Using the Model Framework in an Analytics Package

Product Version: **1.18**

Document Revision: **A**

Date: **March 2017**

Terms Of Use

Table of Contents

List of Tables

Preface

This preface includes information on the following topics:

- Typographic conventions
- Contacting Markit Analytics
- Revision history

Typographic Conventions

This manual uses the typographic conventions shown in the following table.

Convention	Uses	Example
Italic body text	• New terms where they are defined • Book titles	• ...the hierarchy data fields are also called *aggregation keys*. • The *MASF Instrument Reference* gives a summary...
Bold body text	• Emphasis • Graphical user interface labels	• The difference between a **forward** contract and a **futures** contract... • In the **Schedule** area, click **Generate**.
`Monospaced`	• File names and path names • Program code and names of entities defined by code • Commands or data that you enter literally	• the `Holidays.csv` file in the `MarketData` folder • the `FXForward` instrument • Select `FIXATSTART` from the dropdown list.
`Monospaced italic`	• Variable data for which you substitute your own value • Parameter names of MA Script functions where the functions are defined	• *`Vol1,...,VolN`* • `const deep var fnDateRule(`*`nMonth, nYear, g1dtNonBus`*`)`
Light aqua body text	Cross-references and hypertext links	For details, see Technical Support on page 16.

Contacting Markit Analytics

Website

www.ihsmarkit.com

Technical Support

ma-support@markit.com

All countries (toll): +1 306 781 8777

Canada and U.S.A. (toll-free): +1 877 689 1888

Revision History

Product Version	Document Revision	Key Changes
1.18	A	Corrected all chapters: • In the market data map, `aFXImpliedVolCurve` input can only be of type `ImpliedVol`; removed `FXImpliedVol`. Updated the "Common Features" chapter for design changes: • "Historical Covariance Calculation" (updated description of function; updated model curve map inputs `astrCommodity`, `aIRCurve` and added input `aIRShortCurve`; added options map inputs `bCalculateCov` and `bCalculateIRForwardShortAverage`) Updated the "Hybrid Commodity Credit Equity Inflation Multicurrency Model with Black-Karasinski Model for Hazard Rates" chapter for design changes: • New IR calibration data extraction setting `bCalibrateIRMarketPriceOfRiskToIRCurve` Updated the "Hybrid Commodity Credit Equity Inflation Multicurrency Model" chapter for design changes: • Updated market data inputs: changed `aIRRealWorldDriftCurve` to `aIRMarketPriceOfRiskCurve` and corrected description; added inputs `aIRForwardAverageCurve` and `aIRShortAverageCurve` • New data extraction setting `aarTenorIRForwardAverage` Changed name of related manual from “Monte Carlo Simulation: Methodology and Techniques” to “Quasi-Monte Carlo: Methodology and Techniques in MA Model Framework”.

Product Version	Document Revision	Key Changes
1.17	A	Updated the “Common Features” chapter for design changes: • "Model Framework Simulator Settings" (added support for new Sobol sequences for quasi-random number generation) • Added "Historical Covariance Calculation" section Updated the “Multiurrency Multifactor Hull-White Model” chapter for design changes: • Support for choice of optimization methods Updated the "Inflation Multicurrency Multifactor Hull-White Model" chapter for design changes: • New calibration setting `strBasisCurveCalibDisc` • New data extraction settings `rSwaptionShiftstrDaycountFixed`, `nSwapTenorFixed`, `idxBasisCurveCalib`, `idxBasisCurveCalibDisc`, and `bUseBasisCurveForCalibDiscounting` Updated the "Inflation Multicurrency Multifactor Hull-White Model with Derived Inflation Indexes" chapter for design changes: • new data extraction settings `rSwaptionShiftstrDaycountFixed` and `nSwapTenorFixed` Updated the "Hybrid Credit Equity Inflation Multicurrency Model" chapter for design changes: • New calibration setting `strBasisCurveCalibDisc` • New data extraction settings `rSwaptionShiftstrDaycountFixed`, `nSwapTenorFixed`, `idxBasisCurveCalib`, `idxBasisCurveCalibDisc`, and `bUseBasisCurveForCalibDiscounting` Updated the "Hybrid Credit Equity Inflation Multicurrency Model with FX Jump at Name Default" chapter for design changes: • New calibration setting `strBasisCurveCalibDisc` • New data extraction settings `rSwaptionShiftstrDaycountFixed`, `nSwapTenorFixed`, `idxBasisCurveCalib`, `idxBasisCurveCalibDisc`, and `bUseBasisCurveForCalibDiscounting` • New data extraction and calibration classes that work with the historical calibration output Updated the "Hybrid Commodity Credit Equity Inflation Multicurrency Model with Black-Karasinski Model for Hazard Rates" chapter for design changes: • New calibration setting `strBasisCurveCalibDisc` • New data extraction settings `rSwaptionShiftstrDaycountFixed`, `nSwapTenorFixed`, `idxBasisCurveCalib`, `idxBasisCurveCalibDisc`, and `bUseBasisCurveForCalibDiscounting` Updated the "Hybrid Commodity Credit Equity Inflation Multicurrency Model" chapter for design changes: • New calibration setting `strBasisCurveCalibDisc` • New data extraction settings `rSwaptionShiftstrDaycountFixed`, `nSwapTenorFixed`, `idxBasisCurveCalib`, `idxBasisCurveCalibDisc`, and `bUseBasisCurveForCalibDiscounting` Corrected the "Inflation Multicurrency Multifactor Hull-White Model with Derived Inflation Indexes" chapter (it does not support implied calibration of the IR volatility): • Table "Data Extraction Settings Map for FX_IF_IR_HW_NF_DI" (removed the map keys `ampDataExtractionSettingsIR`, `ampDataExtractionSettingsFX`, and `ampBasisCurveSettings`) • Removed the section "IR Calibration Data Extraction Settings (FX_IF_IR_HW_NF_DI)" • Added an example of data extraction settings
1.16	B	Corrected the Model Framework models version to 3.0.

Product Version	Document Revision	Key Changes
1.16	A	In “Related Manuals” table, replaced the set of individual model methodology documents with the single combined one *Markit Analytics Model Framework Mathematical Reference*, and updated the cross-references in all model chapters. Updated chapter “Common Features”: • Added new simulator parameter `bUseEuler`. • Removed information relating to obsolete method of external calibration. Updated chapter “Single-Currency Single-Factor Hull-White Model” for design changes: • Support for new simulator parameter `bUseEuler`. • New calibration setting `strBasisCurveCalibDisc`. • New data extraction settings `rSwaptionShift`, `strDaycountFixed`, `nSwapTenorFixed`, `idxBasisCurveCalib`, `idxBasisCurveCalibDisc`, `bUseBasisCurveForCalibDiscounting`. Updated chapter “Single-Currency Multifactor Hull-White Model” for design changes: • Support for new simulator parameter `bUseEuler`. • Support for choice of optimization methods. • New calibration setting `strBasisCurveCalibDisc`. • New data extraction settings `strDaycountFixed`, `nSwapTenorFixed`, `anCalibSwptnLength`. Updated chapter “Multicurrency Single-Factor Hull-White Model” for design changes: • Support for new simulator parameter `bUseEuler`. • New calibration setting `strBasisCurveCalibDisc`. • New data extraction settings `rSwaptionShift`, `strDaycountFixed`, `nSwapTenorFixed`, `idxBasisCurveCalib`, `idxBasisCurveCalibDisc`, `bUseBasisCurveForCalibDiscounting`. Updated chapter “Multicurrency Multifactor Hull-White Model” for design changes: • Support for new simulator parameter `bUseEuler`. • New calibration setting `strBasisCurveCalibDisc`. • New data extraction settings `strDaycountFixed`, `nSwapTenorFixed`. Clarified chapter “Multicurrency Multifactor Hull-White Model”: • Now indicates which calibration settings are for internal calibration only. Corrected or clarified various model chapters: • All models (calibration setting `strModelParametersOutputFile` is now used only for troubleshooting) • "Single-Currency Multifactor Hull-White Model” (removed inapplicable reference to external calibration in “Market Data Inputs”) Corrected some multicurrency model chapters: • Removed incorrect constraint on calibration setting `astrCCY`. Updated “Day Count Convention Codes” in appendix “Input Codes”: • Added newly implemented values `ACT365LEAP` and `ONEONE`. • Added missing values `ACT365_25`, `ACTACT29`, `ACTFEB29`. • Improved descriptions of all conventions.
1.15	A	Added the following chapters: • “Hybrid Commodity Credit Equity Inflation Multicurrency Model with Black-Karasinski Model for Hazard Rates" • “Hybrid Commodity Credit Equity Inflation Multicurrency Model" Corrected the following chapters: • "Single-Currency Single-Factor Hull-White Model” (corrected reference to methodology document) • "Single-Currency Multifactor Hull-White Model” (replaced methodology discussion with reference to the Model Framework methodology document)
1.14	A	Updated the “Introduction” chapter for changes to the version numbers in the included models table.
1.12	B	Removed development comments throughout the document.

Product Version	Document Revision	Key Changes
1.12	A	Updated the following chapters for design changes: • “Hybrid Credit Equity Inflation Multicurrency Model” (support for derived inflation indexes) • “Hybrid Credit Equity Inflation Multicurrency Model with FX Jump at Name Default” (support for derived inflation indexes) Corrected the following chapters: • "Single-Currency Single-Factor Hull-White Model” (corrected description of `SwaptionVolCurve` in the market data map; deleted inapplicable market data input `pfXInfo`) • "Single-Currency Multifactor Hull-White Model” (deleted inapplicable market data input `pfXInfo`) • “Hybrid Credit Equity Inflation Multicurrency Model” (data extraction setting `bUseMfwkStripper` corrected to `bUseMFWKStripper`) • “Hybrid Credit Equity Inflation Multicurrency Model with FX Jump at Name Default” (data extraction setting `bUseMfwkStripper` corrected to `bUseMFWKStripper`) Added more details to the introductions of the following chapters: • "Single-Currency Single-Factor Hull-White Model” • "Single-Currency Multifactor Hull-White Model”
1.11	A	Updated the following chapters for design changes: • “Hybrid Credit Equity Inflation Multicurrency Model” (new simulator `QMCSimulator_CR_EQ_FX_IF_IR_HW_NF_BK_1F_RNM_Euler`; the simulator `QMCSimulator_CR_EQ_FX_IF_IR_HW_NF_BK_1F_RNM` now supports the setting `strDecomposition`) • “Hybrid Credit Equity Inflation Multicurrency Model with FX Jump at Name Default” (the simulator `QMCSimulator_CR_EQ_FX_IF_IR_HW_NF_JFX_RNM` now supports the setting `strDecomposition`) Clarified all model chapters to note that `Yield` curve ordinates must be positive.
1.10	A	Updated the following chapters for design changes: • “Single-Currency Single-Factor Hull-White Model” (new data extraction component for selected swaptions, and related new settings) • “Multicurrency Single-Factor Hull-White Model” (new IR data extraction settings for selected swaptions method) • “Inflation Multicurrency Multifactor Hull-White Model” (new IR data extraction settings for selected swaptions method) • “Hybrid Credit Equity Inflation Multicurrency Model” (new IR data extraction settings for selected swaptions method) • “Hybrid Credit Equity Inflation Multicurrency Model with FX Jump at Name Default” (new IR data extraction settings for selected swaptions method) Corrected the description of `aINFCurve` in the market data map of the following chapters (curve types `DiscountFactor` and `InflationRate` are also allowed): • “Inflation Multicurrency Multifactor Hull-White Model” • “Inflation Multicurrency Multifactor Hull-White Model with Derived Inflation Indexes” • “Hybrid Credit Equity Inflation Multicurrency Model” • “Hybrid Credit Equity Inflation Multicurrency Model with FX Jump at Name Default” Corrected throughout for code examples that were missing type codes.
1.9	A	Updated product version number only. Other contents unchanged.
1.8	B	Updated the “Introduction” chapter for changes to the version numbers in the included models table.

