Seminararbeit
Computergestützte Statistik: Programmieren mit R

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560682 - Statistik

September 1, 2015

Contents

1 Introduction

The Shiny application introduced in this paper consists of two distinct sub-components: `Option calculator` and `VSTOXX Data`. The component `Option Calculator` can be used to evaluate Black-Scholes price of the option as well as Delta, Gamma, Rho and Vega of the option. User also has the possibility to analyze how a given Greek changes if some market parameters change.

The component `VSTOXX Data` deals with analysis of VSTOOX index and options on it. Using this part user can take a look at the average value of options accros different strikes and maturities. Also user can obtain structure of implied volatility smiles for a given date as well as structure of option prices.

All packages used in application have been collected in the file `packages.R`. These packages must be installed to run application.

This application and all used code and data has been put under version control and can be cloned or downloaded using this link:
`https://github.com/romanlykhnenko/CurrentShiny`

2 Option calculator

2.1 Theoretical Background

Derivatives are financial instruments which derive their value from (or are dependent on) the value of another product, called the underlying. Options are one of the most famous and traded derivatives. In this paper two types of options have been considered: european call and put options. The price of an option under some assumptions has a closed form and is given by Black-Scholes formula. Understanding the risk-types that an option might involve is crucial for all market participants. For such a reason so called Greeks have been introduced. They represent the sensitivity of the option to different factors. The Greeks of european options are:

- Delta (sensitivity to the underlying price)
- Gamma (sensitivity of delta to the underlying price, delta of delta)
- Rho (sensitivity to the risk-free rate)
- Vega (sensitivity to the volatility)

The first part of application enables user to provide all characteristics of the option of interest and obtain price of the option, value of Greeks as well as plots of Greeks as a function of underlying. Also it is possible to investigate how values of Greeks changes if option properties change. Thus, comprehensive analysis of option can be done.

2.2 Class implementation

In order to analyse options it was decided to represent each option as an object of the class `BSworld`. Then all standart operations with an option (e.g. calculation of option price, Greeks etc.) can be represented as methods of this class. By proceeding in such a way, we can pack all data about each option, and all functions, that can be applied to option, into a single component. The `S3` object system has been used to implement class `BSworld` in `R`. Implementation of the class `BSworld` can be found in file `class.R`.

The instance of the class `BSworld` can be created by providing a set of input values, which completely describe an option:

- `S0`: current price of underlying asset
- `K`: strike price of the option
- `T`: time to maturity, which must be represented in years. For instance time to maturity 0.5 means that time from now to expiration date of the option is 0.5 years, i.e. 6 months.
- `r`: risk-free interest rate

- `sigma`: volatility
- `type`: type of the option (call or put)

The initialization of object of class `BSworld` can be done in such a way:

```
> obj <- BSworld(100, 105, 1, 0.05, 0.02, "call")
```

Class `BSworld` has such methods:

- `BSPrice`

  This method returns price of the option based on the Black-Scholes formula

- `BSdelta`

  This method calculates a numerical value for the Delta of an option

- `BSgamma`

  This method calculates a numerical value for the Gamma of an option

- `BSrho`

  This method calculates a numerical value of the Rho of an option

- `BSvega`

  This method calculates a numerical value for the Vega of an option

To create a method of the class `BSworld` such procedure has been used: firstly, define a function that exists outside of the class (the function is defined in a generic way) and then a function specific to a given class is defined. For example, definition of the `BSvega` method looks so:

```
> # reserve the name of the function, and use UseMethod command to tell R to
> # search for the correct function
> BSdelta <- function(someClass) {
+
+   UseMethod("BSdelta", someClass)
+
+ }
> # define function BSdelta specific to class BSworld
> BSdelta.BSworld <- function(instance.of.BSworld) {
+
```

```
+   # get all attributes of the class BSworld using given instance of this class
+   S0 <- instance.of.BSworld$S0
+   K <- instance.of.BSworld$K
+   T <- instance.of.BSworld$T
+   r <- instance.of.BSworld$r
+   sigma <- instance.of.BSworld$sigma
+   type <- instance.of.BSworld$type
+
+   d1 = (log(S0 / K) + (r + 0.5 * sigma^2) * T) / (sigma * sqrt(T))
+
+   deltaCall <- pnorm(d1)
+
+   deltaPut <- -pnorm(-d1)
+
+   valueOut <- ifelse(type == "call", deltaCall, deltaPut)
+
+   return(list(type = type, delta = valueOut))
+
+ }
>
```

Also generic function `print` has been defined for class `BSworld`. This function prints price of the option based on Black-Scholes formula, computed values for Greeks of the option as well as type of the option.

