

Black-Scholes model

Using the binomial option pricing model

Using the binomial option pricing model

- ▶ In each time step, the price of the asset will either increase to uS

Using the binomial option pricing model

- In each time step, the price of the asset will either increase to uS or decrease to dS

Using the binomial option pricing model

- ▶ In each time step, the price of the asset will either increase to uS or decrease to dS
- ▶ The **probability** that the price increases is p

Using the binomial option pricing model

- ▶ In each time step, the price of the asset will either increase to uS or decrease to dS
- ▶ The probability that the price increases is p
- ▶ The price will therefore have a **binomial distribution**

Using the binomial option pricing model

- ▶ In each time step, the price of the asset will either increase to uS or decrease to dS
- ▶ The probability that the price increases is p
- ▶ The price will therefore have a binomial distribution
- ▶ For a given time period, the number of steps is **increased**

Using the binomial option pricing model

- ▶ In each time step, the price of the asset will either increase to uS or decrease to dS
- ▶ The probability that the price increases is p
- ▶ The price will therefore have a binomial distribution
- ▶ For a given time period, the number of steps is increased with the size of asset price increases and decreases becoming **smaller**

Using the binomial option pricing model

- ▶ In each time step, the price of the asset will either increase to uS or decrease to dS
- ▶ The probability that the price increases is p
- ▶ The price will therefore have a binomial distribution
- ▶ For a given time period, the number of steps is increased with the size of asset price increases and decreases becoming smaller
- ▶ Asset increases and decreases are symmetric: $u = \frac{1}{d}$

Using the binomial option pricing model

- ▶ In each time step, the price of the asset will either increase to uS or decrease to dS
- ▶ The probability that the price increases is p
- ▶ The price will therefore have a binomial distribution
- ▶ For a given time period, the number of steps is increased with the size of asset price increases and decreases becoming smaller
- ▶ Asset increases and decreases are symmetric: $u = \frac{1}{d}$
- ⇒ Asset prices become **log-normally distributed**

Using the binomial option pricing model

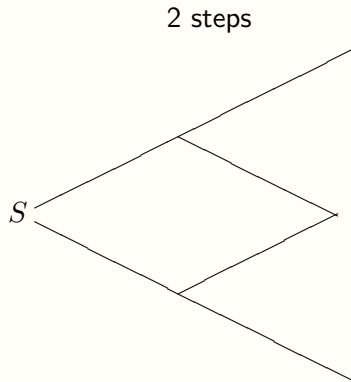
- ▶ In each time step, the price of the asset will either increase to uS or decrease to dS
- ▶ The probability that the price increases is p
- ▶ The price will therefore have a binomial distribution
- ▶ For a given time period, the number of steps is increased with the size of asset price increases and decreases becoming smaller
- ▶ Asset increases and decreases are symmetric: $u = \frac{1}{d}$
- ⇒ Asset prices become log-normally distributed

Increasing the number of steps per time period

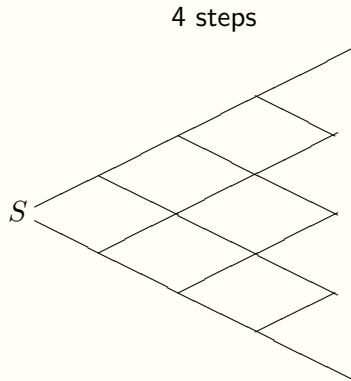
Increasing the number of steps per time period

S

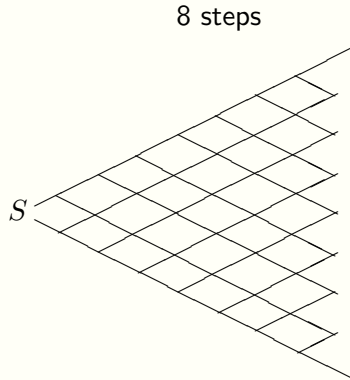
Increasing the number of steps per time period



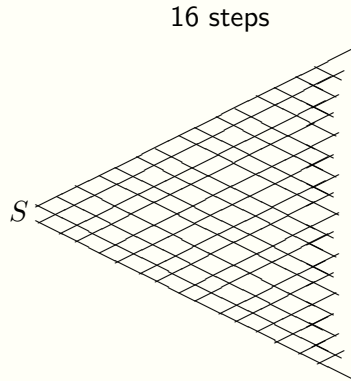
Increasing the number of steps per time period



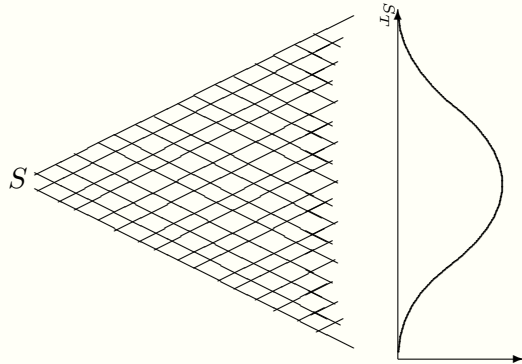
Increasing the number of steps per time period



