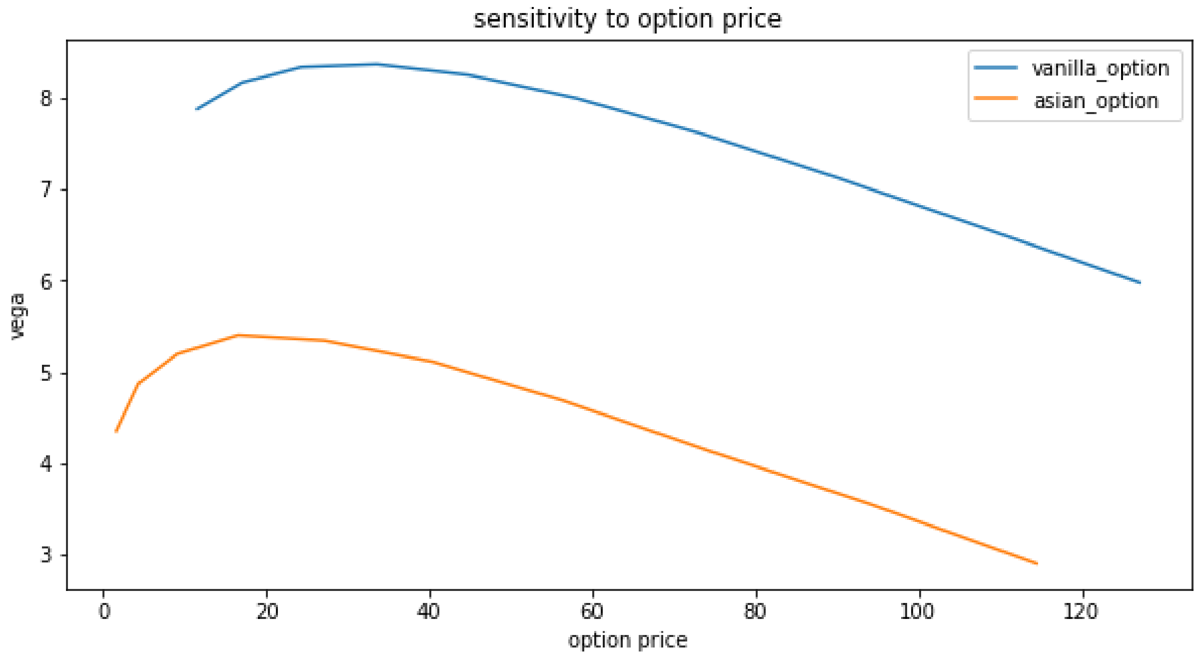
plt.xlabel("option price")
plt.ylabel("vega")
plt.title("sensitivity to option price")
plt.legend()
```

Out[114…

```
<matplotlib.legend.Legend at 0x132c5a518>
```


sensitivity to spot price
vanilla_option
asian_option
vega
8
7
6
5
4
2000
2025
2050
2075
2100
2125
2150
2175
spot price


sensitivity to strike price
vanilla_option
asian_option
vega
8
7
6
5
4
3
2000
2025
2050
2075
2100
2125
2150
2175
strike price


sensitivity to option price
vanilla_option
asian_option
vega
8
7
6
5
4
3
0
20
40
60
80
100
120
option price

In [120…

```
# Theta comparason:
range_price=np.array([2100*(0.95+0.01*j)  for j in range(10)])
vanilla_theta = []
asian_theta = []
for i in range_price:

    Vanilla_option = vanilla_option_theta(t=0,St=i,K=2100,T=1,r=0.01,s
    vanilla_theta.append(Vanilla_option)

    Asian_option = asian_option_theta("fixed","C",S0=i,K=2100,r=0.01,s
    asian_theta.append(Asian_option)



plt.figure(figsize=(10,5))
plt.plot(range_price,vanilla_theta,label='vanilla_option')
plt.plot(range_price,asian_theta,label='asian_option')

plt.xlabel("spot price")
plt.ylabel("theta")
plt.title("sensitivity to spot price")
plt.legend()




range_price=np.array([2100*(0.95+0.01*j)  for j in range(10)])
vanilla_theta = []
asian_theta = []
for i in range_price:

