In [4]:

```
import numpy as np
import matplotlib.pyplot as plt
import math

from scipy.stats import norm

def positive(S,K,del_t,r,sigma):
    val = math.log(S/K) + (r+(sigma*sigma/2))*(del_t)
    return val/(sigma*math.sqrt(del_t))


def negative(S,K,del_t,r,sigma):
    val = math.log(S/K) + (r-(sigma*sigma/2))*(del_t)
    return val/(sigma*math.sqrt(del_t))

def BSM_call_option(S,K,T,t,r,sigma):
    if(t==T):
        return np.maximum(S-K,0)
    term1 = S*norm.cdf(positive(S,K,T-t,r,sigma))
    term2 = K*math.exp(-r*(T-t))*norm.cdf(negative(S,K,T-t,r,sigma))
    return term1-term2

def BSM_put_option(S,K,T,t,r,sigma):
    if(t==T):
        return np.maximum(K-S,0)
    return K*math.exp(-r*(T-t))-S+BSM_call_option(S,K,T,t,r,sigma)

T = 1;
K = 1;
r = 0.05;
sigma = 0.6
t = 0.5
x = 1

BSM_call = [];
BSM_put = []

u = np.linspace(0.5,1.5,100)
for i in u:
    BSM_put.append(BSM_put_option(x,i,T,t,r,sigma))
    BSM_call.append(BSM_call_option(x,i,T,t,r,sigma))

print ('Strike Price(K)       Call Option Price(C(t,x))     Put Option Price(P
(t,x))')
for i in range(0,len(u),10):
    print(round(u[i],6),"                  ",round(BSM_call[i],6),"
",round(BSM_put[i],6))
plt.plot(u,BSM_put,label='P(t,x)',c='b')
plt.plot(u,BSM_call,label='C(t,x)',c='g')

plt.title('C(t,x) and P(t,x) varying K (Strike Price)')
plt.xlabel('K (Strike Price)')
plt.ylabel('Option Price')
plt.legend()
plt.show()



BSM_call = [];
```

```
BSM_put = []
v = np.linspace(0.01,1,100)

for i in v:
    BSM_put.append(BSM_put_option(x,K,T,t,r,i))
    BSM_call.append(BSM_call_option(x,K,T,t,r,i))
print ('Sigma       Call Option Price(C(t,x))     Put Option Price(P(t,x))')
for i in range(0,len(v),10):
    print(round(v[i],6),"              ",round(BSM_call[i],6),"
",round(BSM_put[i],6))

plt.plot(v,BSM_put,label='P(t,x)',c='b')
plt.plot(v,BSM_call,label='C(t,x)',c='g')

plt.title('C(t,x) and P(t,x) varying sigma')
plt.xlabel('Sigma')
plt.ylabel('Option Price')
plt.legend()
plt.show()


BSM_call = [];
BSM_put = []
w = np.linspace(0,1,100)

for i in w:
    BSM_put.append(BSM_put_option(x,K,T,t,i,sigma))
    BSM_call.append(BSM_call_option(x,K,T,t,i,sigma))
print ('Rate      Call Option Price(C(t,x))      Put Option Price(P(t,x))')
for i in range(0,len(w),10):
    print(round(w[i],6),"              ",round(BSM_call[i],6),"
",round(BSM_put[i],6))
plt.plot(w,BSM_put,label='P(t,x)',c='b')
plt.plot(w,BSM_call,label='C(t,x)',c='g')

plt.title('C(t,x) and P(t,x) varying rate (r)')
plt.xlabel('Rate (r)')
plt.ylabel('Option Price')
plt.legend()
plt.show()


BSM_call = [];BSM_put = []
y = np.linspace(0.51,5,100)

for i in y:
    BSM_put.append(BSM_put_option(x,K,i,t,r,sigma))
    BSM_call.append(BSM_call_option(x,K,i,t,r,sigma))
print ('T    Call Option Price(C(t,x))   Put Option Price(P(t,x))')
for i in range(0,len(y),10):
    print(round(y[i],6),"              ",round(BSM_call[i],6),"
",round(BSM_put[i],6))
plt.plot(y,BSM_put,label='P(t,x)',c='b')
plt.plot(y,BSM_call,label='C(t,x)',c='g')

plt.title('C(t,x) and P(t,x) varying Final Time (T)')
plt.xlabel('Final Time (T)')
plt.ylabel('Option Price')
plt.legend()
plt.show()
```

```
BSM_call={}
BSM_put={}
m=np.linspace(0.5,1.5,20)
l=[]
n=np.linspace(0.01,1,20)
k=[]
BSM_call_t=[]
BSM_put_t=[]

for i in range(0,len(n)):
    for j in range(0,len(m)):
        BSM_call[i,j] = BSM_call_option(x,m[j],T,t,r,n[i])
        BSM_put[i,j] = BSM_put_option(x,m[j],T,t,r,n[i])
        l.append(m[j]);k.append(n[i]);
        BSM_call_t.append(BSM_call[i,j]);BSM_put_t.append(BSM_put[i,j])
print ('Strike Price(K)     Sigma    Call Option Price(C(t,x))   Put Option Pric
e(P(t,x))')
for i in range(0,20,2):
    print(round(m[i],6),"         ",round(n[i],6),"              ",round(BSM_cal
l[i,i],6),"                        ",round(BSM_put[i,i],6))
axes = plt.axes(projection ='3d')
X = np.reshape(l, (len(n), len(m)))
Y = np.reshape(k, (len(n), len(m)))
Z = np.reshape(BSM_call_t, (len(n), len(m)))
axes.plot_surface(X, Y, Z,cmap ='plasma', edgecolor ='green')

axes.set_title('3D plot of C(t,x) varying K and sigma' )
axes.set_xlabel('K (Strike Price)')
axes.set_ylabel('sigma')
axes.set_zlabel('C(t,x)')
axes.view_init(40, 60)
plt.show()

axes = plt.axes(projection ='3d')
X = np.reshape(l, (len(n), len(m)))
Y = np.reshape(k, (len(n), len(m)))
Z = np.reshape(BSM_put_t, (len(n), len(m)))
axes.view_init(40, 210)
axes.plot_surface(X, Y, Z, cmap ='viridis', edgecolor='pink')
axes.set_title('3D plot of P(t,x) varying K and sigma' )
axes.set_xlabel('K (Strike Price)')
axes.set_ylabel('sigma')
axes.set_zlabel('P(t,x)')
plt.show()



BSM_call={}
BSM_put={}
m=np.linspace(0.5,1.5,20)
l=[]
n=np.linspace(0,1,20)
k=[]
BSM_call_t=[]
BSM_put_t=[]

for i in range(0,len(n)):
    for j in range(0,len(m)):
        BSM_call[i,j] = BSM_call_option(x,m[j],T,t,n[i],sigma)
```