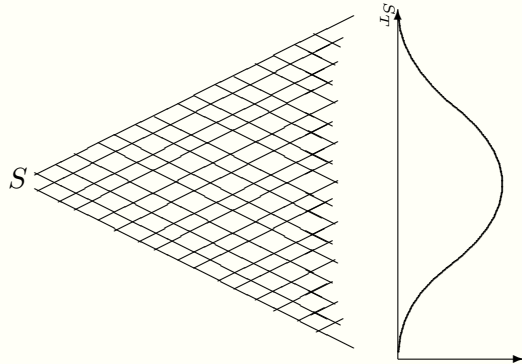
Increasing the number of steps per time period



Increasing the number of steps per time period



Increasing the number of steps per time period



The Black-Scholes formula

The Black-Scholes formula

- ▶ For a large number of steps in the binomial option pricing formula then **converges** to

The Black-Scholes formula

- ▶ For a large number of steps in the binomial option pricing formula then converges to

- ▶ $C = SN(d_1) - Ke^{-rT}N(d_2)$

$$d_1 = \frac{\ln \frac{S}{K} + (r + \frac{1}{2}\sigma^2)T}{\sigma\sqrt{T}}$$

$$d_2 = d_1 - \sigma\sqrt{T}$$

The Black-Scholes formula

- ▶ For a large number of steps in the binomial option pricing formula then converges to
- ▶ $C = SN(d_1) - Ke^{-rT}N(d_2)$
$$d_1 = \frac{\ln \frac{S}{K} + (r + \frac{1}{2}\sigma^2)T}{\sigma\sqrt{T}}$$
$$d_2 = d_1 - \sigma\sqrt{T}$$
- ▶ This is known as the **Black-Scholes formula** of option pricing

The Black-Scholes formula

- ▶ For a large number of steps in the binomial option pricing formula then converges to
- ▶ $C = SN(d_1) - Ke^{-rT}N(d_2)$
$$d_1 = \frac{\ln \frac{S}{K} + (r + \frac{1}{2}\sigma^2)T}{\sigma\sqrt{T}}$$
$$d_2 = d_1 - \sigma\sqrt{T}$$
- ▶ This is known as the Black-Scholes formula of option pricing
- ▶ The **variance of the asset** replaces the size of the increases and decreases of the asset values

The Black-Scholes formula

- ▶ For a large number of steps in the binomial option pricing formula then converges to

- ▶ $C = SN(d_1) - Ke^{-rT}N(d_2)$

$$d_1 = \frac{\ln \frac{S}{K} + (r + \frac{1}{2}\sigma^2)T}{\sigma\sqrt{T}}$$

$$d_2 = d_1 - \sigma\sqrt{T}$$

- ▶ This is known as the Black-Scholes formula of option pricing
- ▶ The variance of the asset replaces the size of the increases and decreases of the asset values: $u = \frac{1}{d} = e^{\sigma\sqrt{\frac{T}{N}}}$

The Black-Scholes formula

- ▶ For a large number of steps in the binomial option pricing formula then converges to
- ▶ $C = S N(d_1) - K e^{-rT} N(d_2)$
$$d_1 = \frac{\ln \frac{S}{K} + (r + \frac{1}{2}\sigma^2)T}{\sigma\sqrt{T}}$$
$$d_2 = d_1 - \sigma\sqrt{T}$$
- ▶ This is known as the Black-Scholes formula of option pricing
- ▶ The variance of the asset replaces the size of the increases and decreases of the asset values: $u = \frac{1}{d} = e^{\sigma\sqrt{\frac{T}{N}}}$
- ▶ The asset price changes are replaced by the **cumulative normal distribution**

The Black-Scholes formula

- ▶ For a large number of steps in the binomial option pricing formula then converges to
- ▶ $C = SN(d_1) - Ke^{-rT}N(d_2)$
$$d_1 = \frac{\ln \frac{S}{K} + (r + \frac{1}{2}\sigma^2)T}{\sigma\sqrt{T}}$$
$$d_2 = d_1 - \sigma\sqrt{T}$$
- ▶ This is known as the Black-Scholes formula of option pricing
- ▶ The variance of the asset replaces the size of the increases and decreases of the asset values: $u = \frac{1}{d} = e^{\sigma\sqrt{\frac{T}{N}}}$
- ▶ The asset price changes are replaced by the cumulative normal distribution

Similarity of Black-Scholes formula and binomial option pricing

Similarity of Black-Scholes formula and binomial option pricing

- ▶ The structure of the results from binomial option pricing are **retained**

Similarity of Black-Scholes formula and binomial option pricing

- ▶ The structure of the results from binomial option pricing are retained
- ▶ Black-Scholes formula: $C = SN(d_1) - Ke^{-rT}N(d_2)$

Similarity of Black-Scholes formula and binomial option pricing

- ▶ The structure of the results from binomial option pricing are retained
- ▶ Black-Scholes formula: $C = SN(d_1) - Ke^{-rT}N(d_2)$
- ▶ Binomial option pricing formula: $C = \Delta S + B$