    Vanilla_option = vanilla_option_theta(t=0,St=2100,K=i,T=1,r=0.01,s
    vanilla_theta.append(Vanilla_option)

    Asian_option = asian_option_theta("fixed","C",S0=2100,K=i,r=0.01,s
    asian_theta.append(Asian_option)



plt.figure(figsize=(10,5))
plt.plot(range_price,vanilla_theta,label='vanilla_option')
plt.plot(range_price,asian_theta,label='asian_option')

plt.xlabel("strike price")
plt.ylabel("theta")
plt.title("sensitivity to strike price")
plt.legend()





range_price=np.array([2100*(0.95+0.01*j)  for j in range(10)])

vanilla_price= []
asian_price = []
vanilla_theta = []
asian_theta = []

for i in range_price:
```

```
    Vanilla_option = vanilla_option_theta(t=0,St=2100,K=i,T=1,r=0.01,s
    vanilla_theta.append(Vanilla_option)

    Vanilla_option = BS_option_price(t=0,St=2100,K=i,T=1,r=0.01,sigma=
    vanilla_price.append(Vanilla_option)


    Asian_option = asian_option_theta("fixed","C",S0=2100,K=i,r=0.01,s
    asian_theta.append(Asian_option)

    Asian_option = HW_BTM("fixed","C",S0=2100,K=i,r=0.01,sigma=0.04,T=
    asian_price.append(Asian_option)