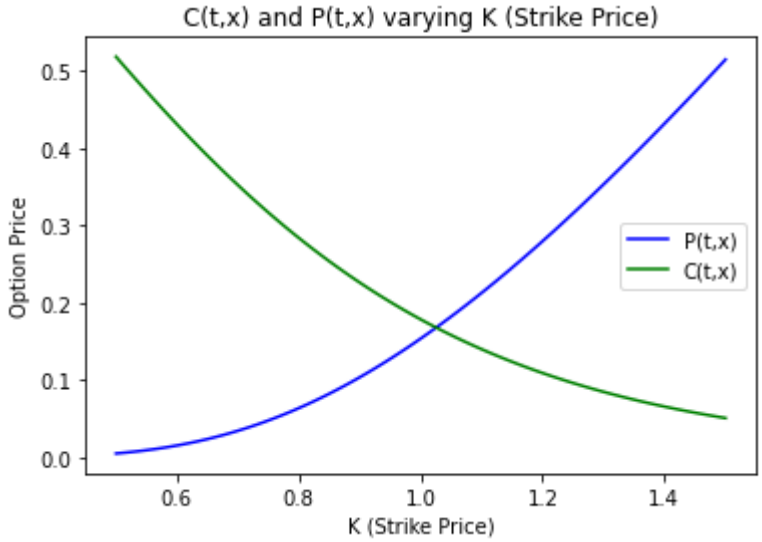
```
        BSM_put[i,j] = BSM_put_option(x,m[j],T,t,n[i],sigma)
        l.append(m[j]);k.append(n[i]);
        BSM_call_t.append(BSM_call[i,j]);BSM_put_t.append(BSM_put[i,j])
print ('Strike Price(K)       Rate        Call Option Price(C(t,x))     Put Opti
on Price(P(t,x))')
for i in range(0,20,2):
    print(round(m[i],6),"         ",round(n[i],6),"              ",round(BSM_cal
l[i,i],6),"                      ",round(BSM_put[i,i],6))

axes = plt.axes(projection ='3d')
X = np.reshape(l, (len(n), len(m)))
Y = np.reshape(k, (len(n), len(m)))
Z = np.reshape(BSM_call_t, (len(n), len(m)))
axes.plot_surface(X, Y, Z,cmap ='plasma', edgecolor ='green')

axes.set_title('3D plot of C(t,x) varying K and r' )
axes.set_xlabel('K (Strike Price)')
axes.set_ylabel('r (rate)')
axes.set_zlabel('C(t,x)')
axes.view_init(40, 60)
plt.show()

axes = plt.axes(projection ='3d')
X = np.reshape(l, (len(n), len(m)))
Y = np.reshape(k, (len(n), len(m)))
Z = np.reshape(BSM_put_t, (len(n), len(m)))
axes.view_init(40, 60)
axes.plot_surface(X, Y, Z, cmap ='viridis', edgecolor='pink')
axes.set_title('3D plot of P(t,x) varying K and r' )
axes.set_xlabel('K (Strike Price)')
axes.set_ylabel('r (rate)')
axes.set_zlabel('P(t,x)')
plt.show()



BSM_call={}
BSM_put={}
m=np.linspace(0.5,1.5,20)
l=[]
n=np.linspace(0.5,5,20)
k=[]
BSM_call_t=[]
BSM_put_t=[]

for i in range(0,len(n)):
    for j in range(0,len(m)):
        BSM_call[i,j] = BSM_call_option(x,m[j],n[i],t,r,sigma)
        BSM_put[i,j] = BSM_put_option(x,m[j],n[i],t,r,sigma)
        l.append(m[j]);k.append(n[i]);
        BSM_call_t.append(BSM_call[i,j]);BSM_put_t.append(BSM_put[i,j])
print ('Strike Price(K)       T      Call Option Price(C(t,x))   Put Option Pric
e(P(t,x))')
for i in range(0,20,2):
    print(round(m[i],6),"         ",round(n[i],6),"              ",round(BSM_cal
l[i,i],6),"                      ",round(BSM_put[i,i],6))

axes = plt.axes(projection ='3d')
X = np.reshape(l, (len(n), len(m)))
Y = np.reshape(k, (len(n), len(m)))
Z = np.reshape(BSM_call_t, (len(n), len(m)))
```

```
axes.plot_surface(X, Y, Z,cmap ='plasma', edgecolor ='green')

axes.set_title('3D plot of C(t,x) varying K and T' )
axes.set_xlabel('K (Strike Price)')
axes.set_ylabel('T (Final Time)')
axes.set_zlabel('C(t,x)')
axes.view_init(40, 60)
plt.show()

axes = plt.axes(projection ='3d')
X = np.reshape(l, (len(n), len(m)))
Y = np.reshape(k, (len(n), len(m)))
Z = np.reshape(BSM_put_t, (len(n), len(m)))
axes.view_init(40, 210)
axes.plot_surface(X, Y, Z, cmap ='viridis', edgecolor='pink')
axes.set_title('3D plot of P(t,x) varying K and T' )
axes.set_xlabel('K (Strike Price)')
axes.set_ylabel('T (Final Time)')
axes.set_zlabel('P(t,x)')
plt.show()



BSM_call={}
BSM_put={}
m=np.linspace(0,1,100)
l=[]
n=np.linspace(0.5,5,20)
k=[]
BSM_call_t=[]
BSM_put_t=[]

for i in range(0,len(n)):
    for j in range(0,len(m)):
        BSM_call[i,j] = BSM_call_option(x,K,n[i],t,m[j],sigma)
        BSM_put[i,j] = BSM_put_option(x,K,n[i],t,m[j],sigma)
        l.append(m[j]);k.append(n[i]);
        BSM_call_t.append(BSM_call[i,j]);BSM_put_t.append(BSM_put[i,j])
print ('Rate         T       Call Option Price(C(t,x))   Put Option Price(P(t,
x))')
for i in range(0,20,2):
    print(round(m[5*i],6),"         ",round(n[i],6),"              ",round(BSM_c
all[i,5*i],6),"                      ",round(BSM_put[i,5*i],6))
axes = plt.axes(projection ='3d')
X = np.reshape(l, (len(n), len(m)))
Y = np.reshape(k, (len(n), len(m)))
Z = np.reshape(BSM_call_t, (len(n), len(m)))
axes.plot_surface(X, Y, Z,cmap ='plasma', edgecolor ='green')

axes.set_title('3D plot of C(t,x) varying r (rate) and T(Final Time)' )
axes.set_xlabel('r (rate)')
axes.set_ylabel('T (Final Time)')
axes.set_zlabel('C(t,x)')

plt.show()

axes = plt.axes(projection ='3d')
X = np.reshape(l, (len(n), len(m)))
Y = np.reshape(k, (len(n), len(m)))
Z = np.reshape(BSM_put_t, (len(n), len(m)))
```

