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## mc\_parisianout

This algorithm is taken from [1] and allows to numerically compute the price and the delta of single Knock-Out Parisian Barrier Options with a Monte Carlo method. The issue, as it is discussed in [there](#), is to provide a good approximation of the first time  $H_D$  at which the price of the underlying stock stays outside the barrier uninterruptedly for longer than a pre-specified delay  $D$ . If such a time is observed to be less or equal to the maturity, the option is nullified, it is activated otherwise. One could numerically determine how much time the stock price is observed to stay outside the barrier by a crude simulation, i.e. through  $k^* \cdot h$ , where  $h$  stands for the time step increment and  $k^*$  denotes the number of consecutive times the underlying asset price has been outside the boundary. Numerical tests show that this method does not perform well because the stock price is checked at discrete instants through simulations and the barrier might have been hit without being detected, giving rise to a non trivial error for the estimate of the option price.

The algorithm ([there](#)) from [1] allows to improve the performance of the crude Monte Carlo method, by giving a careful estimation of  $H_D$  as follows. Setting  $g_u$  as the final time before  $u$  when the barrier is hit, with the constraint  $g_u = u$  if the barrier is never crossed before  $u$ ,  $H_D$  turns out to be the first instant  $u$  such that  $u - g_u \geq D$ . Now, when the stock price is observed to stay outside the barrier either at step  $k - 1$  and  $k$ , an accurate approximation  $p_k^h$  of the probability that the underlying asset price comes back to the domain during the time interval  $((k - 1)h, kh)$  is computed and a bernoulli r.v. with parameter  $p_k^h$  is generated: if it is observed to be equal to 1, then  $g$  is updated and set equal to  $kh$ , otherwise the value of  $g$  does not change.

/\*One forces N if necessary so that delay  
 !!!!!!!!! WARNING !!!!!!!

be greater than the time step increment h\*/

The time step increment  $h$  is initialised; since the value  $D$  of the delay has to be greater than  $h$ , when  $D \leq h$  the number  $N$  of the discretisation points of the time interval  $[0, t]$  ( $t$  standing for the maturity date) is increased.

/\*Initialisation\*/

The variables giving the price, the delta and the corresponding variances are initialised. Moreover, since the paths really simulated are given by the logarithm of the underlying asset price starting at  $s$  and  $s + \varepsilon$ , the considered barrier and starting points are actually the logarithm of the barrier 1 and of the starting points. The coefficients `rloc` and `sigmaloc` are used in order to generate the processes at the discretisation times. Finally, notice that the process starting at  $\ln(s + \varepsilon)$  is equal to the process starting at  $\ln s$  added by  $\ln(1 + \varepsilon/s)$ , which is a constant denoted as `increment`.

/\*Coefficient for the computation of the exit probability\*/

The constant `rap` is used to compute the local probability of crossing the barrier, which turns out to be an exit probability from a barrier.

/\*MC sampling\*/

In this cycle, at step  $i$  the paths  $\ln S^{(i)}(s)$  and  $\ln S^{(i)}(s + \varepsilon)$ , starting at  $s$  and  $s + \varepsilon$ , are simulated. Thus, it starts by initialising the variables `gt`, `hd`, `gt_increment`, `hd_increment` and `lnspot`, giving the current values for  $g$ ,  $H_D$  and the current position `lnspot` of the process.

/\*Inside=0 if the path stays beyond the barrier\*/

/\*uninterruptedly for longer than delay\*/

`inside` and `inside_increment` are boolean variables initialised to 1, switching to 0 when the corresponding value of  $H_D$  is greater than  $D$ , i.e. when the path stays beyond the barrier uninterruptedly for longer than `delay`.

/\*Barrier at time\*/

The barrier is evaluated at time 0.

/\*Simulation of i-th path until Inside=0\*/

In this cycle, both processes are simulated at the discretisation times  $kh$ , whose current name is `time`, until  $k = N$  or the corresponding value of the flag is changed, i.e. until `inside` = 0 or `inside_increment` = 0. At each step  $k$ , a variable, called `correction_active`, is introduced in order to ensure that both paths are generated by means of the same sample.

`correction_active` is firstly equal to 0 and its value switches to 1 whenever a path is observed to stay locally beyond the barrier whereas the other one does not behave in the same way. The value of the old and new simulated points and of the barrier are put in the variables `lastlnspot`, `lnspot`, `lastlnspot_increment`, `lnspot_increment`, `lastbarrier`, `barrier` respectively.