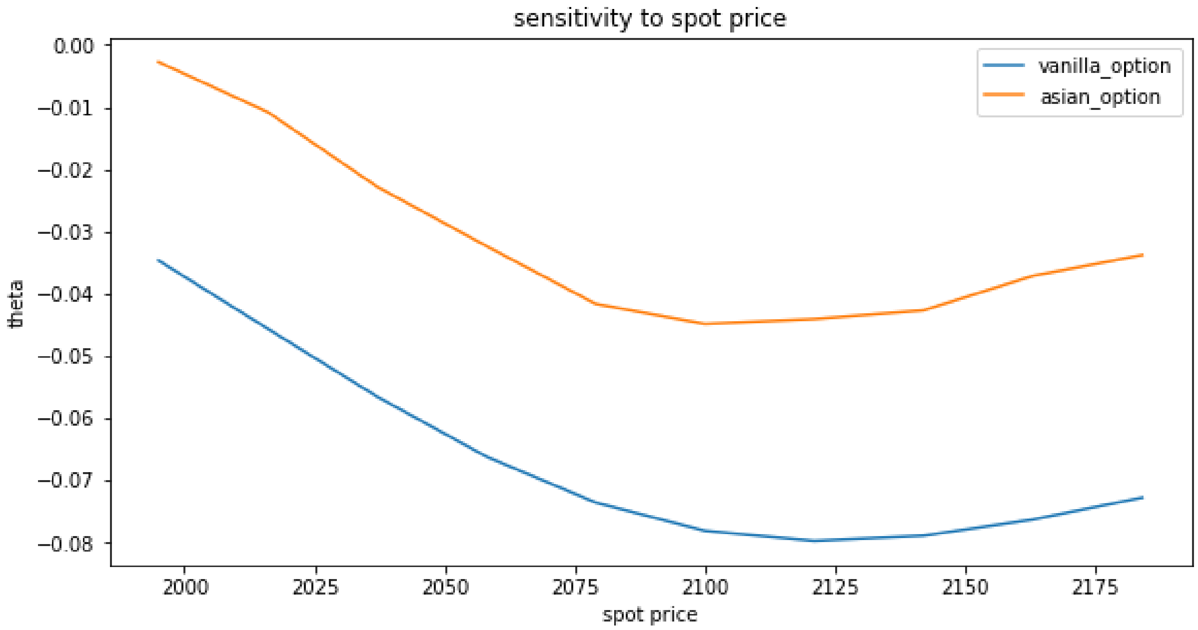


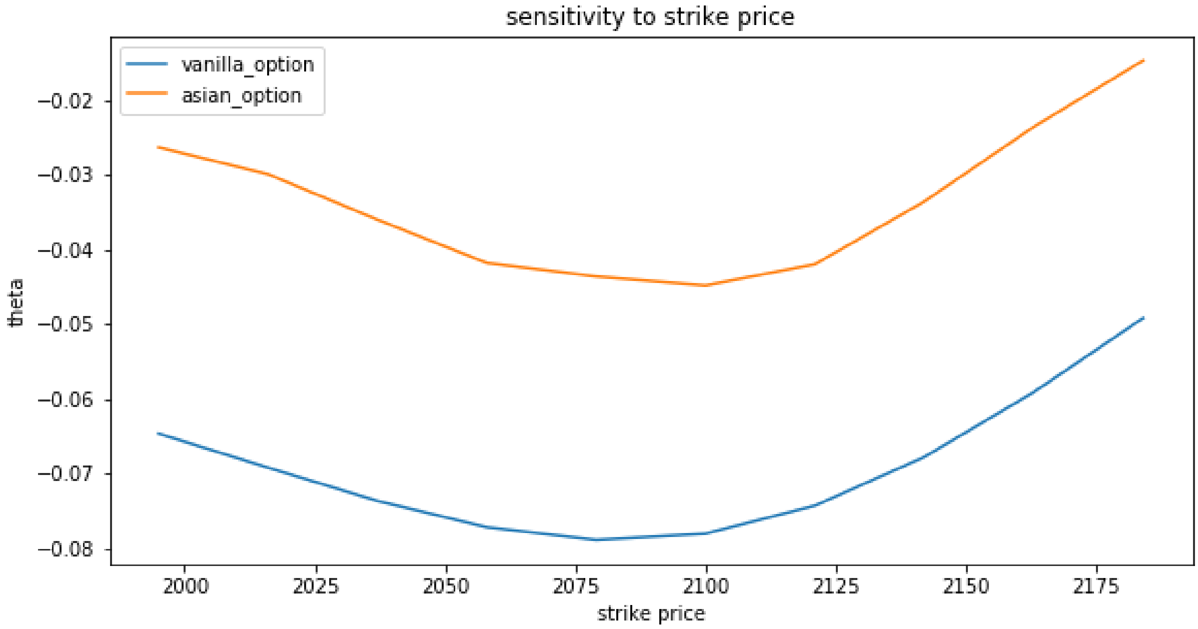
plt.figure(figsize=(10,5))
plt.plot(vanilla_price,vanilla_theta,label='vanilla_option')
plt.plot(asian_price,asian_theta,label='asian_option')