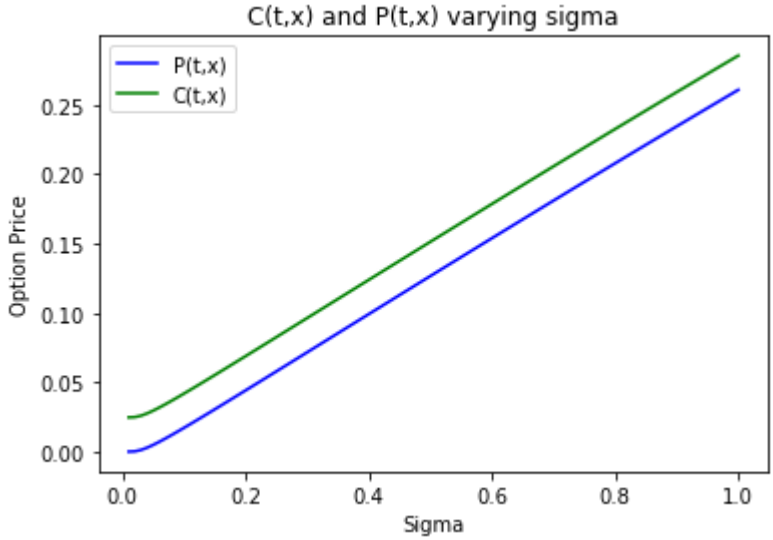
```
axes.plot_surface(X, Y, Z, cmap ='viridis', edgecolor='yellow')
axes.set_title('3D plot of P(t,x) varying with r(rate) and T(Final Time)' )
axes.set_xlabel('r (rate)')
axes.set_ylabel('T (Final Time)')
axes.set_zlabel('P(t,x)')
plt.show()



BSM_call={}
BSM_put={}
m=np.linspace(0,1,100)
l=[]
n=np.linspace(0.01,1,20)
k=[]
BSM_call_t=[]
BSM_put_t=[]

for i in range(0,len(n)):
    for j in range(0,len(m)):
        BSM_call[i,j] = BSM_call_option(x,K,T,t,m[j],n[i])
        BSM_put[i,j] = BSM_put_option(x,K,T,t,m[j],n[i])
        l.append(m[j]);k.append(n[i]);
        BSM_call_t.append(BSM_call[i,j]);BSM_put_t.append(BSM_put[i,j])
print ('Rate             Sigma         Call Option Price(C(t,x))     Put Option
 Price(P(t,x))')
for i in range(0,20,2):
    print(round(m[5*i],6),"         ",round(n[i],6),"              ",round(BSM_c
all[i,5*i],6),"                      ",round(BSM_put[i,5*i],6))
axes = plt.axes(projection ='3d')
X = np.reshape(l, (len(n), len(m)))
Y = np.reshape(k, (len(n), len(m)))
Z = np.reshape(BSM_call_t, (len(n), len(m)))
axes.plot_surface(X, Y, Z,cmap ='viridis', edgecolor ='green')

axes.set_title('3D plot of C(t,x) varying with r and sigma' )
axes.set_xlabel('r (rate)')
axes.set_ylabel('sigma')
axes.set_zlabel('C(t,x)')
axes.view_init(40, 210)
plt.show()

axes = plt.axes(projection ='3d')
X = np.reshape(l, (len(n), len(m)))
Y = np.reshape(k, (len(n), len(m)))
Z = np.reshape(BSM_put_t, (len(n), len(m)))
axes.view_init(40, 30)
axes.plot_surface(X, Y, Z, cmap ='inferno', edgecolor='pink')
axes.set_title('3D plot of P(t,x) varying with r and sigma' )
axes.set_xlabel('r (rate)')
axes.set_ylabel('sigma')
axes.set_zlabel('P(t,x)')
plt.show()


BSM_call={}
BSM_put={}
m=np.linspace(0.5,5,20)
l=[]
n=np.linspace(0.01,1,20)
k=[]
```

```
BSM_call_t=[]
BSM_put_t=[]

for i in range(0,len(n)):
    for j in range(0,len(m)):
        BSM_call[i,j] = BSM_call_option(x,K,T,t,m[j],n[i])
        BSM_put[i,j] = BSM_put_option(x,K,T,t,m[j],n[i])
        l.append(m[j]);k.append(n[i]);
        BSM_call_t.append(BSM_call[i,j]);BSM_put_t.append(BSM_put[i,j])
print ('T      Sigma    Call Option Price(C(t,x))   Put Option Price(P(t,x))')
for i in range(0,20,2):
    print(round(m[i],6),"         ",round(n[i],6),"              ",round(BSM_cal
l[i,i],6),"                      ",round(BSM_put[i,i],6))
axes = plt.axes(projection ='3d')
X = np.reshape(l, (len(n), len(m)))
Y = np.reshape(k, (len(n), len(m)))
Z = np.reshape(BSM_call_t, (len(n), len(m)))
axes.plot_surface(X, Y, Z,cmap ='viridis', edgecolor ='green')

axes.set_title('3D plot of C(t,x) varying with T  and sigma' )
axes.set_xlabel('T (Final Time)')
axes.set_ylabel('sigma')
axes.set_zlabel('C(t,x)')
axes.view_init(40, 210)
plt.show()

axes = plt.axes(projection ='3d')
X = np.reshape(l, (len(n), len(m)))
Y = np.reshape(k, (len(n), len(m)))
Z = np.reshape(BSM_put_t, (len(n), len(m)))
axes.view_init(40, 30)
axes.plot_surface(X, Y, Z, cmap ='inferno', edgecolor='pink')
axes.set_title('3D plot of P(t,x) varying with T  and sigma' )
axes.set_xlabel('T (Final time)')
axes.set_ylabel('sigma')
axes.set_zlabel('P(t,x)')
plt.show()
```