/\*Check if the i-th path has reached the barrier at time\*/  
 /\*Otherwise there is no extinction\*/

The variable `upordown` is defined to be equal to 0 if the considered barrier is an upper one, `upordown` being equal to 1 in the case of lower barrier. The procedure `check_parisianout` checks if the barrier has or has not been reached by the processes and the output is the value for `gt` and `gt_increment`. Once these values are known, `hd` and `hd_increment` can be computed and compared with `delay`: if they are greiter than `delay`, the corresponding values of `inside` and `inside_increment` change and `price_sample` and `price_sample_increment` are set equal to 0; if at the end of the cicle `inside` and `inside_increment` are equal to 0, the payoffs are computed in `price_sample` and `price_sample_increment`.

`check_parisianout` works as follows.

- Suppose `upordown=0`, i.e. an upper barrier framework. `lnspot` and `lastlnspot`, giving the simulated values of  $\ln S_{kh}^{(i)}(s)$  and  $\ln S_{(k-1)h}^{(i)}(s)$  respectively, are compared with the (logarithm of the) barrier:
- if they are both outside the barrier then the probability  $p_k^h$  is computed, `correction_active` is set equal to 1 and a bernoulli r.v. with parameter  $p_k^h$  is considered: a uniform r.v. `uniform` is generated and if `uniform`  $< p_k^h$  then (the path has gone back and) `gt` is updated as the current `time`; if `uniform`  $\geq p_k^h$  then (the path has never gone back and) `gt` is not changed;
  - if `lnspot` is outside but `lastlnspot` is inside the boundary, then the final time `gt` at which the barrier has been crossed is approximated through a suitable instant between  $kh$  and  $(k-1)h$  (see [Monte Carlo for Barrier Option : Algorithm](#) for details);
  - otherwise, `gt` is updated as the current `time`.

The same procedure applies to `lnspot_increment` and `lastlnspot_increment`. It is worth to observe that if `lnspot_increment` and `lastlnspot_increment` are both observed to stay above the barrier then a uniform r.v. is needed; since the paths have to be simulated by means of the same sample, such a uniform r.v. must be taken as the same `uniform` used to compute `gt`, if it has been generated. Thus, if the condition “`!correction_active`” is true, which means that `correction_active`  $\neq 1$ , a new uniform r.v. is considered; whereas if it is false, i.e. the correction has been yet activated, `uniform` does not change and turns out to be the same one which has been previously generated.

Finally, notice that, since  $\varepsilon > 0$ , `lnspot`  $<$  `lnspot_increment` and `lastlnspot`  $<$  `lastlnspot_increment`, so that `correction_active` has to be firstly activated to the path starting at  $s$ .

If `upordown=1`, `correction_active` has to be firstly activated to the path

starting at  $s + \varepsilon$ , so that `check_parisianout` is applied by changing the role to `lnspot` and `lastlnspot` and to `lnspot_increment` and `lastlnspot_increment`.

`/*Delta*/`

The delta of the sample is computed (recall that `increment` =  $\ln(1 + \varepsilon/s)$ ) so that  $\varepsilon \sim \text{increment} * s$ : that is why the variation of the price sample is divided by `increment*s`).

`/*Sum*/`

The partial sums of the observed `price_sample` and `delta_sample` are computed.

`/*Sum of Squares*/`

The partial sums of the squares of the observed `price_sample` and `delta_sample` are computed and will be used to evaluate the empirical variances.

`/*Price*/`

The price is numerically computed by averaging over the  $M$  observed `price_sample`. The variable `pterror_price` is such that the interval (`ptprice` - `pterror_price`, `ptprice` + `pterror_price`) represents the 95% confidence interval for `ptprice`.

`/*Delta*/`

The delta is computed according to the case of a put or call option. The variable `pterror_delta` is such that the interval (`ptdelta` - `pterror_delta`, `ptdelta` + `pterror_delta`) represents the 95% confidence interval for `ptdelta`.

## References

- [1] P.BALDI L.CARAMELLINO M.G.IOVINO. Pricing complex barrier options with general features using sharp large deviation estimate. *Proceedings of the MCQMC Conference, Calremont (LA), USA, 1999.* 1