

# 1 CRR model

A binomial tree model is given as below:

- Let  $X$  be a random walk with a transition probability with step size  $\Delta t$

$$p(X_n = (j+1)\Delta x | X_{n-1} = j\Delta x) = p, \quad p(X_n = (j-1)\Delta x | X_{n-1} = j\Delta x) = 1 - p.$$

A CRR( $N; s, r, \sigma, T$ ) model assumes Stock price  $S$  satisfies with the following additional conditions:

- $S$  starts from  $s$ ;
- $T/\Delta t$  is an integer, standing for number of steps;
- $X_t = \ln S_t$  follows the random walk with transition probability to upper leg probability

$$\hat{p} = \frac{e^{r\Delta t} - e^{-\sigma\sqrt{\Delta t}}}{e^{\sigma\sqrt{\Delta t}} - e^{-\sigma\sqrt{\Delta t}}}$$

and down leg probability  $1 - \hat{p}$ .

[Q.]

- Is CRR arbitrage free model?
- What is the limit behavior of  $X$  as  $\Delta t \rightarrow 0$ ?

## 2 Computation of CRR vanilla options

### 2.1 Vanilla call/put option computing

A pricing engine for vanilla call/put can be designed by either Backward iteration or Monte-carlo method. One shall compare two methods by using the following example.

We consider an option with

type = call, maturity  $T = 1$  and strike  $K = 100$ .

Its underlying stock has

spot price  $S_0 = 100$  and volatility  $\sigma = 20\%$ .

Moreover, the interest rate is 5%.

You are expected to try the following tasks:

1. Compute BSM call value.
2. Compute the value of CRR( $N = 2000$ ) and observe if it is sufficiently close to BSM value?

3. Next, we want to demonstrate the convergence

$$\text{CRR}(N) \rightarrow \text{BSM}, \text{ as } N \rightarrow \infty.$$

To do that, we take the number of steps  $N = 10 + 20k$ , where  $k$  ranges over all integers in  $\{0, 1, \dots, 49\}$ .

**pseudocode**

- plot a graph of the mapping, for  $k \in \text{range}(50)$

$$k \mapsto \text{CRR}(10 + 20k).$$

- on the same figure, plot a horizontal line with the level of BSM value.
- observe if the CRR curve actually converging to the BSM line?

4. Repeat the above convergence demonstration by replacing the number of steps by

$$N = 10 + 25k.$$

Observe the CRR curve converging to BSM line in the same manner?

## 2.2 Extension

One can try to extend the function of the pricing engine by Monte-Carlo method to some other options:

- Digital option
- American option
- Barrier option
- Option with default risk
- Any useful exotic option pricing

Some other investigations are possible if the pricing engine is reliable, for instance

- How does option price change as volatility is getting bigger? What do you think of the price if  $\sigma \rightarrow 0$  or  $\sigma \rightarrow \infty$ ?
- How sensitively does the price change as the spot price is getting bigger? More sensitivity questions can be referred to Greeks.
- Any other useful features for discovery?

## 3 Further investigations

- Can one improve pricing on Digital option and Barrier option? See importance sampling/variance reduction, etc.
- American option is indeed MDP and one can try one can try any of reinforcement learnings. Probably one can start with Q-learning.
- Try Q-learning to American option with barrier/default risk.
- Try deep BSDE to American option with barrier/default risk.