

Mathematics Behind the Options Calculator

Pheneas Newman

October 4, 2025

1 European Call

$$C = Se^{-qT}\Phi(d_1) - Ke^{-rT}\Phi(d_2)$$

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

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

$$\boxed{Se^{-qT}\phi(d_1) = Ke^{-rT}\phi(d_2)} \quad (\text{Black-Scholes identity})$$

C Option price

S Spot price

K Strike price

q Dividend rate

T Time to maturity

r Risk-free rate

σ Volatility

Φ Standard normal CDF

ϕ Standard normal pdf

1.1 Delta

$$\boxed{\Delta = \frac{\partial C}{\partial S} = e^{-qT}\Phi(d_1)}$$

$$\Delta = \frac{\partial C}{\partial S} = e^{-qT}\Phi(d_1) + Se^{-qT}\phi(d_1)\left(\frac{\partial d_1}{\partial S}\right) - Ke^{-rT}\phi(d_2)\left(\frac{\partial d_2}{\partial S}\right)$$

$$= e^{-qT}\Phi(d_1) + \underbrace{Se^{-qT}\phi(d_1)\frac{1}{S\sigma\sqrt{T}} - Ke^{-rT}\phi(d_2)\frac{1}{S\sigma\sqrt{T}}}_{=0}$$

$$\Delta = e^{-qT}\Phi(d_1)$$

1.2 Gamma

$$\Gamma = \frac{\partial^2 C}{\partial S^2} = e^{-qT} (\phi(d_1) \frac{1}{S\sigma\sqrt{T}})$$

$$\begin{aligned}\Gamma &= \frac{\partial^2 C}{\partial S^2} = \frac{\partial \Delta}{\partial S} \\ &= e^{-qT} \frac{\partial}{\partial S} (\Phi(d_1)) \\ \Gamma &= e^{-qT} \phi(d_1) \frac{1}{S\sigma\sqrt{T}}\end{aligned}$$

1.3 Vega

$$\nu = \frac{\partial C}{\partial \sigma} = S e^{-qT} \phi(d_1) \sqrt{T}$$

$$\nu = \frac{\partial C}{\partial \sigma} = S e^{-qT} \phi(d_1) \left(\frac{\partial d_1}{\partial \sigma} \right) - K e^{-rT} \phi(d_2) \left(\frac{\partial d_2}{\partial \sigma} \right)$$

$$\frac{\partial d_1}{\partial \sigma} = \frac{\partial}{\partial \sigma} \left(\frac{\ln(\frac{S}{K})}{\sigma\sqrt{T}} + \frac{T(r-q)}{\sigma\sqrt{T}} \right) + \frac{1}{2}\sqrt{T}$$

$$\frac{\partial d_2}{\partial \sigma} = \frac{\partial}{\partial \sigma} \left(\frac{\ln(\frac{S}{K})}{\sigma\sqrt{T}} + \frac{T(r-q)}{\sigma\sqrt{T}} \right) - \frac{1}{2}\sqrt{T}$$

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

$$\nu = S e^{-qT} \phi(d_1) \sqrt{T}$$

1.4 Theta

$$\Theta = 35$$

$$\Theta = \frac{\partial C}{\partial T} = S \left(-q e^{-qT} \Phi(d_1) + e^{-qT} \phi(d_1) \frac{\partial d_1}{\partial T} \right) - K \left(-r e^{-rT} \Phi(d_2) + e^{-rT} \phi(d_2) - \frac{\partial d_2}{\partial T} \right)$$

1.5 Rho

3 Binary Call (Cash-or-Nothing)

$$\begin{aligned}C_{\text{bin}} &= Q e^{-rT} \Phi(d_2) \\d_1 &= \frac{\ln\left(\frac{S}{K}\right) + (r - q + \frac{1}{2}\sigma^2)T}{\sigma\sqrt{T}} \\d_2 &= d_1 - \sigma\sqrt{T}\end{aligned}$$

3.1 Delta

3.2 Gamma

3.3 Vega

3.4 Theta

3.5 Rho

4 Binary Put (Cash-or-Nothing)

$$\begin{aligned}P_{\text{bin}} &= Q e^{-rT} \Phi(-d_2) \\d_1 &= \frac{\ln\left(\frac{S}{K}\right) + (r - q + \frac{1}{2}\sigma^2)T}{\sigma\sqrt{T}} \\d_2 &= d_1 - \sigma\sqrt{T}\end{aligned}$$

4.1 Delta

4.2 Gamma

4.3 Vega

4.4 Theta

4.5 Rho

5 American Call

$$C^A = \sup_{\tau \in \mathcal{T}[0, T]} \mathbb{E}^{\mathbb{Q}}[e^{-r\tau} (S_{\tau} - K)^+]$$

(equals the European call when $q = 0$, since early exercise has no value).

5.1 Delta

5.2 Gamma

5.3 Vega

5.4 Theta

5.5 Rho