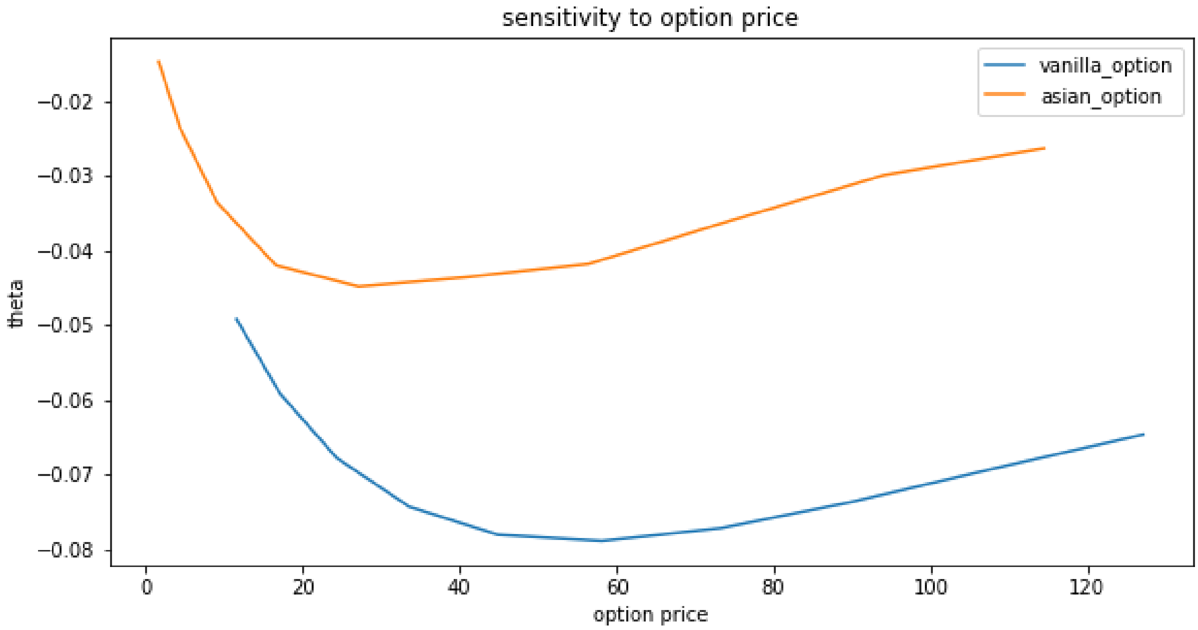
plt.xlabel("option price")
plt.ylabel("theta")
plt.title("sensitivity to option price")
plt.legend()
```

Out[120…

```
<matplotlib.legend.Legend at 0x134c62fd0>
```







In [116…

```
# Rho comparason:
range_price=np.array([2100*(0.95+0.01*j)  for j in range(10)])
vanilla_rho = []
asian_rho = []
for i in range_price:

    Vanilla_option = vanilla_option_rho(t=0,St=i,K=2100,T=1,r=0.01,sig
    vanilla_rho.append(Vanilla_option)

    Asian_option = asian_option_rho("fixed","C",S0=i,K=2100,r=0.01,sig
    asian_rho.append(Asian_option)



plt.figure(figsize=(10,5))
plt.plot(range_price,vanilla_rho,label='vanilla_option')
plt.plot(range_price,asian_rho,label='asian_option')

plt.xlabel("spot price")
plt.ylabel("rho")
plt.title("sensitivity to spot price")
```

```
plt.legend()



range_price=np.array([2100*(0.95+0.01*j)  for j in range(10)])
vanilla_rho = []
asian_rho = []
for i in range_price:

    Vanilla_option = vanilla_option_rho(t=0,St=2100,K=i,T=1,r=0.01,sig
    vanilla_rho.append(Vanilla_option)

    Asian_option = asian_option_rho("fixed","C",S0=2100,K=i,r=0.01,sig
    asian_rho.append(Asian_option)



plt.figure(figsize=(10,5))
plt.plot(range_price,vanilla_rho,label='vanilla_option')
plt.plot(range_price,asian_rho,label='asian_option')

plt.xlabel("strike price")
plt.ylabel("rho")
plt.title("sensitivity to strike price")
plt.legend()




range_price=np.array([2100*(0.95+0.01*j)  for j in range(10)])

vanilla_price= []
asian_price = []
vanilla_rho = []
asian_rho = []

for i in range_price:

    Vanilla_option = vanilla_option_rho(t=0,St=2100,K=i,T=1,r=0.01,sig
    vanilla_rho.append(Vanilla_option)

    Vanilla_option = BS_option_price(t=0,St=2100,K=i,T=1,r=0.01,sigma=
    vanilla_price.append(Vanilla_option)


    Asian_option = asian_option_rho("fixed","C",S0=2100,K=i,r=0.01,sig
    asian_rho.append(Asian_option)

    Asian_option = HW_BTM("fixed","C",S0=2100,K=i,r=0.01,sigma=0.04,T=
    asian_price.append(Asian_option)