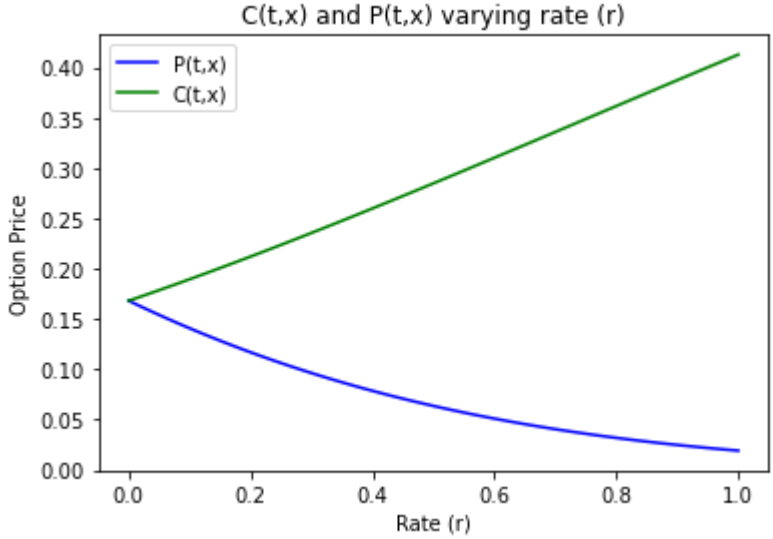
Strike Price(K)	Call Option Price(C(t,x))	Put Option Price (P(t,x))
0.5	0.517768	0.005423
0.60101	0.429708	0.01588
0.70202	0.350549	0.035236
0.80303	0.281857	0.06506
0.90404	0.223993	0.105713
1.005051	0.176399	0.15663
5		
1.106061	0.137972	0.21672
4		
1.207071	0.107382	0.28465
1.308081	0.08329	0.359074
1.409091	0.064463	0.43876
3		