Product Version	Document Revision	Key Changes
1.8	A	Updated throughout for new simulator `QMCSimulator_FX_IF_IR_HW_NF_PWC_RNM` and associated new parameters: • `bUseForeignQuantoAdjustment` • `bUseDeterministicFXDrifts` • `bUseDeterministicInflationDrifts` • `bApproximateXIntegral` Updated the following chapters for design changes: • "Hybrid Credit Equity Inflation Multicurrency Model" (added CR calibration data extraction settings for the external generic survival probability bootstrapper) • "Hybrid Credit Equity Inflation Multicurrency Model with FX Jump at Name Default" (new setting `strSPYieldExtrap`; renamed `strSPDayCount` and `strDayCount` to `strSPDaycount` and `strDaycount`) Corrected the following chapter: • "Hybrid Credit Equity Inflation Multicurrency Model with FX Jump at Name Default" (added missing setting `strSPFrequency`)
1.7.1	A	Added the following simulator parameter for `QMCSimulator_FX_IF_IR_HW_NF_PWC_FM`: • `strDecomposition`
1.7	B	Added the following section to the chapter "Common Features": • "Model Framework Simulator Settings" (information moved from *Markit Analytics Simulation Framework User Guide*). Updated and clarified references to simulator settings in all model chapters.
1.7	A	Added the following chapter: • "Hybrid Credit Equity Inflation Multicurrency Model with FX Jump at Name Default" Updated the following chapter for design changes: • "Inflation Multicurrency Multifactor Hull-White Model" (when using `QModelCalibration_FX_IF_IR_HW_NF_ExtCal`, added ability to specify parameters externally in CSV files) Corrected the following chapter: • "Multicurrency Multifactor Hull-White Model" (data extraction plug-in for external calibration; all external calibration inputs)
1.6	A	Updated the "Introduction" chapter to include version numbers in the included models table. Corrected all multicurrency Hull-White chapters: • In the market data map, `aFXImpliedVolCurve` inputs can be of type `FXImpliedVol` or `ImpliedVol`.
1.5	A	Updated the following chapters for design change: • "Common Features" (added `bCreateDataPointInfo` to IR data extraction settings) • "Hybrid Credit Equity Inflation Multicurrency Model" (CR calibration data extraction settings)

Product Version	Document Revision	Key Changes
1.4	A	Deleted detailed information about the Model Framework market data generator from the chapter "Configuring the Model Framework Market Data Generator", and combined the remaining information about the model preferences file with that from the chapter "Interest Rate Extraction" into the new chapter "Common Features". Moved the model-specific information from these chapters into the individual model chapters. Added the following section to the "Common Features" chapter: • "Adding Credit Support to a Non-Credit Model" Reorganized all model chapters to accommodate the information now distributed into them, and filled in missing details where needed. Added the following model chapter: • "Hybrid Credit Equity Inflation Multicurrency Model" Updated all or most model chapters for the following design changes: • Optional output of calibrated model parameters and calibration data • Name of model preference `mpTradeInfo` changed to `TradeInfo`. • Added calibration option `bUseBasisCurveForCalibDiscounting` to HW models. Corrected or clarified the following model chapters: • Various (added missing calibration output settings and trade information settings) • "Multicurrency Multifactor Hull-White Model" (added settings for internal calibration; corrected description of correlation curves) • "Inflation Multicurrency Multifactor Hull-White Model" (various minor corrections)
1.2	B	Updated the following chapters for design change (parameter name `bEnsureCorrSPD` changed to `bCorrectCorrMtx`): • "Single-Currency Multifactor Hull-White Model" • "Inflation Multicurrency Multifactor Hull-White Model" • "Inflation Multicurrency Multifactor Hull-White Model with Derived Inflation Indexes" Corrected the following chapter: • "Single-Currency Multifactor Hull-White Model" (description of calibration setting `arA` in swaption diagonal method)
1.2	A	New manual.

Chapter 1

Introduction

This chapter describes the purpose and organization of this manual, identifies the instruments described in this manual, and lists related publications.

1.1 Purpose of This Manual

This manual describes how to use selected risk-neutral models of the Markit Analytics Model Framework (MFWK) to simulate risk factors in a Markit Analytics Simulation Framework™ (MASF™) portfolio calculation job.

1.1.1 Included Models

The following table identifies the Model Framework models documented in this manual.

Table 1.1 Included Model Framework Models

Model	Short Name	Version
Single-currency single-factor Hull-White interest rate model	IR_HW_1F	3.0.3
Single-currency multifactor Hull-White interest rate model	IR_HW_NF	3.0.3
Multicurrency single-factor Hull-White interest rate model	FX_IR_HW_1F	3.0.3
Multicurrency multifactor Hull-White interest rate model	FX_IR_HW_NF	3.0.3
Inflation multicurrency multifactor Hull-White interest rate model	FX_IF_IR_HW_NF	3.0.3
Inflation multicurrency multifactor Hull-White interest rate model with derived inflation indexes	FX_IF_IR_HW_NF_DI	3.0.3
Hybrid credit equity inflation multicurrency multifactor Hull-White interest rate model	CR_EQ_FX_IF_IR_HW_NF_BK_1F	3.0.3
Hybrid credit equity inflation multicurrency multifactor Hull-White interest rate model with FX jumps	CR_EQ_FX_IF_IR_HW_NF_JFX	3.0.3
Hybrid commodity credit equity inflation multicurrency model	CM_CR_EQ_FX_IF_IR_HW_NF	3.0.3
Hybrid commodity credit equity inflation multicurrency model with Black-Karasinski model for hazard rates	CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F	3.0.3

1.2 Organization of This Manual

This manual has the following chapters (in addition to the present one):

- Chapter 2, "Common Features," describes inputs used by multiple Model Framework models, including the main model preferences map.
- Chapter 3, "Single-Currency Single-Factor Hull-White Model," provides configuration details for the IR_HW_1F model.
- Chapter 4, "Single-Currency Multifactor Hull-White Model," provides configuration details for the IR_HW_NF model.
- Chapter 5, "Multicurrency Single-Factor Hull-White Model," provides configuration details for the FX_IR_HW_1F model.

- Chapter 6, "Multicurrency Multifactor Hull-White Model," provides configuration details for the FX_IR_HW_NF model.
- Chapter 7, "Inflation Multicurrency Multifactor Hull-White Model," provides configuration details for the FX_IF_IR_HW_NF model.
- Chapter 8, "Inflation Multicurrency Multifactor Hull-White Model with Derived Inflation Indexes," provides configuration details for the FX_IF_IR_HW_NF_DI model.
- Chapter 9, "Hybrid Credit Equity Inflation Multicurrency Model," provides configuration details for the CR_EQ_FX_IF_IR_HW_NF_BK_1F model.
- Chapter 10, "Hybrid Credit Equity Inflation Multicurrency Model with FX Jump at Name Default," provides configuration details for the CR_EQ_FX_IF_IR_HW_NF_JFX model.
- Chapter 11, "Hybrid Commodity Credit Equity Inflation Multicurrency Model with Black-Karasinski Model for Hazard Rates," provides configuration details for the CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F model.
- Chapter 12, "Hybrid Commodity Credit Equity Inflation Multicurrency Model," provides configuration details for the CM_CR_EQ_FX_IF_IR_HW_NF model.
- Appendix A, "Abbreviations," provides a list of the abbreviations and acronyms used in this manual.
- Appendix B, "Input Codes," defines the allowable values of certain enumerated type inputs.

1.3 Related Manuals

Refer to the Markit Analytics manuals and methodology documents in the following table for further information about Markit Analytics Platform™ and MASF, the environment in which you price trades in a Markit Analytics package, and about the instruments and models in this package..

Table 1.2 Related Manuals

Title	Description
Markit Analytics Simulation Framework User Guide	Describes the Markit Analytics Simulation Framework and details how to prepare MASF inputs.
MASF Market Data Providers and Curves	Describes all the available market data providers and market data curve types, and provides detailed input formats for them.
MASF Instrument Reference	For each Markit Analytics instrument other than the "standard" instruments, provides a description of the instrument and an overview of its pricing method, specifies its input data requirements, and identifies the optional intermediate outputs that it generates.
MASF Instrument Reference (Standard Instruments)	A supplement to the *MASF Instrument Reference* for instrument plug-ins that price transactions specified by the industry-standard Financial products Markup Language (FpML) version 5.5 with Markit Analytics extensions.
MASF Instrument Methodologies	Mathematical descriptions of pricing methods implemented by MASF instrument plug-ins.
Markit Analytics Script Reference	An HTML document that you can access from the MA Workbench Help menu. Documents the details of the built-in operators that are available to the MA Script programmer.

Table 1.2 Related Manuals (Continued)

Title	Description
Markit Analytics Model Framework Mathematical Reference	Describes the implementation of the models used in Markit Analytics Model Framework (MFWK).
CDS Pricing and Bootstrapping Methodology Notes	Describes the methods for CDS pricing and bootstrapping of the survival probability that are implemented in the "external" MA CDS pricing and bootstrapping framework.
Quasi-Monte Carlo: Methodology and Techniques in MA Model Framework	Describes methodology and techniques for the Monte Carlo Simulation.

Chapter 2

Common Features

The inputs described in this chapter are common to multiple Model Framework models.

2.1 Configuring the Model Framework Market Data Generator

In order to generate scenarios using a risk-neutral model from the Model Framework in an MASF job, you use the `QMarketDataGenerator_ModelFramework` MASF plug-in. This plug-in is essentially a wrapper for the Model Framework. It conforms to the interface that MASF requires for market data generators, and it invokes a specified model from the Model Framework.

The main configuration inputs for a market data generator are collectively called a *market data generator parameters set* and these reside in a *market data generator parameters file*. The general format for market data generator parameters files (and the particular parameters for the other market data generators) are documented in the *Markit Analytics Simulation Framework User Guide*.

In the case of the Model Framework market data generator, some of the parameters that you can include in the generator parameters file are determined by the simulator component of the Model Framework itself and not by MASF. These simulator settings are described below.

2.1.1 Model Framework Simulator Settings

The table below describes a collection of Model Framework simulator settings that you can include in the market data generator parameters file. Some of these settings are common to all simulators, and some are implemented only by certain simulators. The documentation of each model in this manual specifies which of the latter settings apply to each particular simulator component of the model.

In addition to these simulator settings, you must include some general parameters in the generator parameters file. For information about the common parameters and other information for preparing the MASF inputs, see *Markit Analytics Simulation Framework User Guide*. The example that follows the table includes the common parameters.

For further details on how these settings affect the simulation, especially in the Quasi-Monte Carlo (QMC) setting, see *Quasi-Monte Carlo: Methodology and Techniques in MA Model Framework*.

Table 2.1 Simulator Parameters in the Market Data Generator Parameters File

Parameter Name	Type Code	Description	Constraints	Default Value
`strRandomDrawContext`	S	Method of generating random draws.	One of: • `QRandomPseudo` • `QRandomPseudoAntithetic` • `QRandomQuasi` • `QRandomQuasiBrownianBridge` • `QRandomizedQuasi` • `QRandomizedQuasiBrownianBridge`	
`rMaxTimeStep`	D	Maximum time step size for the simulation, in days. If you use an exact simulation method, set this to a large value so that no unnecessary dates are generated.		
`strQuasiMethod`	S	Type of quasi-random number generator to use in the simulation. For further details see *Quasi-Monte Carlo: Methodology and Techniques in MA Model Framework*.	One of: • `sobol_joe_kuo` • `sobol_broda`	`sobol_joe_kuo`
`strRandomizedMethod`	S	Method of randomizing quasi-Monte Carlo simulations when an estimate of the error is required. When not using randomized QMC, the standard error calculation of QMC will be approximate. For further details see *Quasi-Monte Carlo: Methodology and Techniques in MA Model Framework*.	One of: • `shift` • `scramble` • `lin_permute`	`scramble`
`nRandomizedTrials`	N	Number of trials in the randomized quasi-Monte Carlo simulation used for obtaining a confidence interval for the estimate.	Must evenly divide the number of paths.	`1`
`nSkipQuasi`	N	Number of random paths to skip for quasi-random number generators.		2^{20}
`nSkipPseudo`	N	Number of random paths to skip for pseudo-random number generators.		`0`
`rPillarRatio`	R	Ratio of time steps to treat as pillars in Brownian Bridge discretization. Since earlier dimensions of the quasi-random sequences generally have better properties, these are assigned to the pillars before moving on to non-pillar dates. If not provided, the number of pillars is set to a value that minimizes memory requirement. For details see *Quasi-Monte Carlo: Methodology and Techniques in MA Model Framework*.	Must be > 0 and ≤ 1. At least two pillars are always used.	