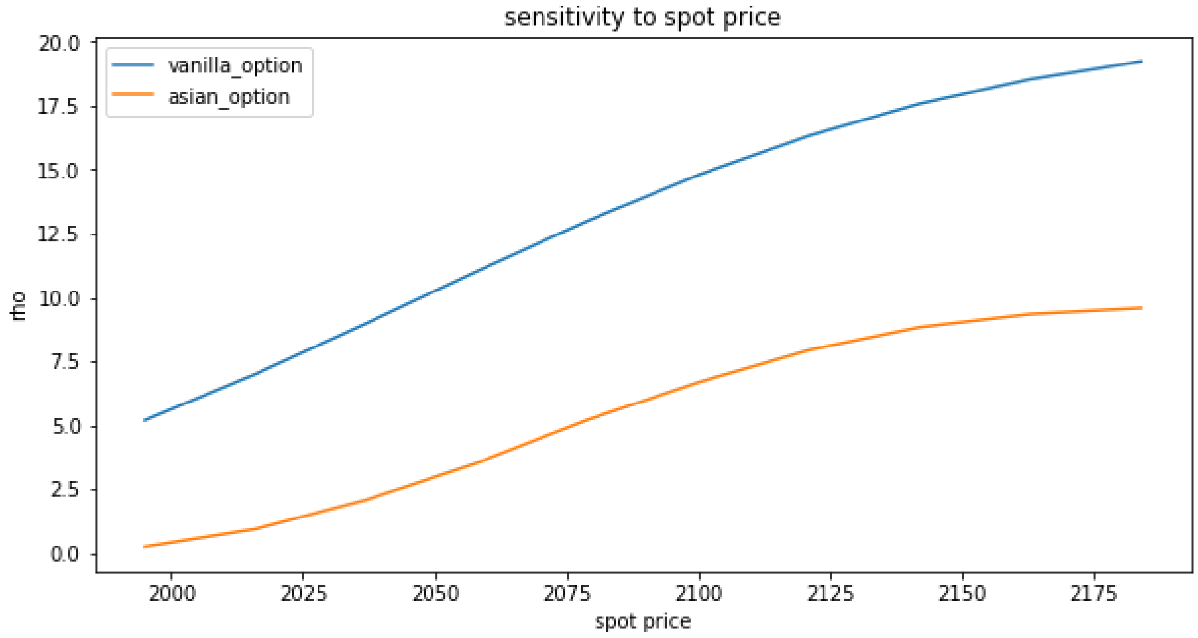


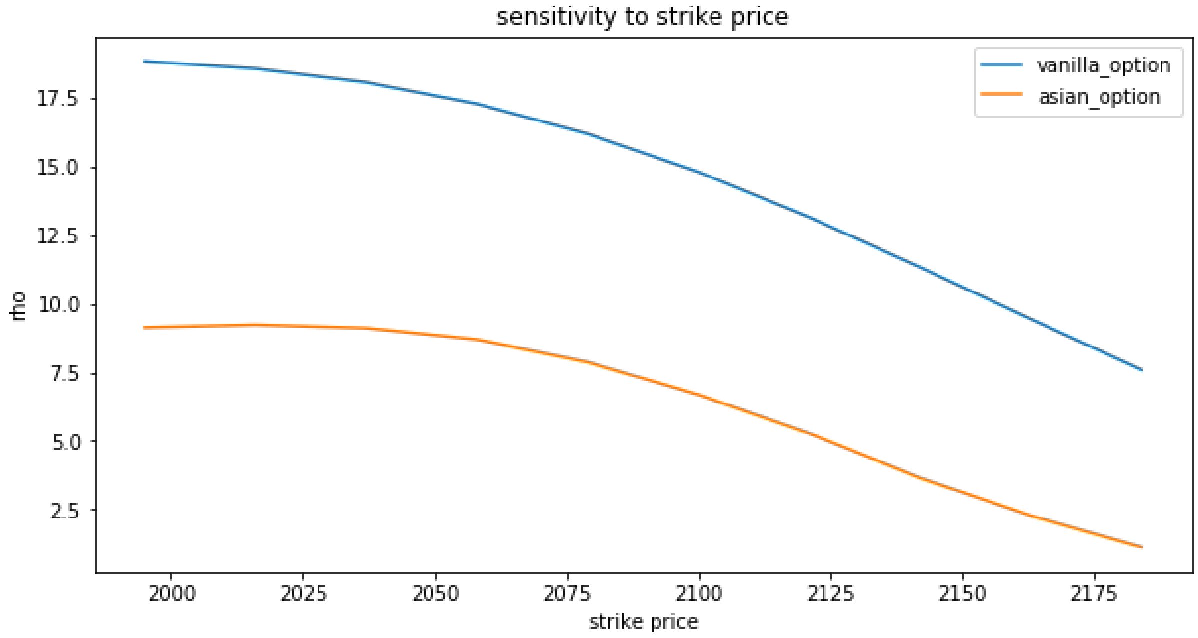
plt.figure(figsize=(10,5))
plt.plot(vanilla_price,vanilla_rho,label='vanilla_option')
plt.plot(asian_price,asian_rho,label='asian_option')