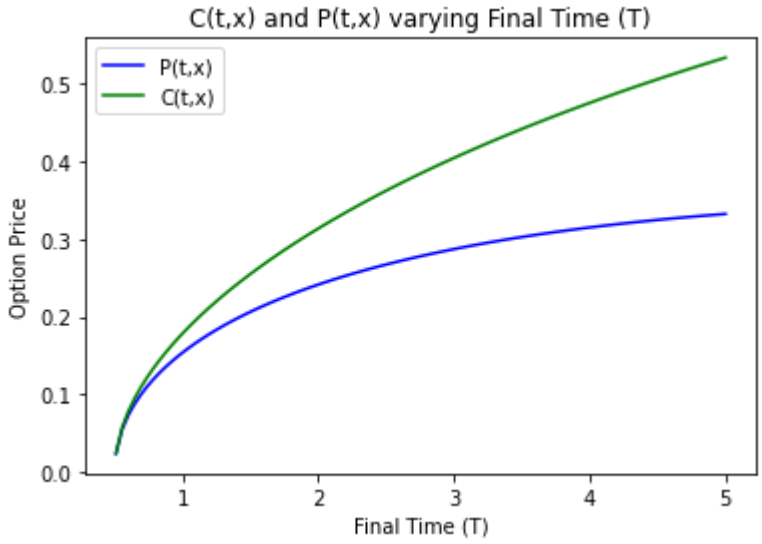
Sigma	Call Option Price(C(t,x))	Put Option Price(P(t,x))
0.01	0.02469	0.0
0.11	0.044553	0.019863
0.21	0.071625	0.046935
0.31	0.0991	0.07441
0.41	0.126597	0.101907
0.51	0.154007	0.129317
0.61	0.181269	0.156579
0.71	0.208339	0.183649
0.81	0.23518	0.21049
0.91	0.261757	0.237067



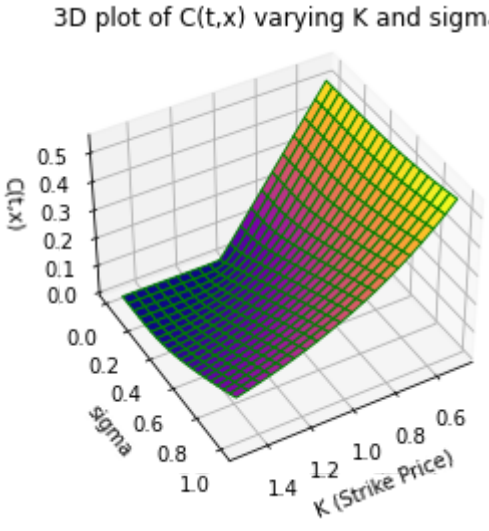
Rate	Call Option Price(C(t,x))	Put Option Price(P(t,x))
0.0	0.167996	0.167996
0.10101	0.189626	0.140376
0.20202	0.212403	0.116327
0.30303	0.236169	0.095574
0.40404	0.260751	0.07783
0.505051	0.285967	0.062804
0.606061	0.311628	0.050204
0.707071	0.337547	0.039748
0.808081	0.363543	0.03116
0.909091	0.389445	0.024182