2.3 Shiny implementation

Option calculator with corresponding user interface has been created based on the class `BSworld`. User interface for Option calculator can be found in tab panel with name Option calculator. Having run Shiny application and after opening tab Option calculator, user can enter all characteristics of the option of interest using corresponding widgets on the left side of the display. After doing this, user can see calculated price of the option as well as Greeks. Also user has a possibility to select one of Greeks to be ploted using `radio buttons` on the left side. It is possible to observe how this plot changes when characteristics of the option are changed. User can also select the length of the interval for underlying asset used to plot Greeks. This can be done by changing value of `sliderInput` with name `rescale x-axis`. On the server side, by selecting values for different characteristics of the option(e.g. strike, stock price, maturity etc.) an instance of the class `BSworld` is created. Then `print` method of the class `BSworld` is applied to the obtained instance of the class `BSworld` which enables a user to see Black-Scholes price of the option as well as calculated Greeks. Plots for all of Greeks are created using wrapper functions for methods of class `BSworld`. These wrapper functions have been collected in file `plotGreeks.R`.

3 Analysis of options on VSTOXX

3.1 Theoretical Background

Volatility derivatives have become an important risk management and trading tool. While first-generation financial models for option pricing take volatility as just one of a number of input parameters(this approach has been used in Option calculator as a foundation to calculate price of the option), second-generation models and products consider volatility as an asset class of its own. Second part of the Shiny application is supposed to give a short analysis of main properties of one of the most traded volatility derivatives - options on the VSTOXX volatility index. VSTOXX volatility index has been introduced in 2005 by Eurex, the derivatives exchange operated by Deutsche Börse AG in Germany, and is calculated based on implied volatilities from options on the EURO STOXX 50 index. Two types of data have been used for analysis: options on VSTOXX and VSTOOX index itself for the time interval from 01.01.2014 to 31.03.2014. This data has been downloaded using Python based tutorials provided by Eurex (http://www.eurexchange.com/advanced-services/vstoxx/) and saved as `csv` files in folder Data.

Later concept of implied volatility will be used. This concept is used to show how option prices calculated using Black-Scholes formula differ from the option prices observed from the market. Implied volatility is essentially such a value of parameter `volatility` in Black-Scholes formula that makes price of option calculated by Black-Scholes formula equal to the real price of the option observed from the market. If Black-Scholes formula were a correct approach for option pricing then implied volatilities must be the same for all strikes, but it is hardly the case in practice, and this phenomenon is known as `volatility smile`.

3.2 Shiny implementation

Analysis of options on VSTOOX is presented in the tab VSTOOX Data. By entering information about type of the option and strike (maturity) user can obtain a plot of average option prices for different strikes (maturities).This feature is produced by running corresponding function from the file `functions.R`. The choice of the appropriate function is determined by input of a user. Afterwards user can select date of interest and obtain implied volatility structure of call options on VSTOXX for a selected date as well as prices of call options observed from the market. Date range is restricted to time interval from 01.01.2014 to 31.03.2014. On the server side, after running an application all helping files are loaded as well as VSTOXX data. These commands run only once when application is launched, because they located above `shinyServer` command in `server.R` file. Afterwards this data and date specfied by user are used by function `impVola` as arguments. This function can be found in the file `funImpVola.R`. Function `impVola` returns data frame which contains all information needed for plots of implied volatility and observed market prices.At the next step reactive conductor is applied to obtained data frame, which leads to creation of the object `plotData` used to plot both volatility smiles and option prices. It should be mentioned that one of tasks of function `impVola` is to compute implied volatilities for all options based on available VSTOOX data. Such an objective is achieved by a numerical procedure based on Newton-Raphson method as it is described in Tompkins (1994). This numerical procedure is implemented in function `bsCallImpVol` from the file `functions.R`. Unfortunately, this procedure can not provide estimation of implied volatility for options with very small Vega since it involves inverting of the value of Vega. Actually options with such a property are known as `far-out-of-the-money option` and all such options have been removed from consideration.

4 Conclusion

Shiny application presented here consists of two parts. First part has a name `Option calculator` and deals with evaluation of all classical characteristics of the option based on attributes provided by user. Implementation of `Option calculator` mainly relies on class `BSworld`, which is realized using `S3` object system. The second part deals with analysis of VSTOOX options. User has a possibility to obtain structure of volatility smiles and observed option prices for a time period from 01.01.2014 to 31.03.2014.

5 List of references

1. http://www.eurexchange.com/advanced-services/vstoxx/
2. J. Hull (2011), Options, Futures, and Other Derivatives, Prentice Hall, 8th edition
3. Tompkins, R. (1994), Options Explained, (1. ed.) MacMillan Press Ltd