



# QPRLib

Version: 202505

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# QPRLib Introduction

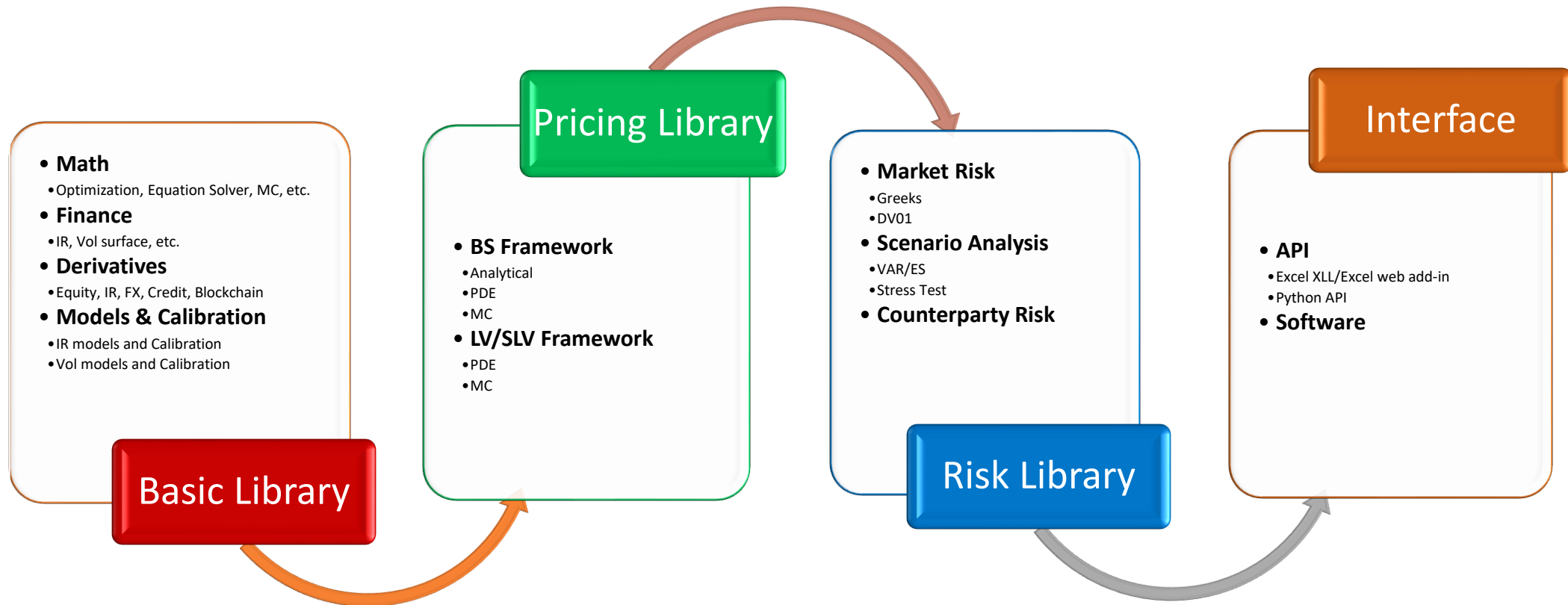
**QPRLib** (Quantitative Pricing Risk Library) is a foundational library developed for the **Chinese** and **Hong Kong** financial derivatives markets. It provides pricing and risk measurement capabilities for specific over-the-counter (OTC) instruments across equity and fixed-income categories, such as structured snowball products and convertible bonds.

This project is under continuous development, and we envision the final version of the QPRLib library to provide the following functionalities:

- *Capability to handle all common financial derivative instruments (e.g., fixed-income products, OTC equity-structured products, etc.);*
- *Multiple models and algorithms available for user selection within the same product category;*
- *A comprehensive analytical framework including product construction, data import, model calibration, pricing and valuation, as well as risk analysis;*
- *Diversified interfaces and seamless IT integration*

# QPRLib Introduction

## Structure



# QPRLib Introduction

## Products

Equity	IR	FX	Credit	Blockchain
<input type="checkbox"/> European/American	<input type="checkbox"/> Convertible bond	<input type="checkbox"/> European/American	<input type="checkbox"/> CDS	<input type="checkbox"/> Perpetual contract
<input type="checkbox"/> Barrier	<input type="checkbox"/> Perpetual bond	<input type="checkbox"/> Barrier	<input type="checkbox"/> CLN	
<input type="checkbox"/> Digital	<input type="checkbox"/> Floating rate bond	<input type="checkbox"/> Asian		
<input type="checkbox"/> Asian	<input type="checkbox"/> Callable and puttable bond			
<input type="checkbox"/> Lookback	<input type="checkbox"/> Swap			
<input type="checkbox"/> Warrant	<input type="checkbox"/> Swaption			
<input type="checkbox"/> Accumulator	<input type="checkbox"/> ABS			
<input type="checkbox"/> Autocallable				

# QPRLib Introduction

## Models & Algorithms For Equity Derivatives

Products	BS			Local Vol		Heston			Stochastic Local Vol	
	Analytical	PDE	MC	PDE	MC	Analytical	PDE	MC	PDE	MC
European	√	√	√	√	√	√	√	√	√	√
American	√	√	X	√	X	X	X	X	X	X
Asian	√	√	√	X	√	X	X	√	X	√
Barrier	√	√	√	√	√	X	X	√	X	√
Digital	√	√	√	√	√	X	X	√	X	√
Lookback	√	X	√	X	√	X	X	√	X	√
Autocallable	X	√	√	√	√	X	X	√	X	√
Accumulator	X	X	√	X	X	X	X	X	X	X
Warrant	√	X	X	X	X	X	X	X	X	X
Three Interval	√	X	√	X	X	X	X	X	X	X
Shark Fin	X	X	√	X	X	X	X	X	X	X
Touch	X	X	√	X	X	X	X	X	X	X

# QPRLib Access

## WEB

Deployed on [47.115.61.38](http://47.115.61.38)

期权定价工具 用户

中国场外衍生产品- 欧式期权定价

合约条款 市场数据 模型校准 定价估值 风险度量

校准模型: LV 校准方法: TanhCosh

LV模型描述:  
 $dS = rSdt + v(t,S)dW$

校准

调用BS定价,请转到定价估值表,在此无需操作;第二步、验证若需调用其他模型定价,可在菜单波动率曲面或链接数据库!