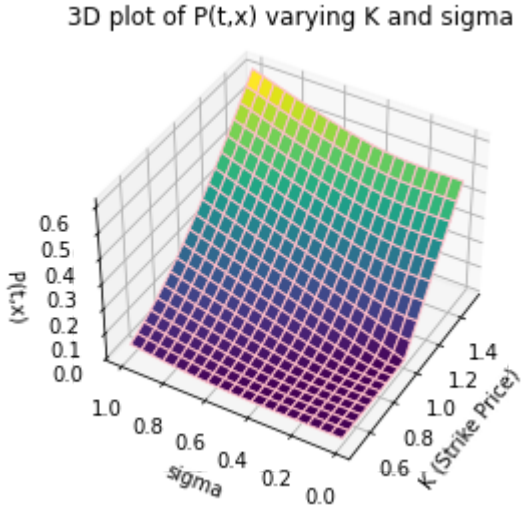


T	Call Option Price(C(t,x))	Put Option Price(P(t,x))
0.51	0.024178	0.023678
0.963535	0.171697	0.148787
1.417071	0.244137	0.199319
1.870606	0.299811	0.233576
2.324141	0.346328	0.259157
2.777677	0.386733	0.279094
3.231212	0.422626	0.29498
3.684747	0.454987	0.30778
4.138283	0.484465	0.318138
4.591818	0.511527	0.326507

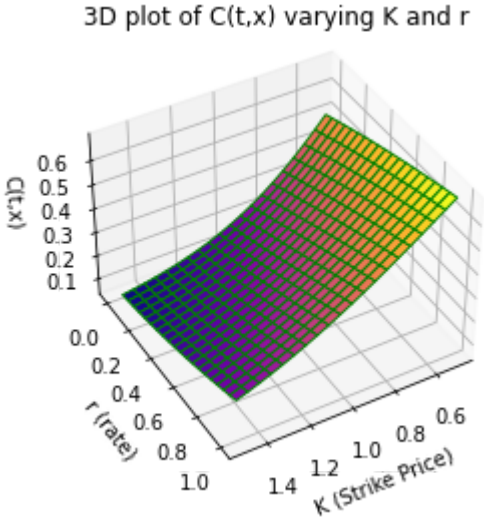


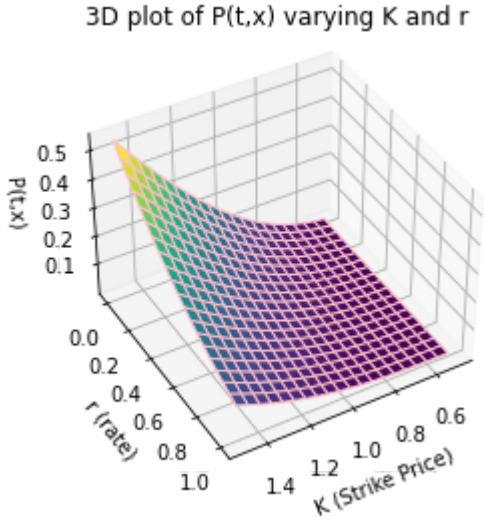
Strike Price(K)	Sigma	Call Option Price(C(t,x))	Put Option Price(P(t,x))
0.5	0.01	0.512345	0.0
0.605263	0.114211	0.409681	0.0
0.710526	0.218421	0.307393	0.000377
0.815789	0.322632	0.221171	0.016819
0.921053	0.426842	0.171749	0.070061
1.026316	0.531053	0.148517	0.149493
1.131579	0.635263	0.139505	0.243145
1.236842	0.739474	0.138476	0.344781
1.342105	0.843684	0.142383	0.451352
1.447368	0.947895	0.149653	0.561285