Similarity of Black-Scholes formula and binomial option pricing

- ▶ The structure of the results from binomial option pricing are retained
- ▶ Black-Scholes formula: $C = S N(d_1) - K e^{-rT} N(d_2)$
- ▶ Binomial option pricing formula: $C = \Delta S + B$
- ▶ The option price is composed of a **number of underlying assets**

Similarity of Black-Scholes formula and binomial option pricing

- ▶ The structure of the results from binomial option pricing are retained
- ▶ Black-Scholes formula: $C = S N(d_1) - K e^{-rT} N(d_2)$
- ▶ Binomial option pricing formula: $C = \Delta S + B$
- ▶ The option price is composed of a **number of underlying assets** and a **loan** to finance the holding of these assets

Similarity of Black-Scholes formula and binomial option pricing

- ▶ The structure of the results from binomial option pricing are retained
- ▶ Black-Scholes formula: $C = SN(d_1) - Ke^{-rT}N(d_2)$
- ▶ Binomial option pricing formula: $C = \Delta S + B$
- ▶ The option price is composed of a number of underlying assets and a loan to finance the holding of these assets

Replicating options

Replicating options

- ▶ Options are **written** by some investors to obtain the premium as revenue

Replicating options

- ▶ Options are written by some investors to obtain the premium as revenue, often banks

Replicating options

- ▶ Options are written by some investors to obtain the premium as revenue, often banks, **insurance companies**

Replicating options

- Options are written by some investors to obtain the premium as revenue, often banks, insurance companies, or **hedge funds**

Replicating options

- ▶ Options are written by some investors to obtain the premium as revenue, often banks, insurance companies, or hedge funds
- ▶ This exposes them to **risks** if the price movement of the underlying asset causes the option to be exercised

Replicating options

- ▶ Options are written by some investors to obtain the premium as revenue, often banks, insurance companies, or hedge funds
- ▶ This exposes them to risks if the price movement of the underlying asset causes the option to be exercised
- ▶ **Option writers** may want to hedge their risks

Replicating options

- ▶ Options are written by some investors to obtain the premium as revenue, often banks, insurance companies, or hedge funds
- ▶ This exposes them to risks if the price movement of the underlying asset causes the option to be exercised
- ▶ Option writers may want to hedge their risks
- ▶ If **creating their own option**, they can develop an off-setting position

Replicating options

- ▶ Options are written by some investors to obtain the premium as revenue, often banks, insurance companies, or hedge funds
- ▶ This exposes them to risks if the price movement of the underlying asset causes the option to be exercised
- ▶ Option writers may want to hedge their risks
- ▶ If creating their own option, they can develop an off-setting position
- ▶ They can do so by holding $N(d_1)$ of the underlying asset

Replicating options

- ▶ Options are written by some investors to obtain the premium as revenue, often banks, insurance companies, or hedge funds
- ▶ This exposes them to risks if the price movement of the underlying asset causes the option to be exercised
- ▶ Option writers may want to hedge their risks
- ▶ If creating their own option, they can develop an off-setting position
- ▶ They can do so by holding $N(d_1)$ of the underlying asset and obtain a loan of $Ke^{-rT}N(d_2)$

Replicating options

- ▶ Options are written by some investors to obtain the premium as revenue, often banks, insurance companies, or hedge funds
- ▶ This exposes them to risks if the price movement of the underlying asset causes the option to be exercised
- ▶ Option writers may want to hedge their risks
- ▶ If creating their own option, they can develop an off-setting position
- ▶ They can do so by holding $N(d_1)$ of the underlying asset and obtain a loan of $Ke^{-rT}N(d_2)$
- ▶ This is known as **option replication**

Replicating options

- ▶ Options are written by some investors to obtain the premium as revenue, often banks, insurance companies, or hedge funds
- ▶ This exposes them to risks if the price movement of the underlying asset causes the option to be exercised
- ▶ Option writers may want to hedge their risks
- ▶ If creating their own option, they can develop an off-setting position
- ▶ They can do so by holding $N(d_1)$ of the underlying asset and obtain a loan of $Ke^{-rT}N(d_2)$
- ▶ This is known as option replication



Copyright © by Andreas Krause

Picture credits:

Cover: Premier regard, Public domain, via Wikimedia Commons, [https://commons.wikimedia.org/wiki/File:DALL-E_-_Financial_markets_\(1\).jpg](https://commons.wikimedia.org/wiki/File:DALL-E_-_Financial_markets_(1).jpg)

Back: Rhododendrites, CC BY-SA 4.0 <https://creativecommons.org/licenses/by-sa/4.0>, via Wikimedia Commons, [https://upload.wikimedia.org/wikipedia/commons/0/04/Manhattan_at_night_south_of_Rockefeller_Center_panorama_\(11263p\).jpg](https://upload.wikimedia.org/wikipedia/commons/0/04/Manhattan_at_night_south_of_Rockefeller_Center_panorama_(11263p).jpg)

Andreas Krause
Department of Economics
University of Bath
Claverton Down
Bath BA2 7AY
United Kingdom

E-mail: mnsak@bath.ac.uk