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## cf\_putupout

Reiner-Rubinstein [1] have developed formulas for pricing standard barrier options:

Let

- $T$  = maturity date ( $T > t$ )
- $K$  = strike price
- $L$  = up barrier
- $R$  = rebate
- $x$  = spot price
- $t$  = pricing date
- $\sigma$  = volatility
- $r$  = interest rate
- $\delta$  = dividend yields
- $\theta = T - t$
- $b = r - \delta$

We set here:

- $A = \phi x e^{-\delta\theta} N(\phi x_1) - \phi K e^{-r\theta} N(\phi x_1 - \phi\sigma\sqrt{\theta})$
- $B = \phi x e^{-\delta\theta} N(\phi x_2) - \phi K e^{-r\theta} N(\phi x_2 - \phi\sigma\sqrt{\theta})$
- $C = \phi x (\frac{L}{x})^{2(\mu+1)} e^{-\delta\theta} N(\eta y_1) - \phi K e^{-r\theta} (\frac{L}{x})^{2\mu} N(\eta y_1 - \eta\sigma\sqrt{\theta})$
- $D = \phi x (\frac{L}{x})^{2(\mu+1)} e^{-\delta\theta} N(\eta y_2) - \phi K e^{-r\theta} (\frac{L}{x})^{2\mu} N(\eta y_2 - \eta\sigma\sqrt{\theta})$
- $E = R e^{-r\theta} \left[ N(\eta x_2 - \eta\sigma\sqrt{\theta}) - (\frac{L}{x})^{2\mu} N(\eta y_2 - \eta\sigma\sqrt{\theta}) \right]$
- $F = R (\frac{L}{x})^{\mu+\lambda} N(\eta z) + (\frac{L}{x})^{\mu-\lambda} N(\eta z - 2\eta\lambda\sigma\sqrt{\theta})$

and

- $dA = \phi e^{-\delta\theta} N(\phi x_1)$
- $dB = \phi e^{-\delta\theta} N(\phi x_2) + e^{-\delta\theta \frac{n(x_2)}{\sigma\sqrt{\theta}}} (1 - \frac{k}{l})$
- $dC = \frac{1}{x} \phi 2\mu \left[ \frac{L}{x} \right]^{2\mu} \left( x e^{-\delta\theta \frac{L^2}{x^2}} N(\eta y_1) - K e^{-r\theta} N(\eta y_1 - \eta \sigma \sqrt{\theta}) - \phi \left( \frac{L}{x} \right)^{2(\mu+1)} e^{-b\theta} N(\eta y_1) \right)$
- $dD = -2\mu \frac{\phi}{x} \left[ \frac{L}{x} \right]^{2\mu} \left( s e^{-\delta\theta \frac{L^2}{x^2}} N(\eta y_2) - K e^{-r\theta} N(\eta y_2) \times \right. \\ \left. \times N \left( \eta y_2 - \eta \sigma \sqrt{\theta} - \phi \left( \frac{L}{x} \right)^{2\mu+2} e^{-\delta\theta} \right) N(\eta y_2) - \phi \eta \left( \frac{L}{x} \right)^{2\mu+2} e^{-\delta\theta} \right) \times \\ \left. \times \frac{n(y_2)}{\sigma\sqrt{\theta}} \left( 1 - \frac{k}{l} \right) \right)$
- $dE = 2 \frac{R}{x} e^{-r\theta} \left( \frac{L}{x} \right)^{2\mu} \left[ N(\eta y_2 - \eta \sigma \sqrt{\theta}) \mu + \eta \frac{n(\eta y_2 - \sigma \sqrt{\theta})}{\sigma\sqrt{\theta}} \right]$
- $dF = -\frac{R}{x} \left( \frac{L}{x} \right)^{\mu+\lambda} \left[ (\mu + \lambda) N(\eta z) + (\mu - \lambda) \left( \frac{L}{x} \right)^{2\lambda} \right] - 2\eta R \left( \frac{L}{x} \right)^{\mu+\lambda} \frac{n(z)}{x\sigma\sqrt{\theta}}$

where

- $x_1 = \frac{\log(x/K)}{\sigma\sqrt{\theta}} + (1 + \mu)\sigma\sqrt{\theta} \quad x_2 = \frac{\log(x/L)}{\sigma\sqrt{\theta}} + (1 + \mu)\sigma\sqrt{\theta}$
- $y_1 = \frac{\log(L^2/xK)}{\sigma\sqrt{\theta}} + (1 + \mu)\sigma\sqrt{\theta} \quad y_2 = \frac{\log(L/x)}{\sigma\sqrt{\theta}} + (1 + \mu)\sigma\sqrt{\theta}$
- $z = \frac{\log(L/x)}{\sigma\sqrt{\theta}} + \lambda\sigma\sqrt{\theta}$
- $\mu = \frac{b - \sigma^2/2}{\sigma^2} \quad \lambda = \sqrt{\mu^2 + \frac{2r}{\sigma^2}}$

and  $\eta, \phi$  belong to  $\{-1, 1\}$  and will be fixed later.

Let

$$M_{t,T} = \sup_{t \leq \tau \leq T} S_\tau \quad \text{and} \quad m_{t,T} = \inf_{t \leq \tau \leq T} S_\tau$$

## Up-Out Put Option

PAYOFF

PRICE

DELTA

$P_T = \begin{cases} (K - S_T)_+ & \text{if } M_{t,T} < L, \\ R & \text{otherwise.} \end{cases}$

$P(t, x) = \begin{cases} B - D + F & \text{if } K > L, \\ A - C + F & \text{otherwise} \end{cases}$

$\frac{\partial P(t, x)}{\partial x} = \begin{cases} dB - dD + dF & \text{if } K > L, \\ dA - dC + dF & \text{otherwise} \end{cases}$

and take

$$\eta = -1 \qquad \phi = -1$$

References

[1] E.REINER M.RUBINSTEIN. Breaking down the barriers. *Risk*, 4:28–35, 191. 1