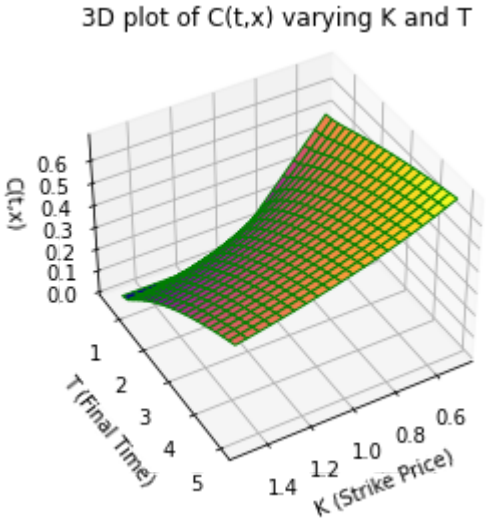


Strike Price(K)	Rate	Call Option Price(C(t,x))	Put Option Price(P(t,x))
0.5	0.0	0.50633	0.00633
0.605263	0.105263	0.439952	0.014183
0.710526	0.210526	0.385594	0.02513
0.815789	0.315789	0.341642	0.038277
0.921053	0.421053	0.306385	0.052583
1.026316	0.526316	0.278251	0.067098
1.131579	0.631579	0.255904	0.081066
1.236842	0.736842	0.238254	0.093933
1.342105	0.842105	0.224432	0.10533
1.447368	0.947368	0.213755	0.115037

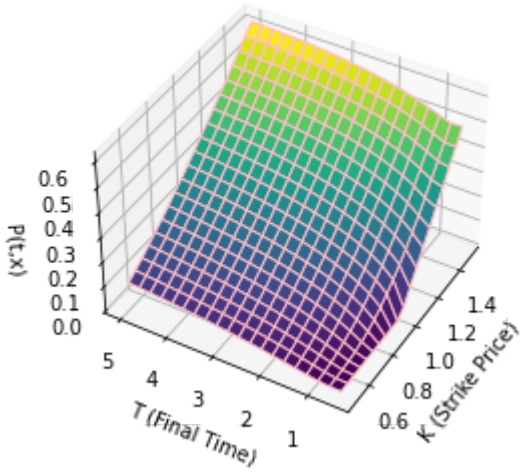




Strike Price(K)	T	Call Option Price(C(t,x))	Put Option Price(P(t,x))
0.5	0.5	0.5	0.0
0.605263	0.973684	0.423979	0.015075
0.710526	1.447368	0.39334	0.070995
0.815789	1.921053	0.382929	0.142766
0.921053	2.394737	0.381812	0.219613
1.026316	2.868421	0.385726	0.297425
1.131579	3.342105	0.392647	0.374325
1.236842	3.815789	0.401475	0.449358
1.342105	4.289474	0.411559	0.52201
1.447368	4.763158	0.422484	0.591999

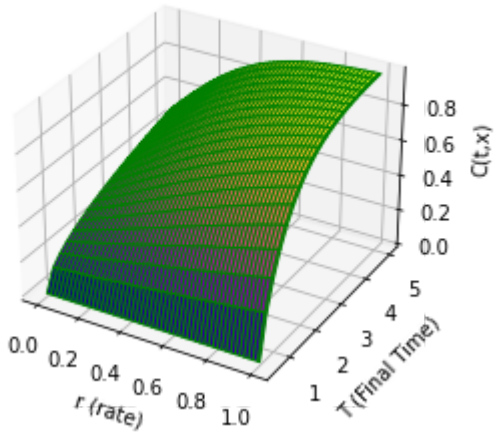


3D plot of P(t,x) varying K and T

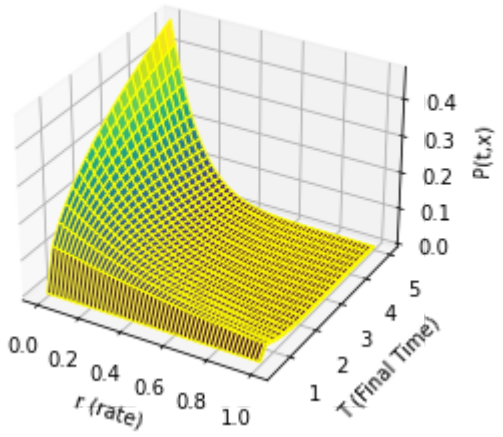


Rate	T	Call Option Price(C(t,x))	Put Option Price(P(t,x))
0.0	0.5	0	0
0.10101	0.973684	0.184174	0.137454
0.20202	1.447368	0.307606	0.133419
0.30303	1.921053	0.443571	0.093675
0.40404	2.394737	0.585992	0.05107
0.505051	2.868421	0.719341	0.021691
0.606061	3.342105	0.828433	0.007054
0.707071	3.815789	0.905814	0.00171
0.808081	4.289474	0.953514	0.000299
0.909091	4.763158	0.979294	3.6e-05

3D plot of C(t,x) varying r (rate) and T(Final Time)