三维 二维

📷 🔍 + ↺ ⬇️ 🗑️ 📄

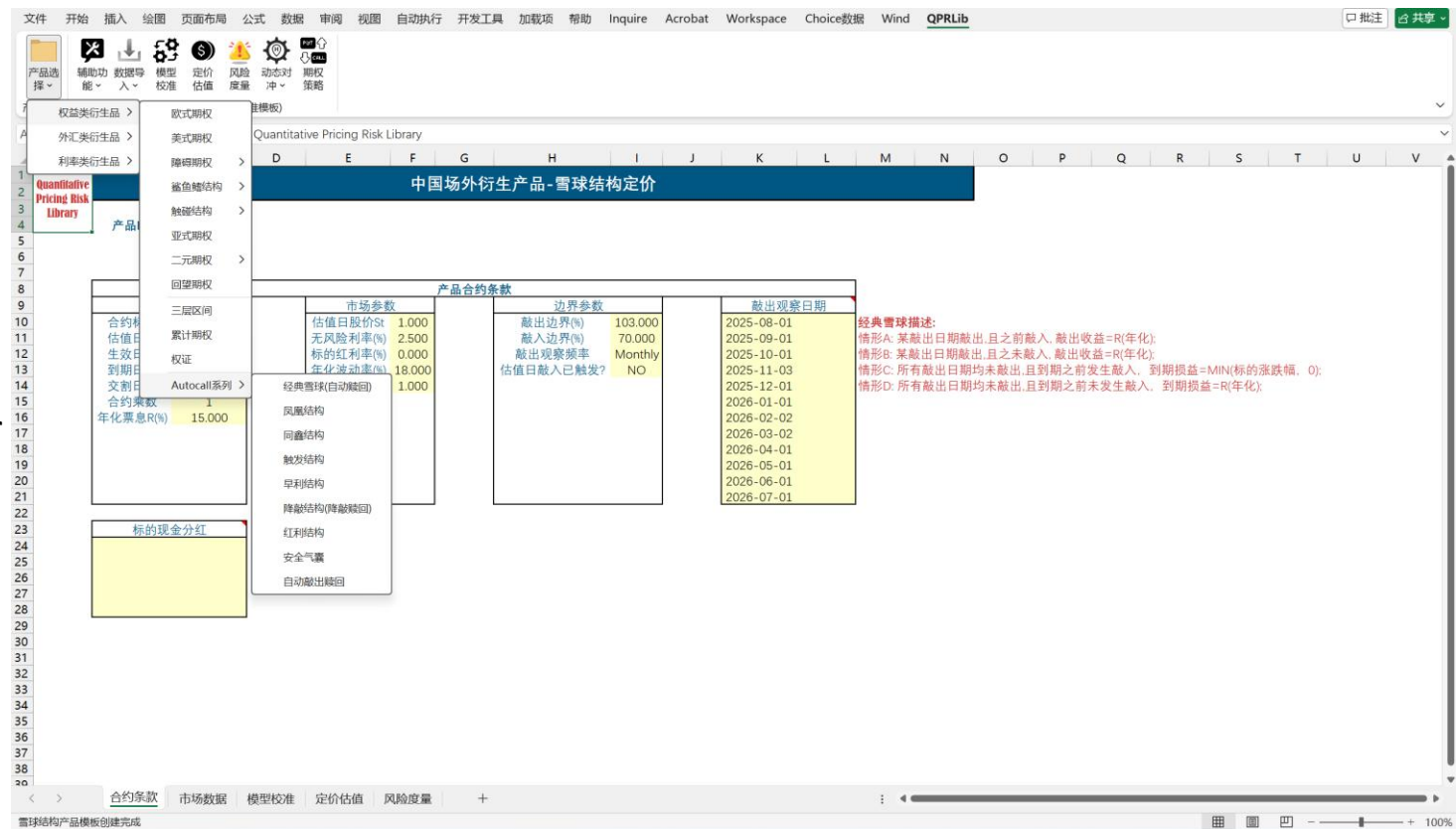


# QPRLib Access

## Install on Computer as Excel Add-in

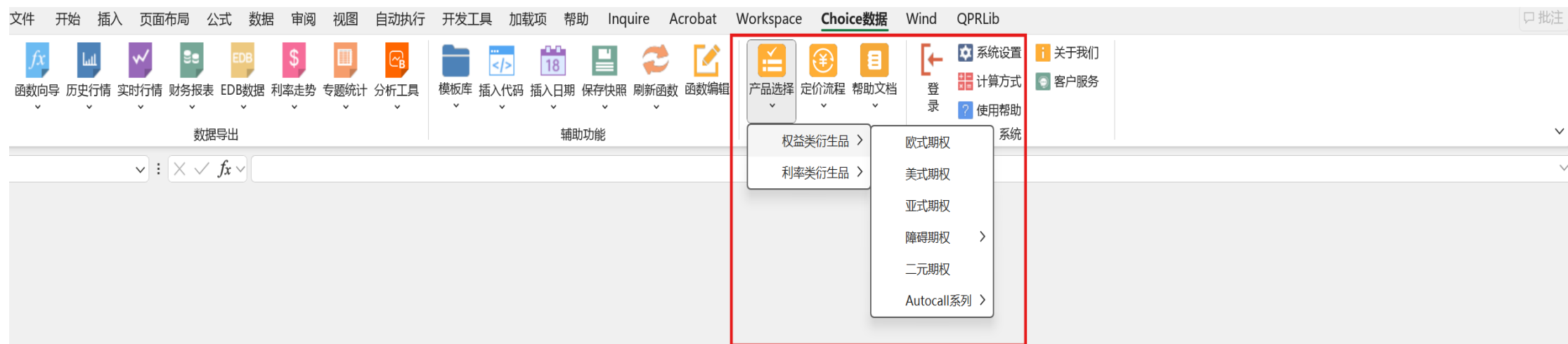
Download the installation package from the PolyU official website (<https://www.polyu.edu.hk/rcqf/qprlib-cn.html>) by obtaining the Installation.zip file.

After extraction, navigate to the *Installation\_online* folder. Depending on whether your computer uses Excel or WPS, right-click the corresponding .bat file and run it as an administrator to complete the installation.



# QPRLib Access

## Choice Terminal



# QPRLib Products

## Euro/Amer Option

$$\text{Payoff: } V_T(S_T, T) = \begin{cases} (S_T - K)^+, & \text{CALL} \\ (K - S_T)^+, & \text{PUT} \end{cases}$$

Euro: Exercise at T;  
Ame: Exercise before or at T;

## Digital Option

$$\text{Payoff: } V_T(S_T, T) = \begin{cases} I_{\{S_T \geq K\}}, & \text{CALL} \\ I_{\{S_T \leq K\}}, & \text{PUT} \end{cases}$$

# QPRLib Products

## Barrier Options — Single Barrier

Barrier Type	Product Description	Relation between Barrier B and Initial Price $S_0$
UpIn	If any observation date $S_t \geq B$ , product behaves as the corresponding European option; if all $S_t < B$ , payoff = 0 at maturity.	$B > S_0$
UpOut	If any observation date $S_t \geq B$ , product expires; if all $S_t < B$ , product behaves as the corresponding European option.	
DnIn	If any observation date $S_t \leq B$ , product behaves as the corresponding European option; if all $S_t > B$ , payoff = 0 at maturity.	$B < S_0$
DnOut	If any observation date $S_t \leq B$ , product expires; if all $S_t > B$ , product behaves as the corresponding European option.	

## Barrier Options — Double Barrier

Barrier Type	Product Description	Relation between Barriers $B_1, B_2$ and Initial Price $S_0$
KnockIn	If any observation date $S_t \geq B_2$ or $S_t \leq B_1$ , product behaves as the corresponding European option; if all $B_1 < S_t < B_2$ , payoff = 0 at maturity.	$B_1 < S_0 < B_2$
KnockOut	If any observation date $S_t \geq B_2$ or $S_t \leq B_1$ , product expires; if all $B_1 < S_t < B_2$ , product behaves as the corresponding European option.	

# QPRLib Products

## Asian Option

Strike Type	Average Type	Payoff
Float Strike	Arithmetic	$V_T(S_T, T) = (S_T - S_A)^+, \text{CALL}; (S_A - S_T)^+, \text{PUT}$
Float Strike	Geometric	$V_T(S_T, T) = (S_T - S_G)^+, \text{CALL}; (S_G - S_T)^+, \text{PUT}$
Fixed Strike	Arithmetic	$V_T(S_T, T) = (S_A - K)^+, \text{CALL}; (K - S_A)^+, \text{PUT}$
Fixed Strike	Geometric	$V_T(S_T, T) = (S_G - K)^+, \text{CALL}; (K - S_G)^+, \text{PUT}$

- Arithmetic average:  $S_A = \frac{1}{N} \sum S_i$
- Geometric average:  $S_G = (\prod S_i)^{1/N}$

# QPRLib Products

## Lookback Option

Strike Type	Call/Put	Payoff
Float Strike	Call	$V_T(S_T, T) = S_T - S_{\min}$
Float Strike	Put	$V_T(S_T, T) = S_{\max} - S_T$
Fixed Strike	Call	$V_T(S_T, T) = (S_{\max} - K)^+$
Fixed Strike	Put	$V_T(S_T, T) = (K - S_{\min})^+$

# QPRLib Products

## Shark Fin——Single

### UpOut Single Shark Fin (requires strike price < knock-out price):

- ◆ **Case A:** If an upward knock-out occurs during the period, the payoff = Principal + annualized upward knock-out return.
- ◆ **Case B:** If no knock-out occurs and the maturity payoff is below the strike price, the payoff = Principal + annualized guaranteed return.
- ◆ **Case C:** If no knock-out occurs and the maturity payoff lies between the strike price and the knock-out price, the payoff = Principal + annualized [guaranteed return + (underlying closing price – strike price) × participation rate].

### DnOut Single Shark Fin (requires knock-out price < strike price):

- ◆ **Case A:** If a downward knock-out occurs during the period, the payoff = Principal + annualized downward knock-out return.
- ◆ **Case B:** If no knock-out occurs and the maturity payoff is above the strike price, the payoff = Principal + annualized guaranteed return.
- ◆ **Case C:** If no knock-out occurs and the maturity payoff lies between the knock-out price and the strike price, the payoff = Principal + annualized [guaranteed return + (strike price – underlying closing price) × participation rate].

## Shark Fin——Double

- ◆ **Case A:** If an upward knock-out occurs during the period, the payoff = Principal + annualized upward knock-out return.
- ◆ **Case B:** If a downward knock-out occurs during the period, the payoff = Principal + annualized downward knock-out return.
- ◆ **Case C:** If no knock-out occurs and the maturity price lies between the upper and lower strike prices, the payoff = Principal + annualized guaranteed return.
- ◆ **Case D:** If no knock-out occurs and the maturity price lies between the upper strike price and the upper knock-out price, the payoff = Principal + annualized [guaranteed return + (underlying closing price – upper strike price) × upper participation rate].
- ◆ **Case E:** If no knock-out occurs and the maturity price lies between the lower knock-out price and the lower strike price, the payoff = Principal + annualized [guaranteed return + (lower strike price – underlying closing price) × lower participation rate].

# QPRLib Products

## Touch—Single

- ◆ **Case A: Up-Touch Type:** If the stock price touches the upper barrier during the contract period, a fixed payoff is received; otherwise, the contract expires worthless at maturity.
- ◆ **Case B: Up-No-Touch Type:** If the stock price does not touch the upper barrier at any time during the contract period, a fixed payoff is received at maturity; otherwise, the contract terminates upon touching.
- ◆ **Case C: Down-Touch Type:** If the stock price touches the lower barrier during the contract period, a fixed payoff is received; otherwise, the contract expires worthless at maturity.
- ◆ **Case D: Down-No-Touch Type:** If the stock price does not touch the lower barrier at any time during the contract period, a fixed payoff is received at maturity; otherwise, the contract terminates upon touching.

## Touch—Double

- ◆ **Case A: Up-Touch Type:** If the underlying price touches either the upper barrier or the lower barrier during the contract period, a fixed payoff is received; otherwise, the contract expires worthless at maturity.
- ◆ **Case B: Up-No-Touch Type:** - If the underlying price does not touch either the upper barrier or the lower barrier during the contract period, a fixed payoff is received at maturity; otherwise, the contract terminates upon touching.

# QPRLib Products

## Three-Layer

**Three-Layer Structure (Bullish: returns increase across intervals 1, 2, 3; Bearish: returns decrease across intervals 1, 2, 3):**

- ◆ **Case A:** If the condition is met: Final underlying price / Initial price < Strike price  $K_1$ , then the payoff = Annualized return of Interval 1.
- ◆ **Case B:** If the condition is met:  $K_1 \leq$  Final underlying price / Initial price  $\leq K_2$ , then the payoff = Annualized return of Interval 2.
- ◆ **Case C:** If the condition is met: Final underlying price / Initial price > Strike price  $K_2$ , then the payoff = Annualized return of Interval 3

## Accumulator

- ◆ **Case A:** On the observation date, if the underlying price lies between the upper and lower bounds, the option buyer purchases a specified quantity of the underlying asset at the lower bound price.
- ◆ **Case B:** On the observation date, if the underlying price is below the lower bound, the option buyer purchases leverage  $\times$  specified quantity of the underlying asset at the lower bound price.
- ◆ **Case C:** On the observation date, if the underlying price is above the upper bound, no settlement is made for that period.

# QPRLib Products

## Warrant

Same as European/American options.

**Note 1:** Exercise ratio defines how many units of underlying asset each warrant converts into.

**Note 2:** CBBC (Callable Bull/Bear Contracts) resale price refers to the residual value or settlement price upon mandatory redemption or maturity.

# QPRLib Products

## Autocall—SB

- ◆ **Case A:** On a knock-out date, if a knock-out occurs and a prior knock-in has occurred, the knock-out payoff = R (annualized).
- ◆ **Case B:** On a knock-out date, if a knock-out occurs and no prior knock-in has occurred, the knock-out payoff = R (annualized).
- ◆ **Case C:** If no knock-out occurs on any knock-out date, and a knock-in occurs before maturity, the maturity payoff =  $\min(\text{underlying}/\text{return}, 0)$ .
- ◆ **Case D:** If no knock-out occurs on any knock-out date, and no knock-in occurs before maturity, the maturity payoff = R (annualized).

## Autocall—TX

- ◆ **Case A:** If no knock-in occurs before maturity, the maturity payoff = (annualized).
- ◆ **Case B:** If a knock-in occurs before maturity and the final underlying return  $>$  , the maturity payoff = (annualized).
- ◆ **Case C:** If a knock-in occurs before maturity and the final underlying return  $<$  , the maturity payoff = underlying return (or underlying decline)

# QPRLib Products

## Autocall—PH

- ◆ **Case A:** On a knock-out date, if a knock-out occurs and a prior knock-in has occurred, the knock-out payoff =  $Jt \cdot R$ .
- ◆ **Case B:** On a knock-out date, if a knock-out occurs and no prior knock-in has occurred, the knock-out payoff =  $Jt \cdot R$ .
- ◆ **Case C:** If no knock-out occurs on any knock-out date, and a knock-in occurs before maturity, and  $ST \geq S0$ , then the maturity payoff =  $Jt \cdot R$ .
- ◆ **Case D:** If no knock-out occurs on any knock-out date, and no knock-in occurs before maturity, and  $ST < S0$ , then the maturity payoff =  $Jt \cdot R + \min(\text{underlying return}, 0)$ .
- ◆ **Case E:** If no knock-out occurs on any knock-out date, and no knock-in occurs before maturity, then the maturity payoff =  $Jt \cdot R$ .

Note:  $Jt$  represents the number of effective observation months at valuation, i.e., the number of knock-out observation dates on which the underlying closing price exceeded the knock-in price.

## Autocall—TO

- ◆ **Case A:** On a knock-out date, if a knock-out occurs and a prior knock-in has occurred, the knock-out payoff =  $R(\text{non-annualized})$ .
- ◆ **Case B:** On a knock-out date, if a knock-out occurs and no prior knock-in has occurred, the knock-out payoff =  $R(\text{non-annualized})$ .
- ◆ **Case C:** If no knock-out occurs on any knock-out date, and  $ST \geq S0$ , a knock-in occurs before maturity, and , then the maturity payoff = 0%.
- ◆ **Case D:** If no knock-out occurs on any knock-out date, and  $ST < S0$ , no knock-in occurs before maturity, and , then the maturity payoff = underlying decline.
- ◆ **Case E:** If no knock-out occurs on any knock-out date, and no knock-in occurs before maturity, then the maturity payoff =  $R(\text{non-annualized})$ .

# QPRLib Products

## Autocall—ZL

- ◆ **Case A:** On a knock-out date, if a knock-out occurs and a prior knock-in has occurred, the knock-out payoff =  $R_1$  before  $T$ ; knock-out payoff =  $R_2$  after  $T$ .
- ◆ **Case B:** On a knock-out date, if a knock-out occurs and no prior knock-in has occurred, the knock-out payoff =  $R_1$  before  $T$ ; knock-out payoff =  $R_2$  after  $T$ .
- ◆ **Case C:** If no knock-out occurs on any knock-out date, and a knock-in occurs before maturity, the maturity payoff =  $\min(\text{underlying return}, 0)$ .
- ◆ **Case D:** If no knock-out occurs on any knock-out date, and no knock-in occurs before maturity, the maturity payoff =  $R_2$ .

## Autocall—JQ

- ◆ **Case A:** On a knock-out date, if a knock-out occurs and a prior knock-in has occurred, the knock-out payoff =  $R$  (annualized).
- ◆ **Case B:** On a knock-out date, if a knock-out occurs and no prior knock-in has occurred, the knock-out payoff =  $R$  (annualized).
- ◆ **Case C:** If no knock-out occurs on any knock-out date, and a knock-in occurs before maturity, the maturity payoff =  $\min(\text{underlying return}, 0)$ .
- ◆ **Case D:** If no knock-out occurs on any knock-out date, and no knock-in occurs before maturity, the maturity payoff =  $R$  (annualized).

Note: The knock-out boundary decreases proportionally with each knock-out date.

# QPRLib Products

## Autocall—HL

- ◆ **Case A:** On a knock-out date, if a knock-out occurs and a prior knock-in has occurred, the knock-out payoff =  $R$  (annualized).
- ◆ **Case B:** On a knock-out date, if a knock-out occurs and no prior knock-in has occurred, the knock-out payoff =  $R$  (annualized).
- ◆ **Case C:** If no knock-out occurs on any knock-out date, and a knock-in occurs before maturity, the maturity payoff =  $\min(\text{underlying return}, 0)$ .
- ◆ **Case D:** If no knock-out occurs on any knock-out date, and no knock-in occurs before maturity, the maturity payoff = Dividend coupon ( $< R$ ).

## Autocall—AB

- ◆ **Case A:** If a knock-in occurs during the period, the maturity yield = underlying return - 1.
- ◆ **Case B:** If no knock-in occurs during the period, the maturity yield =  $\max(0, \text{underlying return} - \text{strike price percentage})$ .

Note: If a cap clause exists, the yield is limited to the capped yield.

## Autocall—AO

- ◆ **Case A:** On a knock-out date, if a knock-out occurs, the knock-out payoff =  $R_1$  (annualized).
- ◆ **Case B:** If no knock-out occurs on any knock-out date, the maturity payoff =  $R_2$  (annualized), where typically  $R_2 < R_1$ .

Note: Unlike the classical snowball structure, this product does not contain a knock-in clause and is capital-protected.

# QPRLib Pricing—Autocall(SB)

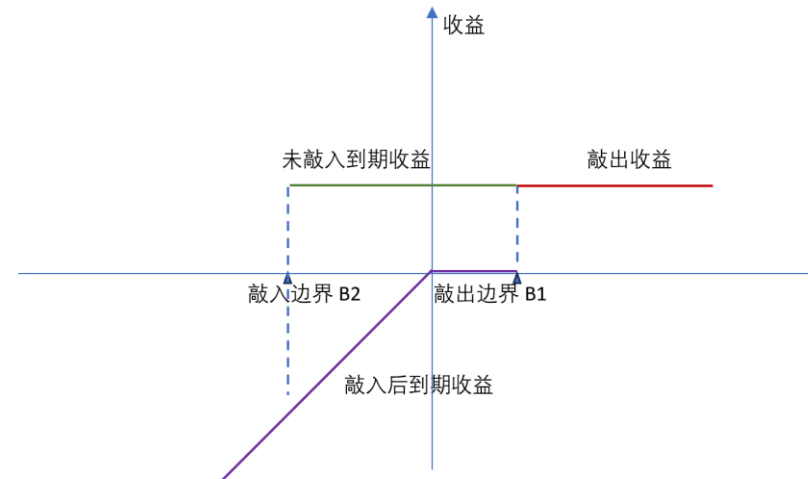
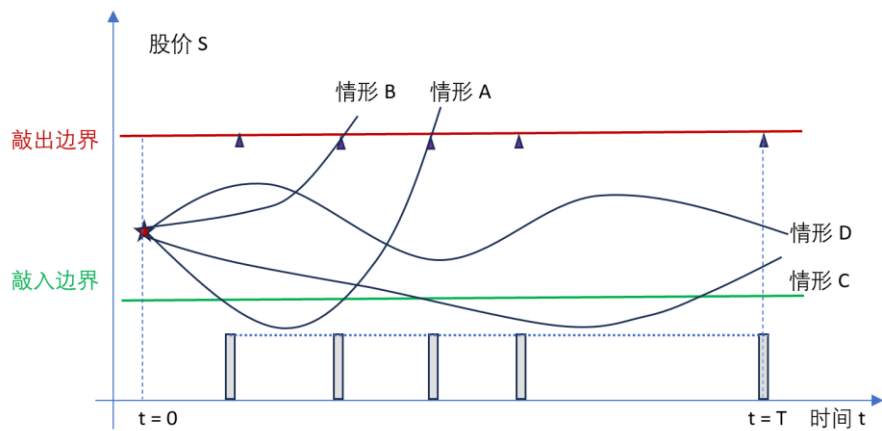
## **Essence of the Classic Snowball:**

The classic snowball essentially represents a double-barrier put option purchased by the issuing broker from investors, with **Down-and-In (DnIn)** and **Up-and-Out (UpOut)** features. This product combines a safety cushion, high probability of success, and relatively stable medium-to-high returns, while carrying tail risk as a nonlinear investment instrument.

## **Market Expectation of Purchasing a Classic Snowball:**

The market outlook for buying a classic snowball is similar to that of selling a put option. The expectation is for a moderate upward trend or sideways consolidation in the market, without significant upward or downward movements

# QPRLib —— Autocal(SB)



# QPRLib —— Autocal(SB)

**Light Yellow Background:**  
User-input or editable parameter area.

**Light Gray Background:**  
System parameter area (non-editable by user).

**Light Blue Background:**  
Result display area (non-editable by user).

文件 开始 插入 页面布局 公式 数据 审阅 视图 自动执行 开发工具 帮助 Choice数据 Wind QPRLib

产品选择 辅助功能 数据导入 模型校准 定价估值 风险度量 帮助

产品目录 金融衍生品估值定价流程 说明

菜单栏, 按钮用于执行特定操作

Quantitative Pricing Risk Library

中国场外衍生产品-雪球结构定价

产品ID: Equity\_SB

产品合约条款					
基本参数		市场参数		边界参数	敲出观察日期
合约标的	510050.SH	估值日股价St	1.000	敲出边界(%)	103.00
估值日期	2024-04-09	无风险利率(%)	2.500	敲入边界(%)	70.00
生效日期	2023-10-02	标的红利率(%)	0.000	敲出观察频率	Monthly
到期日期	2024-10-02	年化波动率(%)	18.000	估值日敲入已触发?	NO
交割日期	2024-10-02	生效日股价S0	1.000		
合约乘数	1				
年化票息R(%)	15.00				

经典雪球描述:  
情形A: 某敲出日期敲出,且之前敲入, 敲出收益=R(年化);  
情形B: 某敲出日期敲出,且之未敲入, 敲出收益=R(年化);  
情形C: 所有敲出日期均未敲出,且到期之前发生敲入, 到期损益=MIN(标的涨跌幅, 0);  
情形D: 所有敲出日期均未敲出,且到期之前未发生敲入, 到期损益=R(年化);

执行的流程:  
A.BS框架下定价: 1.建立产品模板; 2.导入数据; 3.执行定价估值; 4.执行风险度量  
B.LV/SV/SLV模型下定价: 1.建立产品模板; 2.导入数据; 3.校准波动率模型; 4.执行定价估值; 5.执行风险度量

工作表, 用于输入和显示相关数据及图表信息

合约条款 市场数据 模型校准 定价估值 风险度量

# QPRLib —— Autocall(SB)

**Step 1:** In the menu bar, click “Product Selection” to create a product template.

The screenshot shows the QPRLib software interface. The 'Product Selection' menu is open, and the 'Autocall Series' sub-menu is selected. The main window displays a spreadsheet with the following data:

产品合约条款		
市场参数	边界参数	敲出观察日期
估值日股价St	敲出边界(%)	2024-12-02
无风险利率(%)	敲入边界(%)	2025-01-01
标的红利率(%)	敲出观察频率	2025-02-03
年化波动率(%)	估值日敲入已触发?	2025-03-03
经典雪球(自动赎回)		2025-04-01
5.946		2025-05-01
		2025-06-02
		2025-07-01
		2025-08-01
		2025-09-01
		2025-10-01
		2025-11-03

经典雪球描述:  
情形A: 某敲出日期敲出,且之前敲入, 敲出收益=R(年化);  
情形B: 某敲出日期敲出,且之前未敲入, 敲出收益=R(年化);  
情形C: 所有敲出日期均未敲出,且到期之前发生敲入, 到期损益=MIN(标的涨跌幅, 0);  
情形D: 所有敲出日期均未敲出,且到期之前未发生敲入, 到期损益=R(年化);

# QPRLib —— Autocal(SB)

**Step 2:** In the “Contract Terms” worksheet, modify the corresponding product parameters.

Quantitative Pricing Risk Library

中国场外衍生品-雪球结构定价

产品ID: Equity\_SB

产品合约条款							
基本参数		市场参数		边界参数		敲出观察日期	
合约标的	510050.SH	估值日股价St	1.000	敲出边界(%)	103.00	2023-11-02	
估值日期	2024-04-09	无风险利率(%)	2.500	敲入边界(%)	70.00	2023-12-04	
生效日期	2023-10-02	标的红利率(%)	0.000	敲出观察频率	Monthly	2024-01-02	
到期日期	2024-10-02	年化波动率(%)	18.000	估值日敲入已触发?	NO	2024-02-02	
交割日期	2024-10-02	生效日股价S0	1.000			2024-03-04	
合约乘数	1					2024-04-02	
年化票息R(%)	15.00					2024-05-02	
						2024-06-03	
						2024-07-02	
						2024-08-02	
						2024-09-02	
						2024-10-02	

经典雪球描述:  
情形A: 某敲出日期敲出,且之前敲入, 敲出收益=R(年化);  
情形B: 某敲出日期敲出,且之未敲入, 敲出收益=R(年化);  
情形C: 所有敲出日期均未敲出,且到期之前发生敲入, 到期损益=MIN(标的涨跌幅, 0);  
情形D: 所有敲出日期均未敲出,且到期之前未发生敲入, 到期损益=R(年化);

用户输入或通过Choice终端导入

用户输入特定衍生品特有产品参数

标的现金分红

执行流程:  
A.BS框架下定价: 1.建立产品模板; 2.导入数据; 3.执行定价估值; 4.执行风险度量  
B.LV/SV/SLV模型下定价: 1.建立产品模板; 2.导入数据; 3.校准波动率模型; 4.执行定价估值; 5.执行风险度量

合约条款 | 市场数据 | 模型校准 | 定价估值 | 风险度量

# QPRLib —— Autocal(SB)

**Step 3:** In the “Market Data” worksheet, execute the “Import Option Data” operation to import volatility data from Choice.

The screenshot shows the QPRLib software interface. The main window displays the 'Market Data' worksheet. The menu bar includes '文件', '开始', '插入', '页面布局', '公式', '数据', '审阅', '视图', '自动执行', '开发工具', '加载项', '帮助', 'Inquire', 'Acrobat', 'Choice数据', 'Wind', and 'QPRLib'. The toolbar contains icons for '产品选择', '辅助功能', '数据导入', '模型校准', '定价估值', and '风险度量'. The '数据导入' dropdown menu is open, showing 'Choice数据源' and '测试数据源' options. The 'Choice数据源' dropdown is further expanded, showing '导入期权数据(调用API接口,当前适用香港IP)' and '导入期权数据(使用Excel函数,当前不适用香港IP)'. The main worksheet area displays the title '中国场外衍生产品-雪球结构定价' and a table of volatility data. The 'Market Data' tab is selected in the bottom navigation bar.

**Quantitative Pricing Risk Library**

合约标的: 510500.SH  
估值日期: 20250516

备注: 1.当前工作表说明,用户若仅调用BS定价,请转到定价估值表,在此无需操作,若需调用其他模型定价,可在菜单栏/数据导入中选择导入默认波动率曲面或链接数据库!

**数据对象**

defaultData@

期权原始波动率曲面				
最左列:执行价格序列;首行:剩余到期序列				
0.0000	0.0438	0.1342	0.2740	0.5425
0.7925	0.3742	0.0000	0.2373	0.2150
0.8087	0.3536	0.2668	0.2259	0.2128
0.8491	0.2942	0.2312	0.2078	0.2027
0.8895	0.2415	0.2072	0.1927	0.1938
0.9300	0.1912	0.1881	0.1843	0.1889
0.9704	0.1606	0.1765	0.1766	0.1835
1.0108	0.1553	0.1696	0.1762	0.1815
1.0513	0.1652	0.1733	0.1769	0.1827
1.0917	0.1875	0.1841	0.1823	0.1823
1.1321	0.2283	0.2000	0.1880	0.1858
1.1726	0.2800	0.2184	0.1979	0.1878

期权插值波动率曲面				
最左列:执行价格序列;首行:剩余到期序列				
0.0000	0.0438	0.1342	0.2740	0.5425
0.7925	0.3742	0.2700	0.2373	0.2150
0.8087	0.3536	0.2635	0.2259	0.2128
0.8491	0.2942	0.2312	0.2078	0.2027
0.8895	0.2415	0.2072	0.1927	0.1938
0.9300	0.1912	0.1881	0.1843	0.1889
0.9704	0.1606	0.1765	0.1766	0.1835
1.0108	0.1553	0.1696	0.1762	0.1815
1.0513	0.1652	0.1733	0.1769	0.1827
1.0917	0.1875	0.1841	0.1823	0.1823
1.1321	0.2283	0.2000	0.1880	0.1858
1.1726	0.2800	0.2184	0.1979	0.1878

底部导航栏: 合约条款 | **市场数据** | 模型校准 | 定价估值 | 风险度量

底部状态栏: 权益类产品默认数据导入完成

# QPRLib —— Autocal(SB)

**Step 4:** In the “Model Calibration” worksheet, select a specific pricing model, then perform the “Model Calibration” operation to obtain the calibrated model parameters and compare market results with the model outputs.

**确定C4单元格中的模型之后，点击校准模型**

**选择需要校准的模型**

**模型校准方法设置**

**对于Heston模型，此部分为Heston模型优化参数**

**校准后模型对应的波动率曲面**

**市场与模型波动率曲面比较**

Quantitative Pricing Risk Library

中国场外衍生品-雪球结构定价

校准模型: SLV(Heston+LV)

SLV模型描述

$$dS/S = rdt + \sqrt{v}L(t,S)dW1$$

$$dv = \kappa(\theta - v)dt + \xi \sqrt{v}dW2$$

$$dW1dW2 = \rho dt$$

Heston校准方法: 校准3个参数  
LV校准方法: TanhCosh

Heston校准结果					
参数名	$\theta$	$\kappa$	$\xi$	$\rho$	$v0$
初始参数	0.017	2.000	1.000	-0.100	0.017
优化参数	0.053	2.000	0.344	-0.090	0.017
满足Feller:	TRUE				

SLV校准波动率曲面					
最左列: 执行价格序列(K/S0); 首行: 剩余到期序列(T)					
0.841	0.048	0.115	0.210	0.460	
0.862	0.244	0.185	0.187	0.179	
0.882	0.218	0.174	0.180	0.176	
0.903	0.193	0.166	0.173	0.174	
0.923	0.170	0.158	0.168	0.172	
0.944	0.152	0.152	0.163	0.170	
0.964	0.139	0.148	0.160	0.168	
0.985	0.132	0.144	0.157	0.167	
1.005	0.131	0.143	0.155	0.166	
1.026	0.135	0.143	0.154	0.166	
1.046	0.144	0.145	0.155	0.165	
1.067	0.159	0.148	0.156	0.165	
1.087	0.178	0.151	0.158	0.165	
1.108	0.198	0.156	0.160	0.166	

备注: 1.当前工作表说明: 用户若仅调用BS定价, 请转到定价估值表, 在此无需操作; 若需调用其他模型定价, 请在上一“市场数据”表中导入波动率曲面, 并在此选择模型后并点击菜单栏“模型校准”按钮进行校准。

SLV模型校准完成, 运行时间: 2.576172秒

# QPRLib —— Autocal(SB)

**Step 5:** In the “Pricing & Valuation” worksheet, set the model and calculation method, then click the “Pricing & Valuation” button to compute the results.

模型校准完成，并且在C5单元格选择相应的计算方法后，点击按钮执行定价估值

中国场外衍生产品-雪球结构定价

定价模型: LV PDE

计算方法: LV PDE

备注:

1. 当前工作表说明用户可点击菜单栏“定价估值”按钮进行定价; 除BS模型外, 均需首先在“市场数据”表导入数据并在“模型校准”表中校准模型。
2. 计算结果为(标准Greeks+合约乘数)对应结果: Delta/Gamma-标准Delta/Gamma; Vega-标准Vega/100; rho-标准rho/10000; theta-标准theta/365。
3. PDE计算时 Ms是对单位长度的划分数, Mt是对1年的划分数。

计算结果						
定价模型	Price	Delta	Gamma	Vega	Theta	Rho
LV Model(PDE)	1.120E+00	-9.141E-03	-9.755E-01	-3.668E-03	1.450E-06	-4.272E-05

设置定价模型与计算方法

定价结果显示区域

计算参数	
标准化Smin	0
标准化Smax	5
T方向-1年-区间数Mt	500
S方向-单位长度-区间数Ms	500

用户可以在此输入定价相关参数

定价估值程序执行完成

# QPRLib —— Autocal(SB)

**Step 6:**  
In the Risk Measurement worksheet, set the scenario analysis parameters and click the Risk Measurement button to perform the result calculation.

产品选择 辅助功能 数据导入 模型校准 定价估值 风险度量 帮助

产品目录 金融衍生品估值定价流程 说明

Quantitative Pricing Risk Library

中国场外衍生产品-雪球结构定价

备注  
1.当前工作表说明,用户可选择X轴为标的价格或波动率,表示其变动时,产品价格及风险参数的变动,目前仅针对BS模型的计算。

设置情景分析参数

X轴: Spot  
起始点: -40.00% 结束点: 40.00% 步长: 10.00%

		情景分析表格								
		标的价格								
		0.600	0.700	0.800	0.900	1.000	1.100	1.200	1.300	1.400
Price(%)		-45.99%	-36.98%	-8.57%	0.38%	0.00%	-2.08%	-2.25%	-2.25%	-2.25%
Delta(%)		-442.24%	-443.46%	-765.13%	-203.22%	0.00%	-72.54%	-99.78%	-100.00%	-100.00%
Gamma(%)		-100.09%	-104.88%	864.28%	256.98%	0.00%	-203.98%	-101.52%	-100.00%	-100.00%
Price		0.600	0.700	1.016	1.115	1.111	1.088	1.086	1.086	1.086
Delta		1.000	1.004	1.944	0.302	-0.292	-0.080	-0.001	0.000	0.000
Gamma		0.002	0.123	-24.326	-9.006	-2.523	2.623	0.038	0.000	0.000
Vega		0.000	0.000	-0.013	-0.006	-0.001	0.000	0.000	0.000	0.000
Theta		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Rho		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

情景分析结果表格数据显示

情景分析结果图形显示

Price

Delta

Gamma

Vega

风险度量

# QPRLib—Convertible Bond

**Convertible bonds** (short for *convertible corporate bonds*, also known simply as *convertibles*) are a special type of corporate bond that can be converted into common stock at specific times and under certain conditions.

Convertible bonds combine the characteristics of both debt and equity. Like other bonds, they carry a fixed interest rate and maturity date, allowing investors to hold them until maturity and receive principal plus interest. At the same time, during the conversion period, holders have the right to convert the bonds into a certain number of shares at the predetermined conversion price.

# QPRLib——Convertible Bond

**Step 1:** Click “Product Selection / Interest Rate Derivatives / Convertible Bonds” to create a convertible bond product template.

The screenshot shows the QPRLib software interface. The top menu bar includes '产品选择' (Product Selection), '辅助功能' (Auxiliary Functions), '数据导入' (Data Import), '模型校准' (Model Calibration), '定价估值' (Pricing and Valuation), and '风险度量' (Risk Measurement). The '产品选择' menu is open, showing a hierarchy: '权益类衍生品' (Equity Derivatives) > '利率类衍生品' (Interest Rate Derivatives) > '可转换债券' (Convertible Bonds). A red arrow points to the '可转换债券' option with the text '点击按钮创建可转债产品模板' (Click the button to create a convertible bond product template).

The main spreadsheet area is titled '中国利率衍生产品-可转债定价' (China Interest Rate Derivative Product - Convertible Bond Pricing). It contains several tables for product parameters and contract terms.

产品ID: 估值日:		产品合约条款				正股波动率		正股历史收盘价	
转债代码	利率互换期权	转债票息参数	转股条款	赎回条款	回售条款	历史波动率(30天年化)			
转债简称	信贷ABS	第一年	起始转股日	赎回触发价	起始回售日	历史波动率(24月年化)			
正股代码		第二年	当前转股价	赎回条款(N)	回售触发价	历史波动率(60月年化)			
正股简称		第三年		赎回条款(M)	回售条款(N)				
发行日/起息日		第四年		年度允许次数	回售条款(M)				
到期日		第五年		到期赎回价	年度允许次数				
估值日		第六年							
正股价格	ACT/365F								
计息规则									
波动率									
无风险利率									
隐含价差	0.00%								
红利率	0.00%								
违约概率	0.00%								
违约回收率	100.00%								
违约股价跌幅	0.00%								
转债年数									

**执行流程:**  
 第一步. 点击菜单栏:数据导入/Choice数据源/导入转债数据/第一步:获取所有转债交易代码;  
 第二步. 在C10单元格选择需要定价的可转债; 然后点击菜单栏:数据导入/Choice数据源/导入转债数据/第二步:更新单只转债特有信息;  
 第三步. 点击菜单栏按钮: 定价估值. 在第二个工作表中查看结果。

The bottom status bar shows '可转换债券模板创建完成' (Convertible Bond Template Creation Complete) and '90%' zoom level.

# QPRLib——Convertible Bond

**Step 2:** After confirming the valuation date, click the “Step 1” button to import all convertible bond codes. Then, select the convertible bond code in cell C10, and click the “Step 2” button to import the specific information of the selected bond.

The screenshot shows the QPRLib software interface. The 'Choice数据源' menu is open, with '导入转债数据' selected. Below the menu, there are two steps: '第一步:获取所有转债交易代码' and '第二步:更新单只转债特有信息'. The main window displays a table with bond data for '110063.SH'.

转债基本参数		转债票息参数		转股条款		赎回条款		回售条款		正股波动率		正股历史收盘价	
转债代码	110063.SH	第一年	0.30%	起始转股日	2020-06-19	起始赎回日	2020-06-19	起始回售日	2023-12-13	历史波动率(100周年化)	38.92%	2025-04-01	1.79
转债简称	鹰19转债	第二年	0.50%	当前转股价	1.76	赎回触发价	130.00%	回售触发价	70.00%	历史波动率(24月年化)	29.91%	2025-04-02	1.80
正股代码	600567.SH	第三年	0.90%			赎回条款(N)	15	回售条款(N)	30	历史波动率(60月年化)	25.59%	2025-04-03	1.79
正股简称	山鹰国际	第四年	1.50%			赎回条款(M)	30	回售条款(M)	30			2025-04-07	1.61
发行日/起息日	2019-12-13	第五年	2.00%			年度允许次数	-1	年度允许次数	-1			2025-04-08	1.61
到期日	2025-12-13	第六年	2.50%			到期赎回价	111.00%					2025-04-09	1.62
估值日	2025-05-16											2025-04-10	1.65
正股价格	1.71											2025-04-11	1.66
计息规则	ACT/365F											2025-04-14	1.66
波动率	38.70%											2025-04-15	1.65
无风险利率	2.00%											2025-04-16	1.63
红利率	0.00%											2025-04-17	1.63
初始违约强度	0.02											2025-04-18	1.63
违约回收率	40.00%											2025-04-21	1.67
违约股价跌幅	50.00%											2025-04-22	1.67
转债年数	6											2025-04-23	1.66
												2025-04-24	1.67
												2025-04-25	1.68
												2025-04-28	1.72
												2025-04-29	1.69
												2025-04-30	1.68
												2025-05-06	1.72
												2025-05-07	1.75
												2025-05-08	1.74
												2025-05-09	1.73
												2025-05-12	1.74
												2025-05-13	1.74
												2025-05-14	1.74
												2025-05-15	1.72
												2025-05-16	1.71

# QPRLib——Convertible Bond

**Step 3:** In the “Pricing & Valuation” worksheet, click the “Pricing & Valuation” button to perform the result calculation.

Quantitative Pricing Risk Library

中国利率衍生产品 - 可转债定价

定价模型: BS  
计算方法: PDE

计算参数	
时间剖分数	1000
空间剖分数	1000
差分格式	Implicit
等价边界模拟次数	50000

计算结果	
Price	184.919

定价估值程序执行完成

# Black-Scholes(BS)

## ◆ Process

Under the Black–Scholes (BS) model, the underlying asset price follows a lognormal distribution, with volatility assumed to be a constant  $\sigma$  :

$$dS/S = (r - q)dt + \sigma dW_t$$

Since the option price is monotonically increasing with respect to  $\sigma$  , there exists a one-to-one relationship between volatility and option price. The volatility  $\sigma_{imp}$  inferred from market-traded option prices is called **implied volatility**. The collection of implied  $\sigma_{imp}(K, T)$  across different strike prices K and maturities T forms the **implied volatility surface**.

# Local Volatility(LV)

## ◆ Process

Under the Local Volatility (LV) model, the underlying asset price follows a lognormal distribution, where volatility is a deterministic function of  $S$  and  $t$ , denoted as  $\sigma_{LV}(S, t)$

$$dS/S = (r - q)dt + \sigma_{LV}(S, t)dW_t$$

The LV model is generally divided into two categories:

1. Parametric models: If  $\sigma_{LV}(S, t)$  is expressed in a parametric form, such as the CEV model,  $\sigma(S, t) = \sigma_0 S^{\beta-1}$
2. Dupire model: Since  $\sigma_{LV}(S, t)$  corresponds one-to-one with the implied volatility  $\sigma_{imp}(K, T)$ , the market implied volatility surface uniquely determines the local volatility function  $\sigma(K, T)$ ;

**In QPRLib, the implemented version is the Dupire model.**

# Local Volatility(LV)

## ◆ Dupire Model

The Dupire model is generally expressed in three forms, corresponding to derivatives with respect to: “Option Price”, “Implied Volatility”, “Total variance”

### ① $C(K, T)$

$$\sigma_{LV}^2(K, T) = \frac{2\left(\frac{\partial C}{\partial T} + (r-q)K\frac{\partial C}{\partial K} + qC\right)}{K^2\frac{\partial^2 C}{\partial K^2}}$$

### ② $\sigma_{imp}(K, T)$

$$\sigma_{LV}^2(K, T) = \frac{2\left(\frac{\partial \sigma_{imp}}{\partial T} + \frac{\sigma_{imp}}{2T} + (r-q)K\frac{\partial \sigma_{imp}}{\partial K}\right)}{K^2\left[\frac{\partial^2 \sigma_{imp}}{\partial K^2} - d\sqrt{T}\left(\frac{\partial \sigma_{imp}}{\partial K}\right)^2 + \frac{1}{\sigma_{imp}}\left(\frac{1}{K\sqrt{T}} + d\frac{\partial \sigma_{imp}}{\partial K}\right)^2\right]}, d = \frac{\ln\left(\frac{S_0}{K}\right) + \left(r - q + \frac{1}{2}\sigma_{imp}^2\right)T}{\sigma_{imp}\sqrt{T}}$$

### ③ $\omega(K, T) = \sigma_{imp}^2 T$ 【QPRLib Default】

$$\sigma_{LV}^2(K, T) = \frac{\frac{\partial \omega}{\partial T}}{1 - \frac{y}{\omega} \frac{\partial \omega}{\partial y} + \frac{1}{4}\left(-\frac{1}{4} - \frac{1}{\omega} + \frac{y^2}{\omega^2}\right)\left(\frac{\partial \omega}{\partial y}\right)^2 + \frac{1}{2}\frac{\partial^2 \omega}{\partial y^2}}, y = \ln\left(\frac{K}{F_T}\right), F_T = S_0 e^{\int_0^T dt \mu(t)}$$

# Local Volatility(LV)

## ◆ Implied Volatility Surface Interpolation

The Dupire model requires solving first- and second-order derivatives with respect to variables. However, market-traded points are often discrete, so the market surface must be interpolated to obtain a complete implied volatility surface. **QPRLib implements three interpolation methods for this purpose.**

① TanhCosh:  $\sigma(X; \{\sigma_{ATM}, A, B, C, D\}) = \sigma_{ATM} + A \tanh[B(X - 1)] + C \left(1 - \frac{1}{\cosh[D(X-1)]}\right), X = K/S_0$

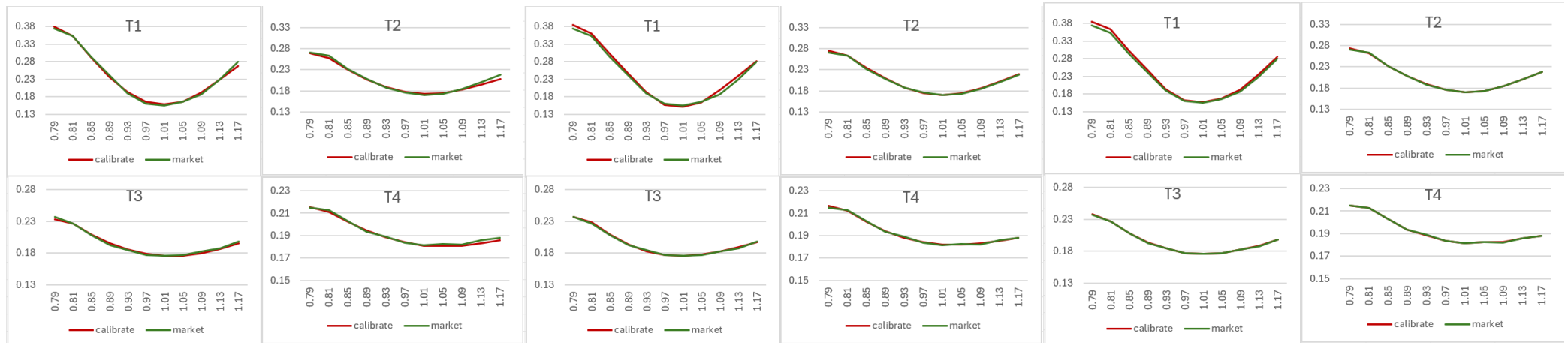
② SVI:  $\omega(k; \{a, b, \rho, m, \sigma\}) = a + b \left\{ \rho(k - m) + \sqrt{(k - m)^2 + \sigma^2} \right\}, k = \ln\left(\frac{K}{S_0}\right), \omega$  为 total variance

③ CubicSpline: N/A

For the above implied volatility models, the **Levenberg–Marquardt** method is typically used to optimize the fixed constant parameters for each term. Once the full implied volatility surface is obtained, derivatives are taken from the complete surface to derive the corresponding local volatility.

# Local Volatility(LV)

◆ Based on QPRLib/Excel test data



**TanhCosh**

**SVI**

**CubicSpline**

Model	L1 Error	L2 Error
TanhCosh	0.10934	0.00056
SVI	0.10142	0.00063
CubicSpline	0.07122	0.00048

# Stochastic volatility(SV)

## ◆ Process

Under the Stochastic Volatility (SV) model, the volatility of the underlying asset is represented as a stochastic process (such as a square-root process). Common SV models include:

Heston

$$\begin{aligned}dS/S &= (r - q)dt + \sqrt{y}dW_t^1 \\ dy &= \kappa(\theta - y)dt + \xi\sqrt{y}dW_t^2\end{aligned}$$

SABR

$$\begin{aligned}dF &= \sigma F^\beta dW_t^1 \\ d\sigma &= \gamma\sigma dW_t^2\end{aligned}$$

In **QPRLib**, the implemented model is the **Heston model**.

The calibration problem of the Heston model is described as follows: using the market implied volatility surface to calibrate the constant parameters  $\{\kappa, \theta, \xi, \rho, y_0\}$ .

# Stochastic volatility(SV)

## ◆ Heston calibration

In the Heston model, there are five parameters to be determined. According to their influence on different aspects of the volatility curve (for a given maturity  $T_i$ ), they can be grouped into three categories:

**level:**  $\theta, y_0$  --> The larger these values, the higher the overall level of volatility. They can be set as the square of the ATM volatility.

**slope:**  $\rho$  --> - Ranging from -1 to 1, the volatility curve shifts from downward-sloping to upward-sloping.

**curvature:**  $\kappa, \xi$  -->  $\kappa$  increases from 0, the overall curvature of the volatility curve flattens, and the level decreases.  $\xi$  increases from 0, the curvature of the volatility curve becomes more pronounced (the smile becomes more evident), and the level decreases.

In **QPRLib**, the parameters are optimized using the **Levenberg–Marquardt** method. The implementation provides two approaches:

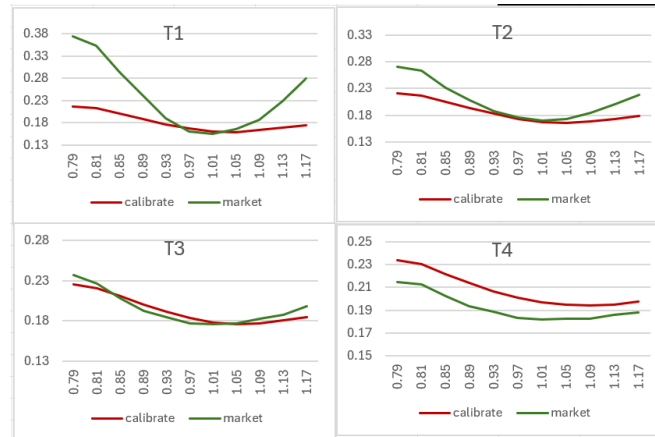
**5-parameter optimization:** Optimize all five parameters  $\{\kappa, \theta, \xi, \rho, y_0\}$ .

**3-parameter optimization:** Fix  $\{\kappa, y_0\}$ , and optimize  $\{\theta, \xi, \rho\}$ .

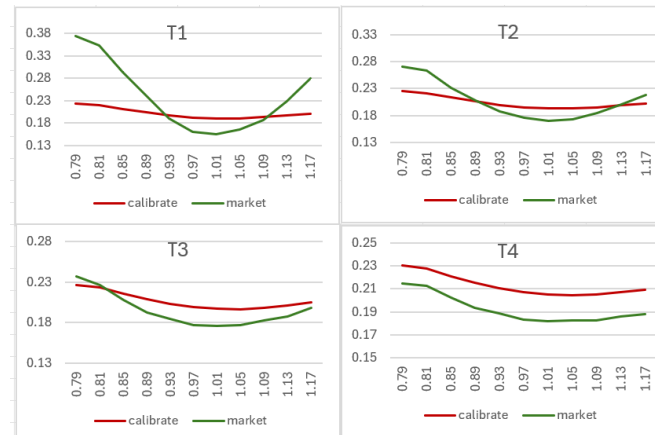
# Stochastic volatility(SV)

◆ Based on QPRLib/Excel test data

Optimize 3 parameters



Optimize 5 parameters



Heston Calibration	L1 Error	L2 Error
Optimize 3 Parameters	1.1383	0.08280
Optimize 5 Parameters	1.2065	0.07196

# Stochastic local volatility(SLV)

## ◆ Process

Under the Stochastic Local Volatility (SLV) model, the volatility of the underlying asset is expressed as the product of a local volatility function (leverage function) and a stochastic process (such as a square-root process). In QPRLib, the SLV model is specifically defined as follows:

$$\begin{aligned}dS/S &= (r - q)dt + L(S, t)\sqrt{y}dW_t^1 \\ dy &= \kappa(\theta - y)dt + \xi\sqrt{y}dW_t^2 \\ dW_t^1 dW_t^2 &= \rho dt\end{aligned}$$

The calibration problem of the SLV model is described as follows: **using the market implied volatility surface to calibrate the constant parameters  $\{\kappa, \theta, \xi, \rho, y_0\}$  as well as the function  $L(S, t)$ .**

# Stochastic local volatility(SLV)

◆ The Option price  $V(s, y, t)$  with SLV model satisfies the PDE

$$\partial_t V = \mathcal{L}V, S > 0, y > 0, t > 0$$

$$V_0 = (S - K)^+$$

$$\text{其中, } \mathcal{L}V = \frac{1}{2}(SL)^2 y \partial_{SS} V + (r - q)S \partial_S V + \frac{1}{2} \xi^2 y \partial_{yy} V + \kappa(\theta - y) \partial_y V + \rho SL \xi y \partial_{Sy} V - rV$$

# Stochastic local volatility(SLV)

◆ The density function  $P(s, y, t)$  of  $(S_t, y_t)$ , satisfies the Fokker-Planc function

$$\partial_T P = \mathcal{L}^* P, S > 0, y > 0, T > 0$$

$$P_0 = \delta(S_0 - S)\delta(y_0 - y)$$

$$\mathcal{L}^* P = \partial_{SS} \left( \frac{1}{2} (SL)^2 y V \right) - \partial_S ((r - q)SV) + \partial_{yy} \left( \frac{1}{2} \xi^2 y V \right) - \partial_y (\kappa(\theta - y)V) + \partial_{Sy} (\rho SL \xi y V) - rV$$

To simplify the representation of subsequent numerical algorithms, we define the following operator:  $\mathcal{L}^* \triangleq F_0 + F_1 + F_2$ , where  $F_0, F_1, F_2$  denote the operators for the **cross term**, the **S-direction**, and the **y-direction**, respectively.

Note that the term  $-rV$  is evenly distributed between  $F_1, F_2$ .

# Stochastic local volatility(SLV)

◆  $L(S, t)$  satisfies the formula

$$L^2(S, t) = \frac{\sigma_{LV}^2(S, t)}{E[y_t | S_t = S]} \dots\dots\dots (1)$$
$$= \frac{\sigma_{LV}^2(S, t)}{\frac{\int_0^\infty y \cdot P(S, y, t) dy}{\int_0^\infty P(S, y, t) dy}} \dots\dots\dots (2)$$

Here,  $\sigma_{LV}(S, t)$  denotes the **local volatility**.

The **MC (Monte Carlo) algorithm** performs model calibration by solving the expectation based on Equation (1), While the **PDE (Partial Differential Equation) algorithm** performs model calibration by solving the probability density function based on Equation (2).

# Stochastic local volatility(SLV)

◆ Based on QPRLib/Excel test data——volatility surface :

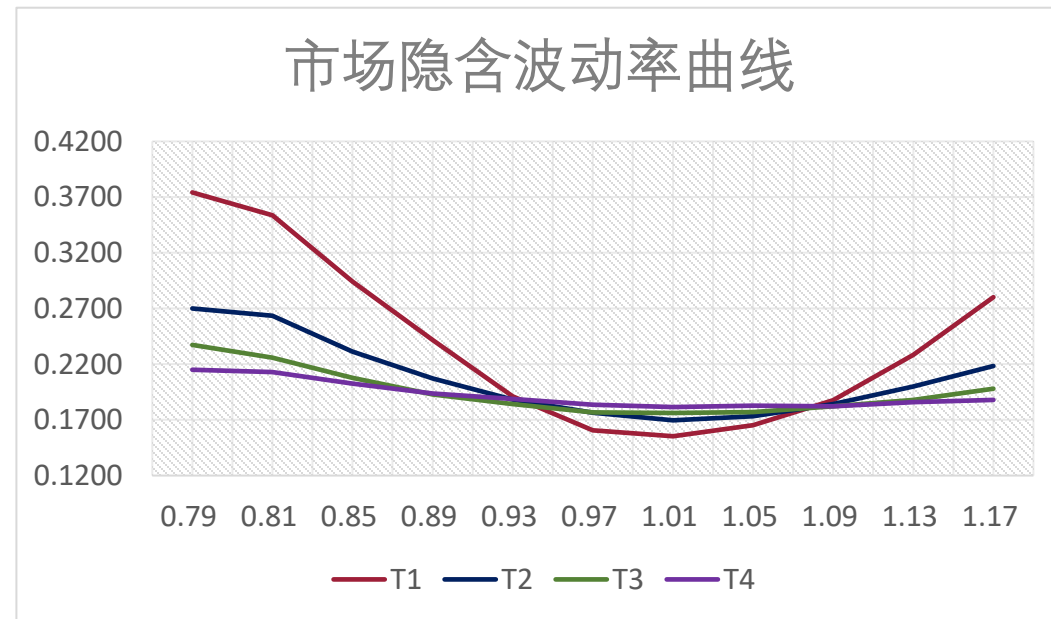
relative strikes = {0.7925,0.8087,0.8491,0.8895,0.93,0.9704,1.0108,1.0513,1.0917,1.1321,1.1726}

maturities = {0.0438, 0.1342, 0.274, 0.5425}

surface={

- {0.3742, 0.2700, 0.2373, 0.215},
- {0.3536, 0.2635, 0.2259, 0.2128},
- {0.2942, 0.2312, 0.2078, 0.2027},
- {0.2415, 0.2072, 0.1927, 0.1938},
- {0.1912, 0.1881, 0.1843, 0.1889},
- {0.1606, 0.1765, 0.1766, 0.1835},
- {0.1553, 0.1696, 0.1762, 0.1815},
- {0.1652, 0.1733, 0.1769, 0.1827},
- {0.1875, 0.1841, 0.1823, 0.1823},
- {0.2283, 0.2000, 0.1880, 0.1858},
- {0.2800, 0.2184, 0.1979, 0.1878}}

Heston parameters={ $\kappa = 0.811, \theta = 0.13, \xi = 0.451, \rho = -0.282, y_0 = 0.025$ }



# Stochastic local volatility(SLV)

◆ Based on QPRLib/Excel test data—grid parameters:

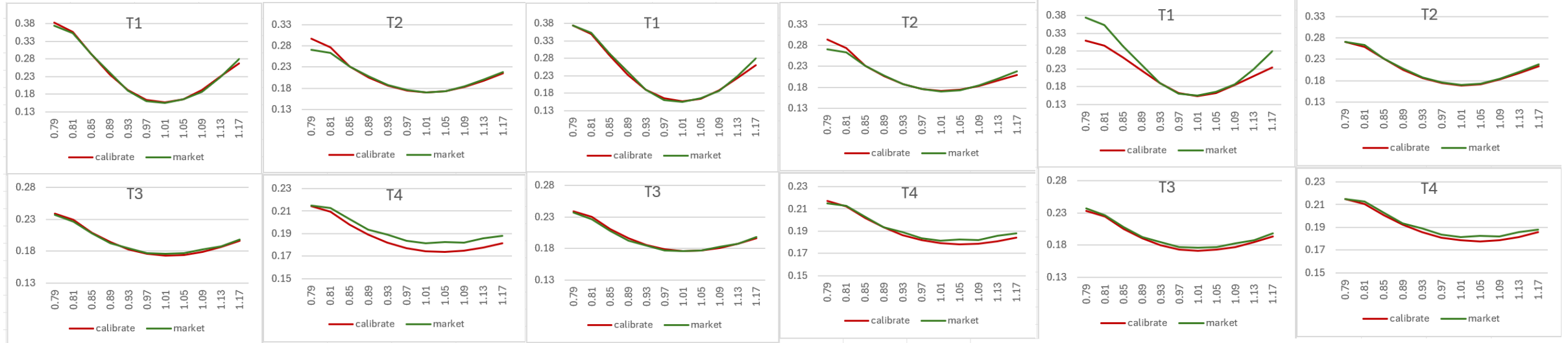
Direction	Min	Max	N	
T	0	0.5967	~45	N/A
K	0.4097	2.5129	~200	99.999942% Range (+/-5 $\sigma$ )
Y	0	1.0516	~300	99.999999% Range

# Stochastic local volatility(SLV)

◆ Based on QPRLib/Excel test data :

Index	Library	Method	Grid	Time(senonds) 【C++/release】	L1 Error	L2 Error	Each step
M1	QPRLib	PDE-Default	uniform	0.30913	0.18406	0.00174	2 Implicit + 1 Explicit
M2		PDE-MCS	Non-uniform in S	0.61412	0.15389	0.00149	4 Implicit + 3 Explicit
M3		<i>PDE-Iteration</i>	<i>Non-uniform in S</i>	<i>22.6866</i>	<i>0.33462</i>	<i>0.01154</i>	
M4		MC(2025-5-3 update)	Non-uniform in S	1.1296	0.18171	0.00234	$2^{16}$ path
M5	QuantLib	PDE-MCS	Non-uniform in S and t	2.5648	0.48328	0.01043	4 Implicit + 3 Explicit
M6		MC	Non-uniform in S and t	1.5535	0.59856	0.01418	$2^{16}$ path

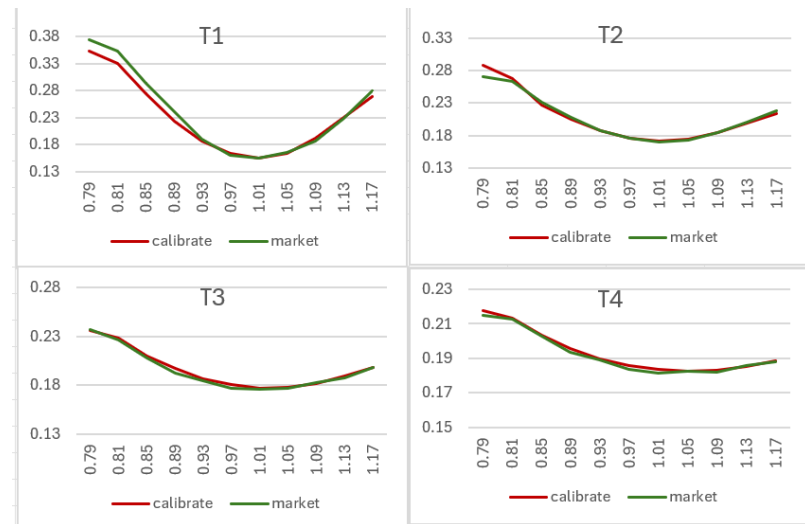
# Stochastic local volatility(SLV)



M1:QPRLib-PDE-Default

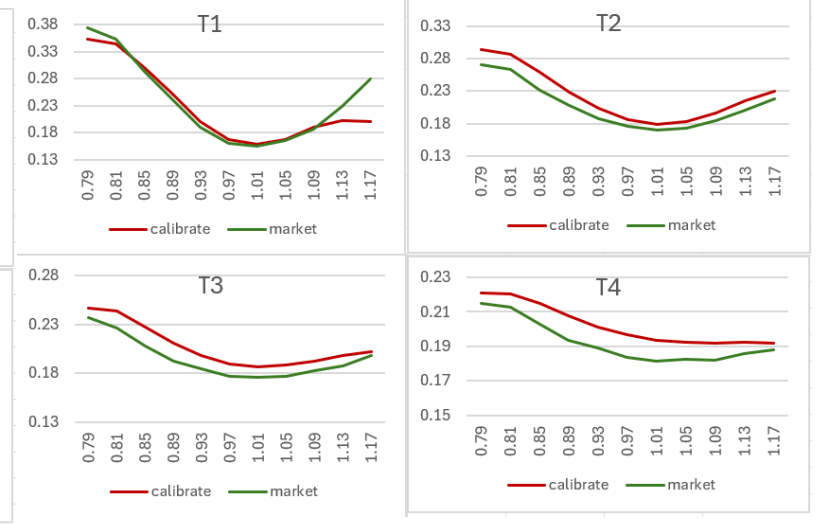
M2:QPRLib-PDE-MCS

M3:QPRLib-PDE-Iteration



M4:QPRLib-MC

M5:QuantLib-PDE-MCS



M6:QuantLib-MC

# Stochastic local volatility(SLV)

◆ M1~M6 Algorithm:

Time step	Calculate $L(S, t)$	PDE Method: Compute the density function at the next time step (denominator of Equation 2). MC Method: Compute the conditional expectation at the next time step (denominator of Equation 1).
$T_0 = 0$	$L(S, 0) = \frac{\sigma_{LV}(S, 0)}{\sqrt{y_0}}$	Based on $L(S, T_0)$ , Calculate $P(S, y, T_1)$ or $E[y_{T_1}   S_{T_1} = S]$
$T_1 = dt$	Calculate $L(S, T_1)$	Based on $L(S, T_1)$ , Calculate $P(S, y, T_2)$ or $E[y_{T_2}   S_{T_2} = S]$
.....	.....	.....

# Stochastic local volatility(SLV)

## ◆ Numerical schemes for solving the density function PDE in M2 and M5:

Both M2 and M5 are based on the Modified Craig–Sneyd (MCS) scheme for computing two-dimensional PDEs, implemented respectively in QPRLib and QuantLib.

$$\left\{ \begin{array}{l} Y_0 = P_{n-1} + \Delta t F(t_{n-1}, P_{n-1}) \\ Y_j = Y_{j-1} + \theta \Delta t (F_j(t_n, Y_j) - (F_j(t_{n-1}, P_{n-1}))), (j = 1, 2) \\ \hat{Y}_0 = Y_0 + \theta \Delta t (F_0(t_n, Y_2) - (F_0(t_{n-1}, P_{n-1}))) \\ \tilde{Y}_0 = \hat{Y}_0 + (\frac{1}{2} - \theta) \Delta t (F(t_n, Y_2) - (F_0(t_{n-1}, P_{n-1}))) \\ \tilde{Y}_j = \tilde{Y}_{j-1} + \theta \Delta t (F_j(t_n, \tilde{Y}_j) - (F_j(t_{n-1}, P_{n-1}))), (j = 1, 2) \\ P_n = \tilde{Y}_2 \end{array} \right.$$