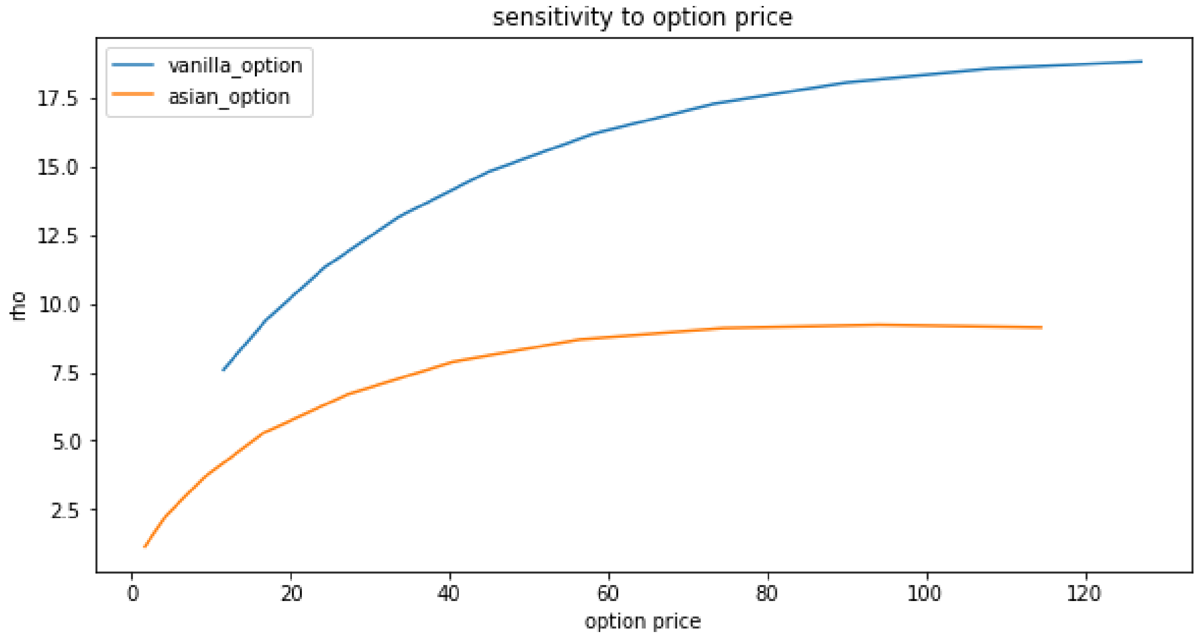
plt.xlabel("option price")
```

```
plt.ylabel("rho")
plt.title("sensitivity to option price")
plt.legend()
```

Out[116… <matplotlib.legend.Legend at 0x132d63748>








```
In [ ]:
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In [ ]:
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In [ ]:
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In [ ]:
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In [ ]:
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