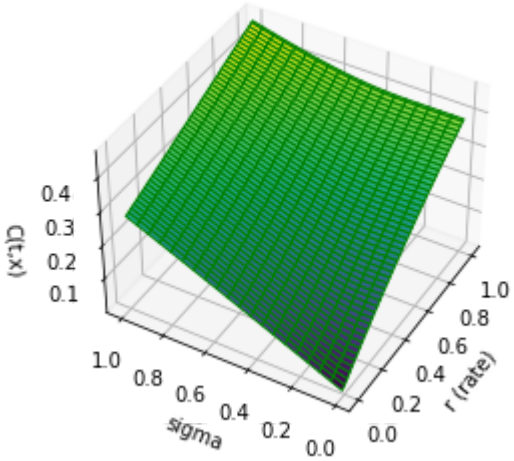


3D plot of P(t,x) varying with r(rate) and T(Final Time)

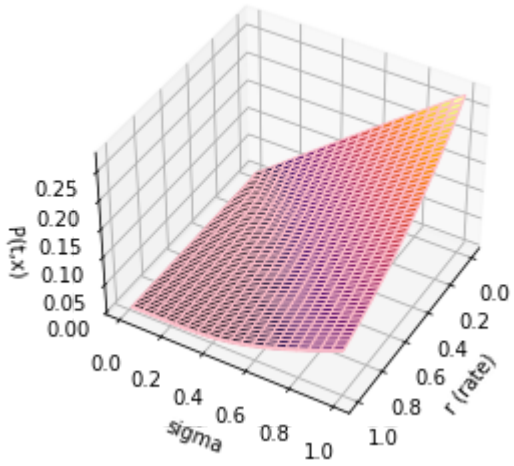


Rate	Sigma	Call Option Price(C(t,x))	Put Option Price(P(t,x))
0.0	0.01	0.002821	0.002821
0.10101	0.114211	0.061988	0.012737
0.20202	0.218421	0.118702	0.022626
0.30303	0.322632	0.172574	0.031979
0.40404	0.426842	0.223708	0.040786
0.505051	0.531053	0.272211	0.049047
0.606061	0.635263	0.318188	0.056765
0.707071	0.739474	0.361744	0.063945
0.808081	0.843684	0.402976	0.070593
0.909091	0.947895	0.441982	0.076719

3D plot of C(t,x) varying with r and sigma

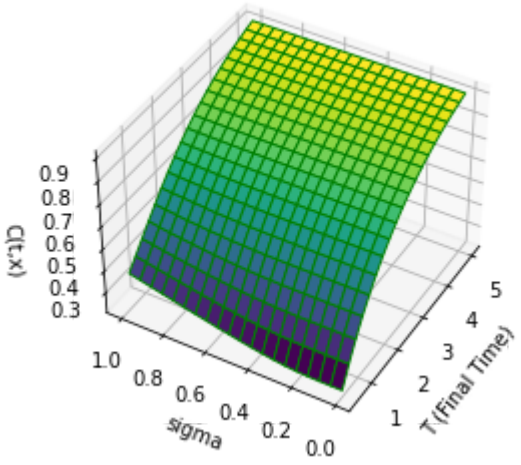


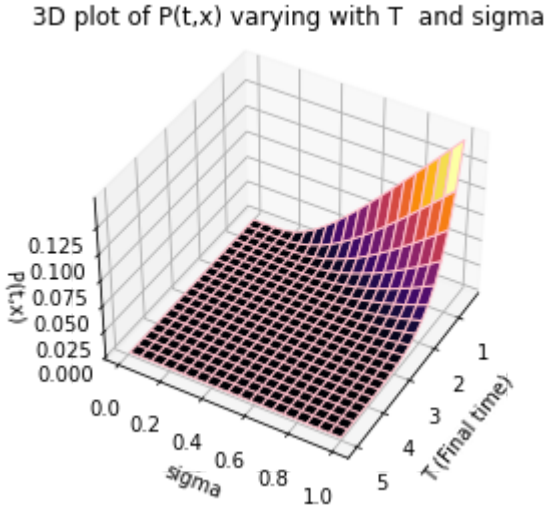
3D plot of P(t,x) varying with r and sigma



T	Sigma	Call Option Price(C(t,x))	Put Option Price(P(t,x))
0.5	0.01	0.221199	
0.0			
0.973684	0.114211	0.385436	
0.0			
1.447368	0.218421	0.515038	
0.0			
1.921053	0.322632	0.617309	
0.0			
2.394737	0.426842	0.698013	
1e-06			
2.868421	0.531053	0.761699	
3e-06			
3.342105	0.635263	0.811956	
5e-06			
3.815789	0.739474	0.851614	
6e-06			
4.289474	0.843684	0.882909	
8e-06			
4.763158	0.947895	0.907605	
9e-06			

3D plot of C(t,x) varying with T and sigma




3D plot of P(t,x) varying with T and sigma
0.125
0.100
0.075
0.050
0.025
0.000
P(t,x)
0.0
0.2
0.4
0.6
0.8
1.0
sigma
1
2
3
4
5
T (Final time)

In [ ]: