

# Group Work Project - M3

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- **Course:** MScFE 620 Discrete-time Stochastic Processes
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```
[1]: # Import helpers
from binomial import binomial_tree, binomial_freq
from filtration import filtration_set
# Import stats
import numpy as np
np.set_printoptions(precision=3, suppress=True) # prettify numpy
import pandas as pd
import matplotlib.pyplot as plt
```

## 1 Question 1) Build a binomial tree for stock price evolution.

Specifically, set the upper movement of the price ( $u$ ) to an expression that will depend on the number on your group.

$$u = (1.10 + \frac{GroupNumber}{100})$$

,

Group 1,  $u = 1.11$ . Group 2 = 1.12. Group 3 = 1.13, ..., Group 50 = 1.60

You can define  $d = 1/u$ .

### 1.1 a) Calculate and show the new Binomial tree for $N=6$ .

```
[2]: # Variables
N = 6 # Number of layers
S0 = 1 # Initial price
group_n = 2 # Group Number 2
```

```
tree_6 = binomial_tree(N, S0, group_n)
stock_prices_6 = tree_6["stock_prices"]
df_stock_price_6 = pd.DataFrame(stock_prices_6)
df_stock_price_6.index.name = 'Time Step'
df_stock_price_6
```

```
[2]:
```

	0	1	2	3	4	5	\
Time Step							
0	1.000000	0.000000	0.000000	0.000000	0.000000	0.000000	
1	0.892857	1.120000	0.000000	0.000000	0.000000	0.000000	
2	0.797194	1.000000	1.254400	0.000000	0.000000	0.000000	
3	0.711780	0.892857	1.120000	1.404928	0.000000	0.000000	
4	0.635518	0.797194	1.000000	1.254400	1.573519	0.000000	
5	0.567427	0.711780	0.892857	1.120000	1.404928	1.762342	
6	0.506631	0.635518	0.797194	1.000000	1.254400	1.573519	

```

          6
Time Step
0          0.000000
1          0.000000
2          0.000000
3          0.000000
4          0.000000
5          0.000000
6          1.973823

```

```
[3]: ### b) What are the terminal values of each path?
df_stock_price_6.iloc[-1]
```

```
[3]: 0    0.506631
     1    0.635518
     2    0.797194
     3    1.000000
     4    1.254400
     5    1.573519
     6    1.973823
     Name: 6, dtype: float64
```

### 1.1.1 b) Define the appropriate filtrations for each of these values.

To define the filtration  $\mathbb{F}$ , we first define a stochastic process  $S = \{S_t : t = 1, \dots, T\}$  where:

$$S_t(\omega) = \omega_n, \omega \in \Omega, n \in \{1, \dots, 2^T\}$$

Define a filtration  $\mathbb{F} = \{\mathcal{F}_t : t = 1, \dots, T\}$  where  $\mathcal{F}_T$  is the natural filtration of  $S$ .

$$\mathcal{F}_T = \sigma(\{S_t : t \leq T\})$$

Specifically, in our binomial model with  $T = 6$ :

- $\mathcal{F}_0 = \{\emptyset, \Omega\}$
- $\mathcal{F}_1 = \sigma(\{w_1, \dots, w_{16}\}, \{w_{17}, \dots, w_{32}\}, \{w_{33}, \dots, w_{48}\}, \{w_{49}, \dots, w_{64}\})$
- $\mathcal{F}_2 = \sigma(\{w_1, \dots, w_8\}, \{w_9, \dots, w_{16}\}, \{w_{17}, \dots, w_{24}\}, \{w_{25}, \dots, w_{32}\}, \{w_{33}, \dots, w_{40}\}, \{w_{41}, \dots, w_{48}\}, \{w_{49}, \dots, w_{56}\}, \{w_{57}, \dots, w_{64}\})$
- $\mathcal{F}_3 = \sigma(\{w_1, \dots, w_4\}, \{w_5, \dots, w_8\}, \{w_9, \dots, w_{12}\}, \{w_{13}, \dots, w_{16}\}, \{w_{17}, \dots, w_{20}\}, \{w_{21}, \dots, w_{24}\}, \{w_{25}, \dots, w_{28}\}, \{w_{29}, \dots, w_{32}\})$
- $\mathcal{F}_4 = \sigma(\{w_1, w_2\}, \{w_3, w_4\}, \{w_5, w_6\}, \{w_7, w_8\}, \{w_9, w_{10}\}, \{w_{11}, w_{12}\}, \{w_{13}, w_{14}\}, \{w_{15}, w_{16}\}, \{w_{17}, w_{18}\}, \{w_{19}, w_{20}\})$
- $\mathcal{F}_5 = \mathcal{F} = 2^\Omega$

[4]: *### b) Define the appropriate filtrations for each of these values.*

```
print("Sampling first 3 filtrations:\n")
S0 = 1
u = 1.12
d = 1/u
N = 3
for i in range(N):
    print(f"\tF{i} = {filtration_set(S0,u,d,N,i)}\n")
```

Sampling first 3 filtrations:

```
F0 = [()], ([1.4049280000000004, 1.12, 1.12, 0.8928571428571428, 1.12,
0.8928571428571428, 0.8928571428571429, 0.711780247813411],)]
```

```
F1 = [()], ([1.4049280000000004, 1.12, 1.12, 0.8928571428571428],),
([1.12, 0.8928571428571428, 0.8928571428571429, 0.711780247813411],),
([1.4049280000000004, 1.12, 1.12, 0.8928571428571428], [1.12,
0.8928571428571428, 0.8928571428571429, 0.711780247813411]))
```

```
F2 = [()], ([1.4049280000000004, 1.12],), ([1.12, 0.8928571428571428],),
([1.12, 0.8928571428571428],), ([0.8928571428571429, 0.711780247813411],),
([1.4049280000000004, 1.12], [1.12, 0.8928571428571428]), ([1.4049280000000004,
1.12], [1.12, 0.8928571428571428]), ([1.4049280000000004, 1.12],
[0.8928571428571429, 0.711780247813411]), ([1.12, 0.8928571428571428], [1.12,
0.8928571428571428]), ([1.12, 0.8928571428571428], [0.8928571428571429,
0.711780247813411]), ([1.12, 0.8928571428571428], [0.8928571428571429,
0.711780247813411]), ([1.4049280000000004, 1.12], [1.12, 0.8928571428571428],
[1.12, 0.8928571428571428]), ([1.4049280000000004, 1.12], [1.12,
0.8928571428571428], [0.8928571428571429, 0.711780247813411]),
([1.4049280000000004, 1.12], [1.12, 0.8928571428571428], [0.8928571428571429,
0.711780247813411]), ([1.12, 0.8928571428571428], [1.12, 0.8928571428571428],
[0.8928571428571429, 0.711780247813411]), ([1.4049280000000004, 1.12], [1.12,
0.8928571428571428], [1.12, 0.8928571428571428], [0.8928571428571429,
0.711780247813411]))
```

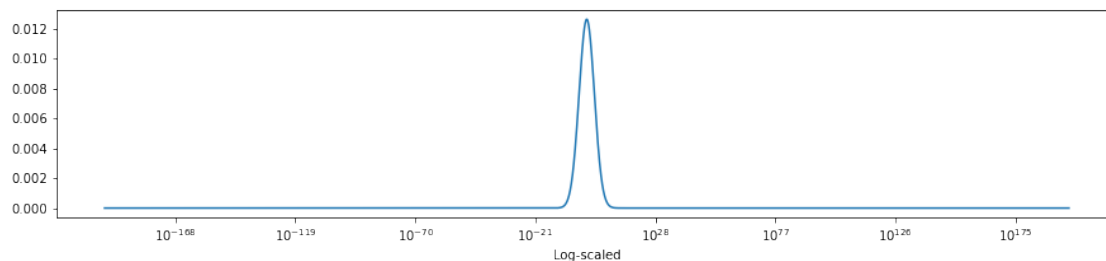
**2 Question 2) Finally, recalculate the tree for N=4,000.**

## 2.1 a) Plot the terminal prices produced by the model

```
[5]: # Variables
S0 = 1 # Initial Price
N = 4000 # number of layers
group_n = 2 # Group Number 2
# Recreate the tree
tree_4000 = binomial_tree(N, S0, group_n)
stock_prices_4000 = tree_4000["stock_prices"]
# Mangling
df_P_4000 = pd.DataFrame(stock_prices_4000)
P_4000 = df_P_4000.iloc[-1:].to_numpy()
```

```
[6]: # Calculate the frequency
freq_arr = binomial_freq(N, relative=True)
```

```
[7]: # Plot
fig, ax = plt.subplots(
    figsize=(15,3)
)
ax.plot(
    P_4000[0],
    freq_arr
)
ax.set_xscale('log')
ax.set_xlabel('Log-scaled')
plt.show()
```



## 2.2 b) Can you identify what type of statistical distribution do these prices resemble to?

After a log-rescale of the x-axis, the post-rescale prices resemble a normal distribution. Hence, the prices themselves resemble a log-normal distribution.

## 2.3 c) Which statistical distribution would Returns follow, that is, using a log-function from previous prices? Indicate the appropriate Probability Density Function for it.

### 2.3.1 Case 1: if we defined $Return = \ln(\frac{Price_t}{Price_{t-1}})$

In this case, then *Returns* are either (roughly)  $u - 1 \approx .12$  or  $1 - d \approx -.12$ .

Its distribution is:

$$\begin{aligned} p_{Returns}(u - 1) &= p_{Returns}(.12) = \mathbb{P}(Returns = .12) = p \\ p_{Returns}(1 - d) &= p_{Returns}(-.12) = \mathbb{P}(Returns = -.12) = 1 - p \end{aligned}$$

where  $p$  is the probability of an up-movement.

### 2.3.2 Case 2: if we defined $Return = \ln(\frac{Price_t}{Price_0})$

then its distribution is the normal distribution,

and its PDF is, accordingly:

$$p_{Returns}(x) = \varphi(x) = \frac{e^{-\frac{1}{2}x^2}}{\sqrt{2\pi}}$$

## 3 Question 3)

### 3.1 a) How many fundamental securities are there in the market?

There are many fundamental securities in the markets:

- Cash & Cash equivalents
- Accounts Receivable / Notes Receivables
- Fixed Deposits
- Equity Shares
- Debentures/ Bonds
- Preference Shares
- Mutual Funds
- Interests in subsidiaries, associates and joint ventures
- Insurance contracts
- Rights and Obligations under leases
- Share-Based Payments

### 3.2 b) At any given node, how many states of the world are there in the binomial tree?

Each node represents 2 states of the world:

- The state where the price goes up
- The state where the price goes down

### 3.3 c) Define market completeness using parts a and b

A complete market is one where contracts can be made to gamble on all states of the world using the existing instruments

**3.4 d) Suppose the underlying stock price jumped. By jumps, we mean that it moves by a factor larger than  $u$  (or smaller than  $d$ ) from 1 node to the next. Would that market still be complete? Why or why not?**

That market is still complete.

- If the price has increased by a factor larger than  $u$ , then it has also increased (at least)  $u$ . That state of the world is still represented in the model.
- If the price has decreased by a factor larger than  $d$ , then it has also decreased (at least)  $d$ . That state of the world is still represented in the model.

## **4 References**

- [Complete Market - Defintions.net](#)