Table 2.1 Simulator Parameters in the Market Data Generator Parameters File (Continued)

Parameter Name	Type Code	Description	Constraints	Default Value
`bFillTimeAxisFirst`	B	If `TRUE`, the superior earlier dimensions of the quasi-random sequence are assigned to pillar dates of the first factor before moving on to the next factor. Otherwise, the random numbers are assigned to first pillar across all factors before moving on to the next pillar. For non-pillar dates, the factor axis always takes precedence over the time axis.	One of: • `TRUE` • `FALSE`	`FALSE`
`bStepOnDFDates`	B	Whether to simulate on every discount factor date. Setting this to `FALSE` may reduce the computation time. Supported by certain simulators only. For the applicability in each model, see the particular model chapter in this manual.	One of: • `TRUE` • `FALSE`	`TRUE`
`bUseEuler`	B	Whether to use the Euler stepper. Supported by certain simulators only. For the applicability in each model, see the particular model chapter in this manual.	One of: • `TRUE` • `FALSE`	`FALSE`
`bPrecalculateCovariances`	B	Whether to precalculate all covariances for all simulation time steps (`TRUE`) or compute the covariance at each simulation time step (`FALSE`). Supported by certain simulators only. For the applicability in each model, see the particular model chapter in this manual.	One of: • `TRUE` • `FALSE`	`TRUE`
`bUseEigenSym`	B	Whether to use eigenvalue decomposition for the covariance matrix (`TRUE`) or Cholesky decomposition (`FALSE`). Supported by certain simulators only. For the applicability in each model, see the particular model chapter in this manual.	One of: • `TRUE` • `FALSE`	`FALSE`
`bUsePCA`	B	(Optional) Whether to use principal component analysis (PCA) in decomposing the covariance matrix. Setting to `TRUE` overrides the `bUseEigenSym` setting. Supported by certain simulators only. For the applicability in each model, see the particular model chapter in this manual.	One of: • `TRUE` • `FALSE`	`FALSE`

Table 2.1 Simulator Parameters in the Market Data Generator Parameters File (Continued)

Parameter Name	Type Code	Description	Constraints	Default Value
`rEigenThreshold`	R	(Optional) Cut-off value relative to largest eigenvalue used for PCA. Eigenvalues below this value are set to zero and the corresponding eigenvectors are discarded. Ignored if `bUsePCA` is FALSE.	Must be a non-negative number.	`1e-10`
`nPC`	N	(Optional) Number of principal components to retain when performing PCA. Ignored if `bUsePCA` is FALSE.	Must be at most the dimension of the covariance matrix being decomposed.	Dimension of the covariance matrix being decompose d (dynamicall y set by the code)
`bCholesky`	B	Whether to use eigenvalue decomposition for the covariance matrix (FALSE) or Cholesky decomposition (TRUE). Supported by certain simulators only. For the applicability in each model, see the particular model chapter in this manual.	One of: • TRUE • FALSE	TRUE
`strDecomposition`	S	Type of decomposition to perform: • Covariance (`cov`) • Exact correlations (`corr`) • Instantaneous correlations (`corr_inst`) Supported by certain simulators only. For the applicability in each model, see the particular model chapter in this manual.	One of: • `cov` • `corr` • `corr_inst`	`cov`
`bApproximateXIntegral`	B	Whether to approximate the x integral term in the risk neutral measure numeraire (TRUE) or solve for the x integral term so that the term is exact (FALSE). Supported by certain simulators only. For the applicability in each model, see the particular model chapter in this manual.	One of: • TRUE • FALSE	FALSE
`bUseStartEndNumeraireCalc`	B	Whether to use both a start and end term when calculating the x integral in the numeraire calculation (TRUE), or only a start term (FALSE). Supported by certain simulators only. For the applicability in each model, see the particular model chapter in this manual.	One of: • TRUE • FALSE	TRUE

Table 2.1 Simulator Parameters in the Market Data Generator Parameters File (Continued)

Parameter Name	Type Code	Description	Constraints	Default Value
`bUseForeignQuantoAdjustment`	B	Whether to calculate cross-currency quanto corrections in the system of equations (TRUE) or not (FALSE). Supported by certain simulators only. For the applicability in each model, see the particular model chapter in this manual.	One of: • TRUE • FALSE	TRUE
`bUseDeterministicFXDrifts`	B	Whether drifts of the exchange rate evolve according to the forward interest rate (TRUE) or are stochastic (FALSE). Supported by certain simulators only. For the applicability in each model, see the particular model chapter in this manual.	One of: • TRUE • FALSE Can be TRUE only when `bUseForeignQuantoAdjustment` is FALSE.	FALSE
`bUseDeterministicInflationDrifts`	B	Whether drifts of the inflation index evolve according to the forward inflation rate (TRUE) or are stochastic (FALSE). Supported by certain simulators only. For the applicability in each model, see the particular model chapter in this manual.	One of: • TRUE • FALSE Can be TRUE only when `bUseForeignQuantoAdjustment` is FALSE.	FALSE

Example

The following figure shows a Model Framework market data generator parameters file that includes some of these simulator settings.

```
strParamSetID, S, SampleGeneratorParams
strMarketDataGeneratorReference, S,
  QMarketDataGeneratorMFWK@quic_market_data_generator_mfwk:12
strModel, S, IR_HW_USD_ModelPrefs
strSimulatorMFWKReference, S,
  QMCSimulator_IR_HW_1F_PWC_FM@quic_model_ir_hw_1f:3.0
strRandomDrawContext, S, QRandomPseudo
rMaxTimeStep, D, 3000000
strMethod, S, mt
bUseEuler, B, TRUE


// The main model preferences map, its subsidiary maps, and the market data provider
// specification map are not shown in this example
```

2.2 Model Preferences Map

In the market data generator parameters file, the `strModel` parameter refers to a *model preferences map* in the same file. The model preferences map specifies the top-level configuration inputs for a Model Framework model. The data formats in this map are the same as for maps in the auxiliary transaction data file. For basic information about the general map format, see the *Markit Analytics Simulation Framework User Guide*.

The following table defines the members of a model preferences map. An example follows the table. The definitions of the subsidiary maps to which this map refers are specific to each model and are described in the chapter about the particular model of interest.

Table 2.2 Model Preferences Map

Map Key	Type Code	Description	Constraints	Default Value
`Model`	S	Reference to a model component in a Model Framework module.	Depends on the model.	
`CalibrationMethod`	S	Reference to a calibration component for the specified model in the Model Framework module. See the note that follows this table.	Depends on the model.	
`CalibrationSettings`	L	Name of a map of settings for the calibrator specified by `CalibrationMethod`. See the note that follows this table.	Referenced map must exist in the market data generator parameters file.	
`CurveNames`	L	Name of a map that identifies the market data curves to use in the calibration and data extraction processes.	Referenced map must exist in the market data generator parameters file.	
`DataExtractionMethod`	S	Reference to a data extraction component for the specified model in the Model Framework module.	Depends on the model.	
`DataExtractionSetttings`	L	Name of a map of settings for the data extractor specified by `DataExtractionMethod`.	Referenced map must exist in the market data generator parameters file.	
`TradeInfo`	L	Name of a map of settings that relate to properties of the portfolio as a whole.	Referenced map must exist in the market data generator parameters file.	

Note: Calibration Settings

Most Model Framework models support two approaches to calibration of the model's parameters:

- *Internal calibration*—You provide market data and control settings, and the model calibrates itself.
- *External calibration*—You calculate the model parameters in a preprocessing step of your own design and supply the resulting parameters as inputs to the model.

The documentation for each model specifies the calibration approaches that it supports (the possible inputs for the `CalibrationMethod` model preference), and the details of the relevant inputs in each case.

Example

This example shows a model preferences map named IR_HW_USD_ModelPrefs for the IR_HW_1F model. It does not show the additional maps to which this one refers

```
IR_HW_USD_ModelPrefs, {
  Model, S, QModel_IR_HW_1F_PWC@quic_model_ir_hw_1f:3.0
  CalibrationMethod, S, QModelCalibration_IR_HW_1F_PWC@quic_model_ir_hw_1f:3.0
  CalibrationSettings, L, IR_HW_USD_CalibrationSettings
  CurveNames, L, IR_HW_USD_CurveNames
  DataExtractionMethod, S, QDataExtraction_IR_HW_1F_PWC@quic_model_ir_hw_1f:3.0
  DataExtractionSettings, L, IR_HW_USD_DataExtractionSettings
  TradeInfo, L, PortfolioInfo
}
```

2.3 Interest Rate Extraction

In the case of internal calibration, the inputs to a Model Framework model include market data (for example, interest rates and exchange rates) and the settings that control extraction of the data to use in the calibration.

This section describes some input settings related to interest rate extraction that are common to multiple Model Framework models.

2.3.1 Bootstrapping Discount Factors

For some models, the data extraction process can prepare discount factors in any of the following ways:

- Take them directly from discount factor curves.
- Compute them directly from yield curves or forward LIBOR curves.
- Bootstrap them from a combination of cash rate, futures price, and swap rate curves.

When the market data map for the model specifies, for each currency, the curves to use in bootstrapping, it does so indirectly via other lists in the model preferences file as described below. The bootstrapping process is also controlled by parameters in the IR data extraction settings map (see “Interest Rate Extraction Settings Map” on page 35).

2.3.2 Specifying the Data to Use in Bootstrapping

Each model requires a market data map (referenced by the `CurveNames` member of the model preferences map). The market data map includes either an `IRCurve` or `aIRCurve` member (among other members). When the `IRCurve` or `aIRCurve` member refers (indirectly) to the curves to use in bootstrapping, provide the referenced lists in the model preferences file in the format described in the following table. You must provide one such list (and its subsidiary lists) for each currency.

Table 2.3 Curve Lists for Bootstrapping

List Name	Type Code	Description	Constraints	Default Value
User-defined	AL	Three-element array that contains the names of lists (each of type AC) of names of curves, in the following order: • The first element refers to a list of names of cash rate curves (of type `CashRate`). • The second element refers to a list of names of futures price curves (of type `FuturesPrice`). • The third element refers to a list of names of swap rate curves (of type `SwapRate`). The cash rate, futures price, and swap rate curve lists can be of different lengths.	Referenced lists must exist in the model preferences file.	

2.3.3 Interest Rate Extraction Settings Map

If the `DataExtractionSettings` member of a model preferences map refers to a map that includes the `mpIRCurveSettings` or `ampIRCurveSettings` member, these members refer in turn to a map that specifies settings that control the data extraction process from interest rate curves, including settings for the bootstrapping process. The following table defines the members of such a map.

Table 2.4 IR Data Extraction Settings Map

Map Key	Type Code	Description	Constraints	Default Value
`strInterpObject`	S	Object to interpolate on when calculating quantities from an IR curve.	One of: • DF • ZeroRate	DF
`strInterp`	S	Interpolation method to use when calculating quantities from an IR curve.		log-lin
`strExtrap`	S	Extrapolation method to use when calculating quantities from an IR curve.		log-lin
`rBootstrapTolerance`	R	Tolerance to use in the root finding procedure. Used only when bootstrapping is performed.		1.0e-15
`bUseCurveSortingRules`	B	Whether to use curve sorting rules to determine data points to use in bootstrapping. Used only when bootstrapping is performed.	One of: • TRUE • FALSE	FALSE

Table 2.4 IR Data Extraction Settings Map (Continued)

Map Key	Type Code	Description	Constraints	Default Value
bUseFuturesOverCash	B	Whether to use futures rather than cash rates. Used only when bootstrapping is performed.	One of: • TRUE • FALSE	FALSE
bUseSwapOverFuture	B	Whether to use swap rates rather than futures. Used only when bootstrapping is performed.	One of: • TRUE • FALSE	FALSE
bUseSwapOverCash	B	Whether to use swap rates rather than cash rates. Used only when bootstrapping is performed.	One of: • TRUE • FALSE	FALSE
bCreateDataPointInfo	B	Whether to store information along each tenor point for calculating greeks. Setting this to FALSE can significantly reduce memory usage.	One of: • TRUE • FALSE	TRUE

2.4 Adding Credit Support to a Non-Credit Model

You can add a deterministic credit interface to some non-credit models. To do so, you must provide additional information in the model preferences map and its subsidiary maps for the particular model. You can add credit support to the following models:

- Single-currency single-factor Hull-White
- Single-currency multifactor Hull-White
- Multicurrency single-factor Hull-White
- Multicurrency multifactor Hull-White
- Inflation multicurrency multifactor Hull-White

The additional inputs for the relevant maps are described below.

2.4.1 Model Preferences Map

The following table lists the additional inputs for credit modeling to include in the model preferences map of a non-credit model.

Table 2.5 Additional Model Preferences for Credit Modeling

Map Key	Type Code	Description	Constraints	Default Value
CreditCalibrationMethod	S	(Optional) Reference to a credit calibration component in a Model Framework module.		QModelCalibration_CR_Deterministic@quic_model_cr_eq_fx_ir_hw_nf_bk_1f:3.0

Table 2.5 Additional Model Preferences for Credit Modeling (Continued)

Map Key	Type Code	Description	Constraints	Default Value
CreditDataExtractionMethod	S	(Optional) Reference to a data extraction component in a Model Framework module to use with the credit calibration.		QDataExtraction_CR_Deterministic@quic_model_cr_eq_fx_ir_hw_nf_bk_1f:3.0
CreditModel	S	(Optional) Reference to a credit model component in a Model Framework module.		QModel_CR_Deterministic@quic_model_cr_eq_fx_ir_hw_nf_bk_1f:3.0

2.4.2 Calibration Settings Map

The following table lists the additional inputs for credit modeling to include in the calibration settings map of a non-credit model.

Table 2.6 Additional Calibration Settings for Credit Modeling

Map Key	Type Code	Description	Constraints	Default Value
astrName	AS	Aliases for the credit curves listed in aCreditCurve in the market data map.	There must be one name for each curve in aCreditCurve in the market data map.	
arRecoveryRate	AR	Recovery rates for the obligors listed in astrName.	There must be one recovery rate for each name in astrName.	

2.4.3 Data Extraction Settings Map

The following table lists the additional inputs for credit modeling to include in the data extraction settings map of a non-credit model.

Table 2.7 Additional Data Extraction Settings for Credit Modeling

Map Key	Type Code	Description	Constraints	Default Value
aidxCDSCCY	AN	Index of the CDS currency for each credit name.	Integers between 0 and the number of foreign currencies of the model.	0
ampSettingsCDS	AL	Names of maps, one for each credit name, that specify credit data extraction settings for purposes of calibration.	Referenced maps must exist in the model preferences file. To use the defaults for all settings, provide an empty map.	An array of empty maps, one for each credit name.

2.4.3.1 Credit Data Extraction Settings Map

The ampSettingsCDS member of the data extraction settings map refers to other maps that each specify data extraction settings for the credit calibration for one obligor. The following table defines the members of a credit data extraction settings map.

Table 2.8 Credit Data Extraction Settings Map

Map Key	Type Code	Description	Constraints	Default Value
bUseIMMDates	B	Whether to use IMM dates. If the calibration date is not an IMM date, the CDS maturity is taken to be from the next IMM date.	One of: • TRUE • FALSE	TRUE
bUseThirdWedsRule	B	Whether to generate the IMM dates using the third Wednesday rule. Ignored if bUseIMMDates is FALSE.	One of: • TRUE • FALSE	FALSE
nIMMFirstMonth	N	The month of the first IMM date of the year. Ignored if bUseIMMDates is FALSE or if bUseThirdWedsRule is TRUE.	Integer between 1 and 12	3
nIMMDay	N	Day of month for the IMM dates. Ignored if bUseIMMDates is FALSE or if bUseThirdWedsRule is TRUE.	Integer between 1 and 31	20
bRoundMidPointToNearestDay	B	Whether to round the coupon period mid points, calculated for accrued interest, to the nearest day.	One of: • TRUE • FALSE	TRUE
bUseYearFracForAccInt	B	Whether to use the year fraction in the calculation of the accrued interest using midpoint approximation.	One of: • TRUE • FALSE	TRUE
rDaysPerAnnumAccInt	R	Number of days per annum in the calculation of the accrued interest using midpoint approximation, if bUseYearFracForAccInt is FALSE.		365.25[dy]
rFwdHazardRateFloor	R	Floor value for the forward hazard rate in bootstrapping.		1e-5
bAccInt	B	Whether to use the accrued interest in bootstrapping.	One of: • TRUE • FALSE	TRUE

Table 2.8 Credit Data Extraction Settings Map (Continued)

Map Key	Type Code	Description	Constraints	Default Value
`bTest`	B	Whether to perform the round trip test on par credit spread in bootstrapping.	One of: • TRUE • FALSE	FALSE
`bBootstrapClean`	B	Whether to take into account the accrued rebate for IMM dates in bootstrapping.	One of: • TRUE • FALSE	TRUE
`bUseSurvProbDiff`	B	Whether to bootstrap a curve of par credit spreads using a midpoint approximation and the difference of survival probabilities for default in period term calculations (TRUE), or use regular CDS bootstrapping (FALSE).	One of: • TRUE • FALSE	FALSE
`rSlopeTol`	R	Tolerance for checking the slope of the objective function. Its reciprocal is used to check if the slope is approaching infinity. Ignored if `bUseSurvProbDiff` is FALSE.		1e-5

2.4.4 Market Data Map

The following table lists the additional inputs for credit modeling to include in the market data map of a non-credit model.

Table 2.9 Additional Market Data Inputs for Credit Modeling

Map Key	Type Code	Description	Constraints	Default Value
`aCreditCurve`	AS	Names of credit curves (of type `SurvivalProbability` or `ParCreditSpread`), one for each obligor.	Referenced curves must exist in the market data HDF5 file.	

Example

```
// FX IR HW 1F model with credit
USD_EUR_FX_IR_HW_Credit,{ CalibrationMethod, S,
    QModelCalibration_FX_IR_HW_1F_PWC@quic_model_fx_ir_hw_1f:2
  CalibrationSettings, L, USD_EUR_FX_IR_HW_Credit_CalibrationSettings
  CurveNames, L, USD_EUR_FX_IR_HW_Credit_CurveNames
  DataExtractionMethod, S, QDataExtraction_FX_IR_HW_1F_PWC@quic_model_fx_ir_hw_1f:2
  DataExtractionSettings, L, USD_EUR_FX_IR_HW_Credit_DataExtractionSettings
  Model, S, QModel_FX_IR_HW_1F_PWC@quic_model_fx_ir_hw_1f:2
  TradeDataExtractionMethod, S, QTradeExtractionMaturity
  TradeDataExtractionSettings, L, FX_IR_HW_TradeDataExtractionSettings
  CreditCalibrationMethod, S,
     QModelCalibration_CR_Deterministic@quic_model_cr_eq_fx_ir_hw_nf_bk_1f:2
```

```
  CreditDataExtractionMethod, S,
     QDataExtraction_CR_Deterministic@quic_model_cr_eq_fx_ir_hw_nf_bk_1f:2
  CreditModel, S, QModel_CR_Deterministic@quic_model_cr_eq_fx_ir_hw_nf_bk_1f:2
  }

USD_EUR_FX_IR_HW_Credit_CalibrationSettings,{
  astrCCY, AS, USD, EUR
  astrName, AS, CounterParty1, CounterParty2
  arRecoveryRate, AR, 0.4, 0.35
  }

USD_EUR_FX_IR_HW_Credit_CurveNames,{
  aMeanReversionCurve, AS, USDMR.MeanReversion.USD, EURMR.MeanReversion.EUR
  aIRCurve, AS, USDDF.DiscountFactor.USD, EURDF.DiscountFactor.EUR
  aCreditCurve, AS, CounterParty1.SurvivalProbability.USD,
     CounterParty2.SurvivalProbability.EUR
  aSwaptionVolCurve, AS, SemiannualSwapVol.SwaptionVolMtx.USD,
     SemiannualSwapVol.SwaptionVolMtx.EUR
  aSpotFXCurve, AS, USD.Exchange.USD, USD.Exchange.EUR
  aFXImpliedVolCurve, AS, USD.ImpliedVol.USD, USD.ImpliedVol.EUR
  aCorrelationCurve, AS, ..., ShortRateUSD.CorrelBlock.ShortRateEUR, ...,
     ShortRateUSD.CorrelBlock.SpotFXEUR ..., ShortRateEUR.CorrelBlock.SpotFXEUR
  }
```

2.5 Historical Covariance Calculation

The following Markit Analytics entry function generates the covariance matrix from the input historical data:

`Analytics_HistoricalCovarianceMFWKCSV``(` *`mpInputs`* `)`

In addition, it optionally calculates the IR forward and short rate average. The calculation is based on the configuration of the input simulation risk factor parameters file and input calibration settings. The output data are generated in the format of the market data curves and are saved to the output CSV file. The generated curves are further used by the simulation model calibration methods to produce model parameters for use in the simulation.

The covariance calculation depends on the configuration of the input risk factor parameters file of the simulation model. The model parameters specified in the risk factor parameters file are used as the input parameters by the covariance calculation function to provide the consistency between its output and the simulation model. The following data extraction methods are supported by the historical covariance calculation function:

- `QDataExctraction_CM_CR_EQ_FX_IF_IR_HW_CombCorr`
- `QDataExctraction_CM_CR_EQ_FX_IF_IR_HW_CombCov`

For information on configuring the function’s input map (*`mpInputs`*) and an example of the function call, see the API documentation for the quic_analytics module in the *Markit Analytics Solution 1.18 Reference*. This section provides a description of the settings file that is referenced in the inputs of the function.

The covariance calculation settings file contains a model curve map and an options map. The model curve map specifies the curves in the input historical data file from which to extract time series for the calculation of the covariance between model factors. The options map specifies the options of the covariance calculation method. The tables below define the members of these maps.

Table 2.10 Model Curve Map

Map Key	Type Code	Description	Constraints	Default Value
`astrCCY`	AS	Names of the currencies in the simulation model.	Must be the same as the names specified by the calibration settings map in the input risk factor parameters CSV file.	
`astrEquity`	AS	(Optional) Names of the equities in the simulation model. Required if provided in the calibration settings map in the input risk factor parameters CSV file.	Must be the same as the names specified by the calibration settings map in the input risk factor parameters CSV file.	
`astrName`	AS	(Optional) Credit names in the simulation model. Required if provided in the calibration settings map in the input risk factor parameters CSV file.	Must be the same as the names specified by the calibration settings map in the input risk factor parameters CSV file.	
`astrII`	AS	(Optional) Names of the inflation indexes in the simulation model. Required if provided in the calibration settings map in the input risk factor parameter CSV file.	Must be the same as the names specified by the calibration settings map in the input risk factor parameters CSV file.	
`astrCommodity`	AS	(Optional) Names of the commodities in the simulation model. Required if provided in the calibration settings map in the input risk factor parameter CSV file.	Must be the same as the names specified by the calibration settings map in the input risk factor parameters CSV file.	
`aIRCurve`	AS	Names of the curves (of type `Yield`) in the input historical market data HDF5 file from which to extract the historical forward interest rates, one curve for each currency specified in `astrCCY`. If the value is void for a currency, the forward rates for that currency are assumed to have zero volatility, average, and correlation with the other model factors. The required forward rate tenors for the covariance calculation are specified by the `aarBenchmarkTenorIR` input in the data extraction settings map in the input risk factor parameters file. The required forward rate tenors for the average calculation are specified by the `aarTenorIRForwardAverage` input in the data extraction settings map in the input risk factor parameters file.	Referenced curves must exist in the input historical market data HDF5 file.	
`aIRShortCurve`	AS	Names of curves (of type `Yield` or `Scalar`) in the input historical market data HDF5 file from which to extract the historical short interest rates. If the value is void for a currency, the short rate for that currency is assumed to have zero average.	Referenced curves must exist in the input historical market data HDF5 file	`aIRCurve`

Table 2.10 Model Curve Map (Continued)

Map Key	Type Code	Description	Constraints	Default Value
`aSpotFXCurve`	AS	Names of the curves (of type `Exchange`) in the input historical market data HDF5 file from which to extract the historical spot exchange rates, one curve for each currency specified in `astrCCY`. The first name matching the domestic currency can be set to void. If the value is void for a foreign currency, the spot exchange rate for that currency is assumed to have zero volatility and zero correlation with the other model factors.	Referenced curves must exist in the input historical market data HDF5 file.	
`aSpotEQCurve`	AS	(Optional) Names of the curves (of type `Equity` or `EquityIndex`) in the input historical market data HDF5 file to extract the historical spot equity prices, one curve for each equity specified in `astrEquity`. If the value is void for an equity, the spot price process for that equity is assumed to have zero volatility and zero correlation with the other model factors. Ignored if `astrEquity` is omitted.	Referenced curves must exist in the input historical market data HDF5 file.	
`aCreditCurve`	AS	(Optional) Names of the curves (of type `SurvivalProbability`) in the input historical market data HDF5 file from which to extract the historical forward hazard rate, one curve for each credit name specified in `astrName`. If the value is void for a name, the forward hazard rate for that name is assumed to have zero volatility and zero correlation with the other model factors. The required forward hazard rate tenor is specified by the `aarBenchmarkTenorCR` input in the data extraction settings map in the input risk factor parameters file. Ignored if `astrName` is omitted.	Referenced curves must exist in the input historical market data HDF5 file.	
`aINFCurve`	AS	(Optional) Names of the curves (of type `DiscountFactor`, `Yield`, or `InflationRate`) in the input historical market data HDF5 file from which to extract the historical forward inflation rate, one curve for each inflation index specified in `astrII`. If the value is void for an inflation index, the forward inflation rates corresponding to that index are assumed to have zero volatility and zero correlation with the other model factors. The required forward inflation rate tenors are specified by the `aarBenchmarkTenorINFSpread` input in the data extraction settings map in the input risk factor parameters file. Ignored if `astrII` is omitted.	Referenced curves must exist in the input historical market data HDF5 file.	

Table 2.10 Model Curve Map (Continued)

Map Key	Type Code	Description	Constraints	Default Value
`aSpotIICurve`	AS	(Optional) Names of the curves (of type `InflationIndex`) in the input historical market data HDF5 file from which to extract the historical spot inflation index, one curve for each inflation index specified in `astrII`. If the value is void for an inflation index, the spot price of that index is assumed to have zero volatility and zero correlation with the other model factors. Ignored if `astrII` is omitted.	Referenced curves must exist in the input historical market data HDF5 file.	
`aCMCurve`	AS	(Optional) Names of the curves (of type `Commodity`) in the input historical market data HDF5 file from which to extract the historical spot commodity price and forward convenience spreads, one curve for each commodity specified in `astrCommodity`. The required forward convenience spread tenors are specified by the `aarBenchmarkTenorCMSpread` input in the data extraction settings map in the input risk factor parameters file. If the value is void for a commodity, the spot price and convenience spread factor increments for that commodity are assumed to have zero volatility and zero correlation with the other model factors. Ignored if `astrCommodity` is omitted.	Referenced curves must exist in the input historical market data HDF5 file.	

Table 2.11 Options Map

Map Key	Type Code	Description	Constraints	Default Value
`bInterp`	B	Whether to interpolate data for missing observations.	One of: • TRUE • FALSE	FALSE
`bExtrap`	B	Whether to add the dates of the calibration window to the set of observation dates.	One of: • TRUE • FALSE	FALSE
`strObsInterpType`	S	Interpolation type if `bInterp` is TRUE.	See Table B.3 on page 328.	`lin`
`bSampleVariance`	B	Whether to use the sample variance formula instead of the population variance.	One of: • TRUE • FALSE	FALSE
`nPrecisionDigitsToCSV`	N	Integer that specifies the numerical precision of the output values.	>0	6
`bCalculateCov`	B	Whether to calculate the covariance matrix from historical data.	One of: • TRUE • FALSE	TRUE

Table 2.11 Options Map (Continued)

Map Key	Type Code	Description	Constraints	Default Value
`bCalculateIRForwardShortAverage`	B	Whether to calculate the average forward and short interest rate from historical data.	One of: • TRUE • FALSE	TRUE

Chapter 3

Single-Currency Single-Factor Hull-White Model

The single-currency single-factor Hull-White interest rate model (IR_HW_1F) treats the short-rate volatility as a piecewise constant function in time. It includes support for a LIBOR basis adjustment.

This model takes into account the forecasting curve when calibrating to swaptions, which enables it to calibrate in markets with negative discounting swap rates but positive forecasting swap rates.

The simulation is done in the forward measure and an exact simulation method is used.

The calibration component can exactly calibrate to one instrument per maturity. The calibration involves the use of numerical root-finding procedures for two purposes:

- To obtain short rate volatilities to match market prices.
- To perform the Jamshidian decomposition procedure when calibrating to swaptions.

The root-finding process involves two methods:

1. First apply a Newton-Raphson method.
2. If the first method fails, attempt to bracket the root and apply the bisection method.

The data extraction component can extract either a set of caplets or a swaption diagonal from market data curves.

For information about the methodology of the IR_HW_1F model, see the following chapter in *Markit Analytics Model Framework Mathematical Reference*: “Single Factor Hull-White Model”.

3.1 Module (IR_HW_1F)

The Model Framework module that implements the single-currency single-factor Hull-White interest rate model (IR_HW_1F) is as follows:

```
quic_model_ir_hw_1f:3.0
```

Combine this module name with the module component names identified in this chapter to form a complete module reference. For example, if the component is `QModel_IR_HW_1F_PWC`, the complete module reference is as follows:

```
QModel_IR_HW_1F_PWC@quic_model_ir_hw_1f:3.0
```

3.2 Market Data Generator Parameters (IR_HW_1F)

A market data generator parameters set for the Model Framework market data generator includes certain parameters whose value depends on the particular model. These include some parameters that are used directly by the generator itself and others that are used only by the Model Framework model that it invokes (in particular by the model’s simulator component). For descriptions of the direct generator parameters, see the *Markit Analytics Simulation Framework User Guide*. The parameters that are used by Model Framework simulators are described in “Model Framework Simulator Settings” on page 28.

Some of the simulator settings are used by all models and others are used only by certain models. For the latter subset of settings, the information below shows which ones are used by this model.

Generator Parameter: `strSimulatorMFWKReference`

The parameter `strSimulatorMFWKReference` specifies the simulator plug-in for the model. The following values of this parameter are available for the IR_HW_1F model:

- Exact simulation algorithm under the forward measure:

  `QMCSimulator_IR_HW_1F_PWC_FM@quic_model_ir_hw_1f:3.0`

- Simulation algorithm under the risk-neutral measure:

  `QMCSimulator_IR_HW_1F_PWC_RNM@quic_model_ir_hw_1f:3.0`

Applicability of Simulator Settings

The following table identifies which simulator plug-ins (if any) support the specified simulator settings.

Table 3.1 Support for Simulator Settings (IR_HW_1F)

Parameter	Simulators That Support the Parameter
bStepOnDFDates	• QMCSimulator_IR_HW_1F_PWC_FM • QMCSimulator_IR_HW_1F_PWC_RNM
bUseEuler	• QMCSimulator_IR_HW_1F_PWC_FM • QMCSimulator_IR_HW_1F_PWC_RNM
bPrecalculateCovariances	Not applicable
bUseEigenSym and bUsePCA	Not applicable
bCholesky	Not applicable
strDecomposition	Not applicable
bUseStartEndNumeraireCalc	QMCSimulator_IR_HW_1F_PWC_RNM
bUseForeignQuantoAdjustment	Not applicable
bUseDeterministicFXDrifts	Not applicable
bUseDeterministicInflationDrifts	Not applicable
bApproximateXIntegral	Not applicable

3.3 Model Preferences (IR_HW_1F)

You specify the settings for the model in a model preferences map and in the subsidiary maps that it references. For a general description of a model preferences map, see “Model Preferences Map” on page 32.

You can include credit modeling in this model by specifying additional inputs in the model preferences map and its subsidiary maps. These additional inputs are described in “Adding Credit Support to a Non-Credit Model” on page 36.

3.3.1 Components (IR_HW_1F)

The following table identifies the available plug-ins (components of the IR_HW_1F module) that implement the model. You specify these as values of members of the model preferences map in the form of full module references.

Table 3.2 Model Plug-In Components (IR_HW_1F)

Model Preference	Available Components of the Module
Model	QModel_IR_HW_1F_PWC
CalibrationMethod	QModelCalibration_IR_HW_1F_PWC

Table 3.2 Model Plug-In Components (IR_HW_1F) (Continued)

Model Preference	Available Components of the Module
`DataExtractionMethod`	One of: • `QDataExtraction_IR_HW_1F_PWC` Use this component when you provide calibration data in the form of a swaption volatility matrix or a caplet volatility curve. • `QDataExtraction_IR_HW_1F_PWC_SwaptionStrike` Use this component when you provide calibration data in the form of a `SwaptionVolCube` curve. • `QDataExtraction_IR_HW_1F_PWC_SelectedSwaptions` Use this component when you want to specify exactly which swaptions to use in the calibration.

In addition, you must specify the maps that are identified by the other members of the model preferences map. The remainder of this chapter defines these subsidiary maps.

Example

The following figure shows a sample model preferences map that specifies components for this model. In the model preferences file, each map member occupies a single line.

```
IR_HW_BA_USD, {
  Model, S, QModel_IR_HW_1F_PWC@quic_model_ir_hw_1f:3.0
  CalibrationMethod, S,
    QModelCalibration_IR_HW_1F_PWC@quic_model_ir_hw_1f:3.0
  CalibrationSettings, L, IR_HW_USD_CalibrationSettings
  CurveNames, L, IR_HW_1F_BA_CurveNames
  DataExtractionMethod, S,
    QDataExtraction_IR_HW_1F_PWC@quic_model_ir_hw_1f:3.0
  DataExtractionSettings, L, IR_HW_USD_DataExtractionSettings
  TradeInfo, L, Portfolio_Info
}
```

3.3.2 Calibration Settings (IR_HW_1F)

The `CalibrationSettings` member of a model preferences map refers to another map that specifies parameters for the model calibration process. The following table defines the members of a calibration settings map for the single-currency single-factor Hull-White model with LIBOR basis adjustment.

Table 3.3 Calibration Settings Map for IR_HW_1F

Map Key	Type Code	Description	Constraints	Default Value
`strCCYDom`	S	Name of the domestic currency.	Standard 3-character currency identifier	
`bUseCapletFormula`	B	Whether to use the caplet formula. If set to TRUE, but the input calibrating instruments are swaptions, this setting reverts to FALSE.	One of: • TRUE • FALSE	FALSE

Table 3.3 Calibration Settings Map for IR_HW_1F (Continued)

Map Key	Type Code	Description	Constraints	Default Value
`rNotional`	R	Notional amount to use when calculating prices during calibration.		1.0
`mpRootFindSettings`	L	Name of a map of settings for the root-finding procedure.	Referenced map must exist in the auxiliary transaction data file.	Empty map
`bAllowNegativeMR`	B	Whether to allow the calibration process to generate a negative mean reversion parameter.	One of: • TRUE • FALSE	FALSE
`astrBasisCurve`	AS	(Optional) Nicknames of the interest rate curves used for additive LIBOR basis adjustment.	Include a nickname for each of the curves, in order, specified by the `aBasisCurve` member of the market data map.	
`strBasisCurveCalib`	S	(Optional) Nickname of the interest rate curve to use for additive LIBOR basis adjustment during calibration.	Must be one of the names in `astrBasisCurve`.	The LIBOR basis adjustment is not performed.
`bUseBasisCurveForCalibDiscounting`	B	Whether to use the basis curve, if specified by `strBasisCurveCalib`, for both discounting and forecasting in the calibration (TRUE) or just for forecasting (FALSE).	One of: • TRUE • FALSE	FALSE
`strBasisCurveCalibDisc`	S	(Optional) Nickname of the interest rate curve to use for discounting during calibration. Ignored if `bUseBasisCurveForCalibDiscounting` is set to TRUE.	Must be one of the names in `astrBasisCurve`.	Interest rate curve specified by the market data map member `IRCurve`.
`bNormalVolatilities`	B	Whether to assume normal (TRUE) or log-normal (FALSE) volatilities.	One of: • TRUE • FALSE	FALSE
`bOutputFitResults`	B	Whether to report the results of the calibration (comparison of the prices of calibrating instruments from the calibrated model and calculated analytically from market data).	One of: • TRUE • FALSE	FALSE
`strOutputFile`	S	(Optional) File path of the CSV file to which calibration results are written (if requested by `bOutputFitResults`).		Results are displayed in the audit pane only.

Table 3.3 Calibration Settings Map for IR_HW_1F (Continued)

Map Key	Type Code	Description	Constraints	Default Value
`strModelParametersOutputFile`	S	(Optional) File path of the HDF5 file to which the calculated model parameters are written. This file has the same format as a file for externally calibrated parameters. Typically used only for troubleshooting. If omitted, no file is produced.		
`strModelParametersOutputName`	S	(Optional) Name to give this model parameters set in the file specified by `strModelParametersOutputFile`.		`mpModelParams`
`bOutputCalibrationData`	B	Whether to include the calibration data in the HDF5 file specified by `strModelParametersOutputFile`. Typically used only for troubleshooting because it may significantly increase the size of the file.	One of: • TRUE • FALSE	FALSE
`mpOutputSettings`	L	(Optional) Name of a map of settings to control the output of calibration results.	Referenced map must exist in the auxiliary transaction data file.	Empty map

Example

```
IR_HW_1F_USD_CalibrationSettings, {
  strCCYDom, S, USD
  bUseCapletFormula, B, TRUE
  rNotional, R, 1
  astrBasisCurve, AS, USD_Forecasting.Yield.USD
  strBasisCurveCalib, S, USD_Forecasting.Yield.USD
  mpRootFindSettings, L, MS_USD_RootFindingSettings
  bOutputFitResults, B, TRUE
  strOutputFile, S, CalibrationFitResults.csv
}
```

3.3.2.1 Root-Finding Settings (IR_HW_1F)

The `mpRootFindSettings` member of a Hull-White calibration settings map refers to another map that specifies settings for the root-finding process. Most of these settings specify various numerical tolerances. Normally, the default values are sufficient.

The following table defines the members of a root-finding settings map for the single-currency single-factor Hull-White model with LIBOR basis adjustment.

Table 3.4 Root-Finding Settings Map for IR_HW_1F

Map Key	Type Code	Description	Constraints	Default Value
`rVolSensTol`	R	Volatility sensitivity tolerance.		0.001
`rSigmaConst`	R	Sigma used in initial guess for root find (units are per annum). If all calibrating instruments are removed, this value is used as the Hull-White volatility parameter.		0.01
`rErrorTol`	R	Error tolerance for root find to match market prices.		1.0e–14
`rRelTolNR`	R	Relative tolerance in Newton-Raphson method for root find to match market prices.		1.0e–13
`nMaxIterNR`	N	Maximum number of iterations in Newton-Raphson method for root find to match market prices.		100
`nMaxIterBracket`	N	Maximum number of iterations used in bracketing for root find to match market prices.		20
`rBracketLow`	R	Low value for bracketing for root find to match market prices.		1.0e–10
`rBracketHigh`	R	High value for bracketing for root find to match market prices.		1.0e–1
`nMaxDiv`	N	Maximum number of divisions in bisection for root find to match market prices.		100
`rRootGuessJam`	R	Initial guess for root in Jamshidian decomposition.		0.0
`rErrorTolJam`	R	Error tolerance in Jamshidian decomposition.		1.0e–13
`rRelTolNRJam`	R	Relative tolerance in Newton-Raphson method for root find in Jamshidian decomposition.		1.0e–15
`nMaxIterNRJam`	N	Maximum number of iterations in Newton-Raphson method for root find in Jamshidian decomposition.		100
`rMinXJam`	R	Minimum X value in bracketing for Jamshidian decomposition.		–0.1
`rMaxXJam`	R	Maximum X value in bracketing for Jamshidian decomposition.		0.1
`nMaxDivJam`	N	Maximum number of iterations in bisection for root find in Jamshidian decomposition.		100

3.3.2.2 Calibration Results Output Settings (IR_HW_1F)

The mpOutputSettings member of a Hull-White calibration settings map refers to another map that specifies settings for controlling the output of calibration results. The present output process does not use any settings.

3.3.3 Market Data Inputs (IR_HW_1F)

The CurveNames member of a model preferences map refers to a map that identifies the market data curves that are required for pricing, simulation, and if applicable, internal model calibration. The following table defines the members of a market data map for the single-currency single-factor Hull-White model with LIBOR basis adjustment.

Table 3.5 Market Data Map for IR_HW_1F

Map Key	Type Code	Description	Constraints	Default Value
IRCurve	S or L	Either: • Name of a curve for discounting (of type DiscountFactor, Yield, or FwdLibor). • Name of a list that specifies a set of curves to use in bootstrapping the discount factor. For details about the list of curves for bootstrapping, see “Specifying the Data to Use in Bootstrapping” on page 34.	Referenced curve must exist in the market data HDF5 file, or referenced map must exist in the auxiliary transaction data file. Ordinates of a Yield curve must be >0.	
aBasisCurve	AS	(Optional) Names of curves (of type DiscountFactor, Yield, or FwdLibor) that specify the forecasting interest rates to use for LIBOR basis adjustments.	Referenced curves must exist in the market data HDF5 file. Ordinates of a Yield curve must be >0.	
MeanReversionCurve	S	Name of a mean reversion curve (of type MeanReversion).	Referenced curve must exist in the market data HDF5 file.	
CapletVolCurve	S	Name of a caplet volatility curve (of type CapletVol). Can be omitted if you calibrate to swaption volatilities.	Referenced curve must exist in the market data HDF5 file.	
SwaptionVolCurve	S	Name of a swaption volatility matrix curve (of type SwaptionVolMtx; can also be of type SwaptionVolCube if using QDataExtraction_IR_HW_1F_PWC_SelectedSwaptions). Can be omitted if you calibrate to caplet volatilities.	Referenced curve must exist in the market data HDF5 file.	

Example

```
SampleHWCalibrationData, {
  IRCurve, S, USD.Yield.USD
  aBasisCurve, AS, USDLibor3M.Yield.USD
  MeanReversionCurve, S, USDMR.MeanReversion.USD
  SwaptionVolCurve, S, USD.SwaptionVolMtx.USD
}
```

3.3.4 Data Extraction Settings (IR_HW_1F)

The `DataExtractionSettings` member of a Hull-White model preferences map refers to another map that specifies parameters for the data extraction process. The following table defines the members of a data extraction settings map for the single-currency single-factor Hull-White model with LIBOR basis adjustment.

Table 3.6 Data Extraction Settings Map for IR_HW_1F

Map Key	Type Code	Description	Constraints	Default Value
`mpIRCurveSettings`	L	Name of a map of settings for the IR curve data extraction. The settings in this map are listed in "Interest Rate Extraction Settings Map" on page 35.	Referenced map must exist in the auxiliary transaction data file.	Empty map
`ampBasisCurveSettings`	AL	Names of maps of settings for the basis data extraction, one for each interest rate curve specified by `aBasisCurve` in the market data map. The settings in these maps are listed in "Interest Rate Extraction Settings Map" on page 35.	Referenced maps must exist in the auxiliary transaction data file.	The settings specified by `mpIRCurveSettings` are used.
`strMethod`	S	Type of calibrating instrument to extract. If you specify `SwaptionColumn`, include `nLengthMonths` in the trade information map. `SwaptionColumn` is not supported when the `DataExtractionMethod` is `QDataExtraction_IR_HW_1F_PWC_SelectedSwaptions`	One of: • `Caplet` • `Swaption` • `SwaptionColumn`	`Swaption`
`bExtrapolateDF`	B	Whether to extrapolate discount factors.	One of: • TRUE • FALSE	FALSE

Table 3.6 Data Extraction Settings Map for IR_HW_1F (Continued)

Map Key	Type Code	Description	Constraints	Default Value
`nMonthsExtrapDFEnd`	N	Number of months after the calibration date in which to extrapolate the discount factors.		0
`rSwaptionShift`	R	(Optional) If specified, the market swaption price in the calibration of the model is calculated under the assumption that the swap rate has a shifted log-normal distribution with the specified shift size. In this case, the swaption price in the calibration is calculated using Black's formula with the adjusted swap rate and strike obtained by subtracting `rSwaptionShift` from the original swap rate and strike of the calibrating swaptions.		0
`strDaycountFixed`	S	(Optional) Day count convention in the fixed leg of the calibrating swaptions.	See Table B.2 on page 327.	The *`dayCountConv`* attribute of the input swaption volatility curve is used.
`nSwapTenorFixed`	N	(Optional) Coupon frequency (in months) in the fixed leg of the calibrating swaptions.		The *`tenor`* attribute of the input swaption volatility curve is used.
Use the additional inputs in this section only when `DataExtractionMethod` is `QDataExtraction_IR_HW_1F_PWC_SelectedSwaptions`				
`astrSwaptionExpiry`	AS	(Optional) Time to expiry to specify the swaption volatilities for extraction from the input swaption volatility curve, in the same units as the expiry ordinates in the curve.		The times to expiry are assumed to be the expiry ordinate values of the input swaption volatility curve.
`anSwaptionLength`	AN	(Optional) Lengths in months of the swaptions to specify the volatility for extraction from the input swaption volatility curve, one for each expiry date specified by `astrSwaptionExpiry`. Ignored if `astrSwaptionExpiry` is omitted.	Same number of elements as `astrSwaptionExpiry`.	The co-terminal swaption volatility is extracted for all expiry dates specified in `astrSwaptionExpiry`.

Table 3.6 Data Extraction Settings Map for IR_HW_1F (Continued)

Map Key	Type Code	Description	Constraints	Default Value
arSwaptionStrike	AR	(Optional) Swaption strike to specify the volatility for extraction from the input swaption volatility curve, one for each expiry date specified by astrSwaptionExpiry. Ignored if astrSwaptionExpiry is omitted. Used only when the swaption volatility curve is of type SwaptionVolCube.	Same number of elements as astrSwaptionExpiry.	The at-the-money strike is used for all expiry dates specified in astrSwaptionExpiry.
strSwaptionStrikeType	S	(Optional) Type of the strikes specified in arSwaptionStrike. Ignored if arSwaptionStrike is omitted. Used only when the swaption volatility curve is of type SwaptionVolCube.	One of: • ABSOLUTE • F-K • K-F • F/K • K/F F is the underlying par swap rate for the swaption period. ABSOLUTE means that values represent the strike K. The remaining strike types mean that values are specified in relative terms.	ABSOLUTE
idxBasisCurveCalib	N	(Optional) Index of the interest rate curve to use for additive LIBOR basis adjustment in the calculation of the swap rate during the extraction of the ATM volatility.	Integer between 0 and n–1, where n is the number of curves specified by the market data map member aBasisCurve.	The LIBOR basis adjustment is not performed.
idxBasisCurveCalibDisc	N	(Optional) Index of the interest rate curve to use for discounting in the calculation of the swap rate during the extraction of the ATM volatility. Ignored if bUseBasisCurveForCalibDiscounting is set to TRUE.	Integer between 0 and n–1, where n is the number of curves specified by the market data map member aBasisCurve.	Interest rate curve specified by the market data map member IRCurve.
bUseBasisCurveForCalibDiscounting	B	Whether to use the basis curve, if specified by idxBasisCurveCalib, for both discounting and forecasting in the calculation of the swap rate (TRUE) or just for forecasting (FALSE).	One of: • TRUE • FALSE	FALSE

Examples

The first example assumes the data extraction method is QDataExtraction_IR_HW_1F_PWC, and it extracts caplet volatilities.

```
SampleHWDataExtractionSettings, {
  mpIRCurveSettings, L, IRExtractionSettings
  strMethod, S, Caplet
}
```

The second example assumes the data extraction method is QDataExtraction_IR_HW_1F_PWC_SelectedSwaptions, the input curve type is SwaptionVolCube, and the expiries are in months.

```
SampleHWDataExtractionSettings_SelectedSwaptions, {
  mpIRCurveSettings, L, IRExtractionSettings
  strMethod, S, Swaption
  astrSwaptionExpiry, AS, 3, 6, 9, 12
  anSwpationLength, AN, 24, 24, 24, 24
  arSwaptionStrike, AR, 0.9, 1.0, 1.1, 1.2
  strSwaptionStrikeType, S, F/K
}
```

3.3.5 Trade Information (IR_HW_1F)

The TradeInfo member of the model preferences map refers to another map that specifies information about the portfolio as a whole and other trade-related information. The following table defines the members of a trade information map for the single-currency single-factor Hull-White model.

Table 3.7 Trade Information Map for IR_HW_1F

Map Key	Type Code	Description	Constraints	Default Value
dtLastCashflow	D	Last date on which a cash flow occurs for any trade in the portfolio.		
g1dtExercise	GD	Swaption expiry dates to use for selecting calibration instruments. Required if the data extractor is QDataExtraction_IR_HW_1F_PWC_SwaptionStrike.		
g1rStrike	GR	Strike to use for selecting calibration instruments at each expiry date. Required if the data extractor is QDataExtraction_IR_HW_1F_PWC_SwaptionStrike.	Same number of elements as g1dtExercise.	

Table 3.7 Trade Information Map for IR_HW_1F (Continued)

Map Key	Type Code	Description	Constraints	Default Value
strInterp	S	Interpolation method to use in extracting swaption volatilities. Applies if the data extractor is QDataExtraction_IR_HW_1F_PWC_SwaptionStrike.	See Table B.3 on page 328.	lin
strExtrap	S	Extrapolation method to use in extracting swaption volatilities. Applies if the data extractor is QDataExtraction_IR_HW_1F_PWC_SwaptionStrike.	See Table B.3 on page 328.	near
nLengthMonths	N	Swap length, in months, of the swaption volatilities to extract when the extraction method is SwaptionColumn.		

Chapter 4

Single-Currency Multifactor Hull-White Model

The single-currency multifactor Hull-White interest rate model (IR_HW_NF) is a multifactor short rate model with the following features:

- Treats the model volatilities as piecewise constant functions in time.
- Includes support for a LIBOR basis adjustment.
- Takes into account the forecasting curve when calibrating to swaptions, which enables it to calibrate in markets with negative discounting swap rates but positive forecasting swap rates.

The simulation is done in the forward measure and an exact simulation method is used.

For information about the methodology of the IR_HW_NF model, see the following chapter in *Markit Analytics Model Framework Mathematical Reference*: “Multi-Factor Hull-White Interest Rate Model”.

4.1 Module (IR_HW_NF)

The Model Framework module that implements the single-currency multifactor Hull-White interest rate model (IR_HW_NF) is as follows:

```
quic_model_ir_hw_nf:3.0
```

Combine this module name with the module component names identified in this chapter to form a complete module reference. For example, if the component is `QModel_IR_HW_NF_PWC`, the complete module reference is as follows:

```
QModel_IR_HW_NF_PWC@quic_model_ir_hw_nf:3.0
```

4.2 Market Data Generator Parameters (IR_HW_NF)

A market data generator parameters set for the Model Framework market data generator includes certain parameters whose value depends on the particular model. These include some parameters that are used directly by the generator itself and others that are used only by the Model Framework model that it invokes (in particular by the model's simulator component). For descriptions of the direct generator parameters, see the *Markit Analytics Simulation Framework User Guide*. The parameters that are used by Model Framework simulators are described in "Model Framework Simulator Settings" on page 28.

Some of the simulator settings are used by all models and others are used only by certain models. For the latter subset of settings, the information below shows which ones are used by this model.

Generator Parameter: `strSimulatorMFWKReference`

The parameter `strSimulatorMFWKReference` specifies the simulator plug-in for the model. The following values of this parameter are available for the IR_HW_NF model:

- Exact simulation algorithm under the forward measure:

  `QMCSimulator_IR_HW_NF_PWC_FM@quic_model_ir_hw_nf:3.0`

- Simulation algorithm under the risk-neutral measure:

  `QMCSimulator_IR_HW_NF_PWC_RNM@quic_model_ir_hw_nf:3.0`

Applicability of Simulator Settings

The following table identifies which simulator plug-ins (if any) support the specified simulator settings.

Table 4.1 Support for Simulator Settings (IR_HW_NF)

Parameter	Simulators That Support the Parameter
`bStepOnDFDates`	• `QMCSimulator_IR_HW_NF_PWC_FM` • `QMCSimulator_IR_HW_NF_PWC_RNM`
`bUseEuler`	• `QMCSimulator_IR_HW_NF_PWC_FM` • `QMCSimulator_IR_HW_NF_PWC_RNM`
`bPrecalculateCovariances`	Not applicable
`bUseEigenSym` and `bUsePCA`	• `QMCSimulator_IR_HW_NF_PWC_FM` • `QMCSimulator_IR_HW_NF_PWC_RNM`

Table 4.1 Support for Simulator Settings (IR_HW_NF) (Continued)

Parameter	Simulators That Support the Parameter
bCholesky	Not applicable
strDecomposition	Not applicable
bUseStartEndNumeraireCalc	QMCSimulator_IR_HW_NF_PWC_RNM
bUseForeignQuantoAdjustment	Not applicable
bUseDeterministicFXDrifts	Not applicable
bUseDeterministicInflationDrifts	Not applicable
bApproximateXIntegral	Not applicable

4.3 Model Preferences (IR_HW_NF)

You specify the settings for the model in a model preferences map and in the subsidiary maps that it references. For a general description of a model preferences map, see “Model Preferences Map” on page 32.

You can include credit modeling in this model by specifying additional inputs in the model preferences map and its subsidiary maps. These additional inputs are described in “Adding Credit Support to a Non-Credit Model” on page 36.

4.3.1 Components (IR_HW_NF)

The following table identifies the available plug-ins (components of the IR_HW_NF module) that implement the model. You specify these as values of members of the model preferences map in the form of full module references.

Table 4.2 Model Plug-In Components (IR_HW_NF)

Model Preference	Available Components of the Module
Model	QModel_IR_HW_NF_PWC
CalibrationMethod	One of: • QModelCalibration_IR_HW_NF_PWC Regular calibration. • QModelCalibration_IR_HW_NF_PWC_SwaptionDiagonal Calibrates to the diagonal of the swaption matrix. Supports term structures of eta scale factors and correlations.
DataExtractionMethod	One of: • QDataExtraction_IR_HW_NF_PWC • QDataExtraction_IR_HW_NF_PWC_SwaptionDiagonal For calibration to the diagonal of the swaption matrix.

In addition, you must specify the maps that are identified by the other members of the model preferences map. The remainder of this chapter defines these subsidiary maps.

Example

The following figure shows a sample model preferences map that specifies components for this model. In the model preferences file, each map member occupies a single line.

```
USD_IR_HW_NF_ModelPrefs_Internal, {
  Model, S, QModel_IR_HW_NF_PWC@quic_model_ir_hw_nf:3.0
  CalibrationMethod, S, QModelCalibration_IR_HW_NF_PWC@quic_model_ir_hw_nf:3.0
  CalibrationSettings, L, IR_HW_NF_USD_CalibrationSettings
  DataExtractionMethod, S, QDataExtraction_IR_HW_NF_PWC@quic_model_ir_hw_nf:3.0
  DataExtractionSettings, L, IR_HW_NF_USD_DataExtractionSettings
  TradeInfo, L, Portfolio_Info
}
```

4.3.2 Calibration Settings (IR_HW_NF)

The `CalibrationSettings` member of a model preferences map refers to another map that specifies parameters for the model calibration process. The following table defines the members of a calibration settings map for the single-currency multifactor Hull-White model with LIBOR basis adjustment.

Table 4.3 Calibration Settings Map for IR_HW_NF

Map Key	Type Code	Description	Constraints	Default Value
The inputs in this section are common to all the calibration methods.				
`strCCYDom`	S	Name of the domestic currency.	Standard 3-character currency identifier	
`astrBasisCurve`	AS	(Optional) Nicknames of the interest rate curves used for additive LIBOR basis adjustment.	Include a nickname for each of the curves, in order, specified by the `aBasisCurve` member of the market data map.	
`strBasisCurveCalib`	S	(Optional) Nickname of the interest rate curve to use for additive LIBOR basis adjustment during calibration.	Must be one of the names in `astrBasisCurve`.	The LIBOR basis adjustment is not performed.
`bUseBasisCurveForCalibDiscounting`	B	Whether to use the basis curve, if specified by `strBasisCurveCalib`, for both discounting and forecasting in the calibration (TRUE) or just for forecasting (FALSE).	One of: • TRUE • FALSE	FALSE

Table 4.3 Calibration Settings Map for IR_HW_NF (Continued)

Map Key	Type Code	Description	Constraints	Default Value
strBasisCurveCalibDisc	S	(Optional) Nickname of the interest rate curve to use for discounting during calibration. Ignored if bUseBasisCurveForCalibDiscounting is set to TRUE.	Must be one of the names in astrBasisCurve.	Interest rate curve specified by the market data map member IRCurve.
bNormalVolatilities	B	Whether to assume normal (TRUE) or log-normal (FALSE) volatilities.	One of: • TRUE • FALSE	FALSE
rDaysPerAnnum	R	Number of days per annum. Used for scaling arA, arTau, swaption volatilities, and initial instantaneous forward rates.		365.25
strSwaptionType	S	Type of the swaption.	One of: • Payer • Receiver	Receiver
rNotional	R	Notional amount to use when calculating prices during calibration.		100.0 (for regular calibration) 1.0 (for swaption diagonal calibration)
bOutputFitResults	B	Whether to report the results of the calibration (comparison of the prices of calibrating instruments from the calibrated model and calculated analytically from market data).	One of: • TRUE • FALSE	FALSE
strOutputFile	S	(Optional) File path of the CSV file to which calibration results are written (if requested by bOutputFitResults).		Results are displayed in the audit pane only.
strModelParametersOutputFile	S	(Optional) File path of the HDF5 file to which the calculated model parameters are written. This file has the same format as a file for externally calibrated parameters. Typically used only for troubleshooting.		No file is produced.
strModelParametersOutputName	S	(Optional) Name to give this model parameters set in the file specified by strModelParametersOutputFile.		mpModelParams

Table 4.3 Calibration Settings Map for IR_HW_NF (Continued)

Map Key	Type Code	Description	Constraints	Default Value
`bOutputCalibrationData`	B	Whether to include the calibration data in the HDF5 file specified by `strModelParametersOutputFile`. Typically used only for troubleshooting because it may significantly increase the size of the file.	One of: • TRUE • FALSE	FALSE
`mpOutputSettings`	L	(Optional) Name of a map of settings to control the output of calibration results.	Referenced map must exist in the auxiliary transaction data file.	Empty map
Use the inputs in this section only when `CalibrationMethod` is `QModelCalibration_IR_HW_NF_PWC`.				
`arA`	AR	Array of risk factor mean reversion parameters.		default <0.01,0.1,0.2,1.0>
`arTau`	AR	Array of forward rate tenor points in days.		default <182,2*365,3650, 2*3650>
`anEtaMonths`	AN	(Optional) Number of months between calibration date and jump dates of interest rate volatility to generate volatility jump dates.		Volatility jump dates are generated from the maturity dates of input swaption volatility matrix.
`arFitParamGuess`	AR	Initial guess of fit parameters.		sqrt(0.1) for each element
`rSmoothT`	R	Value of the smoothness penalty in the volatility calibration in time direction.		1e-5
`rSmoothF`	R	Value of the smoothness penalty in the volatility calibration in the instantaneous forward rate direction.		0.0
`bFitErrorDivVolVega`	B	Whether to divide the fitting error by the swaption volatility vega in the optimization procedure during the calibration.	One of: • TRUE • FALSE	TRUE
`bCorrOrdinatesInMonths`	B	Whether the ordinates of the correlation curves are in months (TRUE) or days (FALSE).	One of: • TRUE • FALSE	FALSE
`bAuditQOF`	B	Whether to output information about the quality of fit.	One of: • TRUE • FALSE	FALSE
`bAuditError`	B	Whether to output information about errors that occur during the calibration process.	One of: • TRUE • FALSE	FALSE

Table 4.3 Calibration Settings Map for IR_HW_NF (Continued)

Map Key	Type Code	Description	Constraints	Default Value
bAuditFitParams	B	Whether to output the values of the fitted parameters.	One of: • TRUE • FALSE	FALSE
mpOptimizationSettings	L	(Optional) Name of a map of settings for optimizing the fit of model parameters to market-observed quantities. See “Optimization Settings (IR_HW_NF)” on page 66.	Referenced map must exist in the auxiliary transaction data file.	
aarInputCorrMtx	AL	Names of lists of type AR that specify the correlation matrices, one list for each risk factor. Each list has the same structure as described for arInputCorrMtx. Used if you don't provide correlations via the market data.		
Use the inputs in this section only when CalibrationMethod is QModelCalibration_IR_HW_NF_PWC_SwaptionDiagonal.				
arA	AR	Array of risk factor mean reversion parameters. If aMeanReversionCurve is provided in the Market Data map, you can ignore this input. If both are provided, aMeanReversionCurve is used.	One element for each factor.	
arEtaScaleFactor	AR	Eta scale factors. If aEtaScaleFactorCurve is provided in the Market Data map, you can ignore this input. If both are provided, aEtaScaleFactorCurve will be used.	One element for each factor. First element must be 1.0.	
arInputCorrMtx	AR	Values in the correlation matrix. See the note below this table. If aCorrelCurve is provided in the Market Data map, you can ignore this input. If both are provided, aCorrelCurve will be used.		
rEta0Guess	R	Initial guess for eta.		0.01
rErrorTol	R	Error tolerance for root find to match market prices. Applies only when the calibrator is QModelCalibration_IR_HW_NF_PWC_SwaptionDiagonal.		1.0e–14

Table 4.3 Calibration Settings Map for IR_HW_NF (Continued)

Map Key	Type Code	Description	Constraints	Default Value
`rVolSensTol`	R	Volatility sensitivity tolerance. Applies only when the calibrator is `QModelCalibration_IR_HW_NF_PWC_SwaptionDiagonal`.		0.001
`mpRootFindSettings`	L	(Optional) Name of a map of settings for the root-finding procedure.	Referenced map must exist in the auxiliary transaction data file.	For the default values of individual settings, see "Root-Finding Settings (IR_HW_NF)" on page 67.
`bCorrectCorrMtx`	B	Whether to ensure that the input correlation matrix is positive semidefinite by using principal components analysis.		TRUE
`rEigenThreshold`	R	If `bCorrectCorrMtx` is TRUE, all eigenvectors associated with eigenvalues less than this threshold times the largest eigenvalue are set to zero.		`1e-15`

Note: `arInputCorrMtx`

For an N-factor model with risk factors $x_1,\ldots,x_N$, the correlation input requires $N^*(N–1)/2$ values (the number of unique off-diagonal elements in the correlation matrix), where:

- The first $N–1$ entries corresponds to the correlations between x_1 and $x_2, \ldots, x_N$.
- The next $N–2$ entries corresponds to the correlations between x_2 and $x_3, \ldots, x_N$.
- The next $N–3$ entries corresponds to the correlations between x_3 and $x_4, \ldots, x_N$.
- And so on....

Example

```
IR_HW_NF_USD_CalibrationSettings, {
  strCCYDom, S, USD
  rNotional, R, 1
  astrBasisCurve, AS, USD_Forecasting.Yield.USD
  strBasisCurveCalib, S, USD_Forecasting.Yield.USD
  mpRootFindSettings, L, MS_USD_RootFindingSettings
}
```

4.3.2.1 Optimization Settings (IR_HW_NF)

The `mpOptimizationSettings` member of the calibration settings map refers to another map that specifies settings for the optimization procedure.

The following table defines the members of the optimization settings map for the single-currency multifactor Hull-White model. (This applies to the `QModelCalibration_IR_HW_NF_PWC` calibrator only.)

Table 4.4 Optimization Settings Map for IR_HW_NF

Map Key	Type Code	Description	Constraints	Default Value
`OPTIMIZATIONMETHOD`	S	Name of a function that performs the optimization: One of: • `minmd_f` (an Engine operator) • `Simplex` (an MA Script function in the module `quic_numerical_methods`) The remaining members of this map are the settings for the selected function.	One of: • `minmd_f` • `Simplex`	`minmd_f`
The inputs in this section are the supported options for the `minmd_f` optimization method.				

`MXFCAL`
`MXITER`
`AFCTOL`
`RFCTOL`
`LMAX0`
`SCTOL`
`LMAXS`
`XCTOL`
`XFTOL`
		For detailed descriptions, constraints, and default values see the `minmd_f` page in the online *Markit Analytics Script Reference*.		

The inputs in this section are the options for the `Simplex` optimization method.				
`MXITER`	N	Maximum number of iterations.		200
`AFCTOL`	R	Tolerance for convergence.		1e-8
`LAMBDA`	R	Parameter for creating the initial simplex.		0.1
`RESTART`	B	Whether to apply a restart.	One of: • TRUE • FALSE	TRUE
`RHO`	R	Reflection coefficient.		1.0
`CHI`	R	Expansion coefficient.		2.0
`GAMMA`	R	Contraction coefficient.		0.5
`SIGMA`	R	Shrinkage coefficient.		0.5
`EPSILON`	R	Small number used in the convergence calculation.		1e-12

4.3.2.2 Root-Finding Settings (IR_HW_NF)

The `mpRootFindSettings` member of the calibration settings map refers to another map that specifies settings for the root-finding process. Most of these settings specify various numerical tolerances. Normally, the default values are sufficient.

The following table defines the members of a root-finding settings map for the single-currency multifactor Hull-White model. (This applies to the `QModelCalibration_IR_HW_NF_PWC_SwaptionDiagonal` calibrator only.)

Table 4.5 Root-Finding Settings Map for IR_HW_NF

Map Key	Type Code	Description	Constraints	Default Value
`rErrorTol`	`R`	Error tolerance for root find to match market prices.		1.0e–14
`rRelTolNR`	`R`	Relative tolerance in Newton-Raphson method for root find to match market prices.		1.0e–13
`nMaxIterNR`	`N`	Maximum number of iterations in Newton-Raphson method for root find to match market prices.		100
`nMaxIterBracket`	`N`	Maximum number of iterations used in bracketing for root find to match market prices.		20
`rBracketLow`	`R`	Low value for bracketing for root find to match market prices.		1.0e–10
`rBracketHigh`	`R`	High value for bracketing for root find to match market prices.		1.0e–1
`nMaxDiv`	`N`	Maximum number of divisions in bisection for root find to match market prices.		100

4.3.2.3 Calibration Results Output Settings (IR_HW_NF)

The `mpOutputSettings` member of the calibration settings map refers to another map that specifies settings for controlling the output of calibration results. The following table defines the settings that are used.

Table 4.6 Calibration Results Output Settings Map for IR_HW_NF

Map Key	Type Code	Description	Constraints	Default Value
`bRecalculateFitPrice`	`B`	Controls whether to recalculate the swaption fit price using the calibrated model or use previous stored values.		`false`
`bAuditVolFitError`	`B`	Controls whether to report the fitted instrument (swaption) price or report fitted volatility.		`false`

4.3.3 Market Data Inputs (IR_HW_NF)

The `CurveNames` member of a model preferences map refers to a map that identifies the market data curves that are required for pricing, simulation, and internal model calibration. The table below defines the members of a market data map for the single-currency multifactor Hull-White model.

Table 4.7 Market Data Map for IR_HW_NF

Map Key	Type Code	Description	Constraints	Default Value
`IRCurve`	S or L	Either: • Name of a curve for discounting (of type `DiscountFactor`, `Yield`, or `FwdLibor`). • Name of a list that specifies a set of curves to use in bootstrapping the discount factor. For details about the list of curves for bootstrapping, see "Specifying the Data to Use in Bootstrapping" on page 34.	Referenced curve must exist in the market data HDF5 file, or referenced map must exist in the auxiliary transaction data file. Ordinates of a `Yield` curve must be >0.	
`SwaptionVolCurve`	S	Name of a swaption volatility curve (of type `SwaptionVolMtx` or `SwaptionVolCube`).	Referenced curve must exist in the market data HDF5 file.	
`aBasisCurve`	AS	(Optional) Names of curves (of type `DiscountFactor`, `Yield`, or `FwdLibor`) that specify the forecasting interest rates to use for LIBOR basis adjustments.	Referenced curves must exist in the market data HDF5 file. Ordinates of a `Yield` curve must be >0.	
Use the inputs in this section only when `CalibrationMethod` is `QModelCalibration_IR_HW_NF_PWC`.				
`CorrelationCurve`	S	Name of a correlation curve (of type `CorrelBlock`) that gives the correlations between model risk factors.	Referenced curves must exist in the market data HDF5 file.	
Use the inputs in this section only when `CalibrationMethod` is `QModelCalibration_IR_HW_NF_PWC_SwaptionDiagonal`.				
`aMeanReversionCurve`	AS	Names of mean reversion curves (of type `MeanReversion`), one for each factor. If `arA` is provided in the calibration settings map, you can ignore this input. If both `aMeanReversionCurve` and `arA` are provided, `aMeanReversionCurve` is used.	Referenced curves must exist in the market data HDF5 file.	

Table 4.7 Market Data Map for IR_HW_NF (Continued)

Map Key	Type Code	Description	Constraints	Default Value
`aEtaScaleFactorCurve`	AS	(Optional) Names of curves (of type `EtaScaleFactor`), one for each risk factor, that provide a time-varying volatility scale factor, in the same order as the mean reversion curves. Overrides static scale factors specified by `arEtaScaleFactor` in the calibration settings map.	Referenced curves must exist in the market data HDF5 file.	
`aCorrelCurve`	AS	(Optional) Names of curves (of type `InputCorrelation`) which each provide the time-varying correlation between one pair of risk factors. For more details, see the note that follows this table. Overrides static correlations specified by `arInputCorrMtx` in the calibration settings map.	Referenced curves must exist in the market data HDF5 file.	

Note: `aCorrelCurve`

The order in which you list the `InputCorrelation` curves must correspond to the upper half of a static correlation matrix in row sequence, without the diagonal. For example, if the model has 4 risk factors $R_1,\ldots,R_4$, and we denote the curve that provides the time-varying correlation between R_i and R_j as (R_i,R_j), the curves must appear in the following order:

$$(R_1,R_2),\ (R_1,R_3),\ (R_1,R_4),\ (R_2,R_3),\ (R_2,R_4),\ (R_3,R_4)$$

Examples

The first example includes the typical inputs needed for internal calibration.

```
EURMktData_Internal_Calib, {
  IRCurve, S, EUR.Yield.EUR
  SwaptionVolCurve, S, EUR.SwaptionVolMtx.EUR
  CorrelationCurve, S, IRHWNF2.CorrelBlock.IRHWNF2
}
```

The second example is for internal calibration with time-varying volatility scaling and time-varying correlations.In this example, the model has only 2 risk factors, so only one `InputCorrelation` curve is required in the `aCorrelCurve` list.

```
EURMktData_Swaption_Diagonal_with_Time_Dependence, {
  IRCurve, S, EUR.Yield.EUR
  SwaptionVolCurve, S, EUR.SwaptionVolMtx.EUR
  aMeanReversionCurve, AS, EURMR1.MeanReversion.EUR
  ..., EURMR2.MeanReversion.EUR
  aEtaScaleFactorCurve, AS, EUREtaScale1.EtaScaleFactor.EUR
  ...,   EUREtaScale2.EtaScaleFactor.EUR
  aCorrelCurve, AS, EURInputCorr1.InputCorrelation.EUR
}
```

4.3.4 Data Extraction Settings (IR_HW_NF)

The `DataExtractionSettings` member of a Hull-White model preferences map refers to another map that specifies parameters for the data extraction process. The following table defines the members of a data extraction settings map for the single-currency multifactor Hull-White model.

Table 4.8 Data Extraction Settings Map for IR_HW_NF

Map Key	Type Code	Description	Constraints	Default Value
`mpIRCurveSettings`	`L`	Name of a map of settings for the IR curve data extraction. The settings in this map are listed in "Interest Rate Extraction Settings Map" on page 35.	Referenced map must exist in the auxiliary transaction data file.	Empty map
`ampBasisCurveSettings`	`AL`	Names of maps of settings for the basis data extraction, one for each interest rate provider specified by `aBasisCurve` in the market data map. The settings in these maps are listed in "Interest Rate Extraction Settings Map" on page 35.	Referenced maps must exist in the auxiliary transaction data file.	The settings specified by `mpIRCurveSettings` are used.
`strMethod`	`S`	Type of calibrating instrument to extract.	One of: • `Caplet` • `Swaption`	`Swaption`
`bExtrapolateDF`	`B`	Whether to extrapolate discount factors.	One of: • TRUE • FALSE	FALSE
`nMonthsExtrapDFEnd`	`N`	Number of months after the calibration date in which to extrapolate the discount factors.		0
`strDaycountFixed`	`S`	(Optional) Day count convention in the fixed leg of the calibrating swaptions.	See Table B.2 on page 327.	The *`dayCountConv`* attribute of the input swaption volatility curve is used.
`nSwapTenorFixed`	`N`	(Optional) Coupon frequency (in months) in the fixed leg of the calibrating swaptions.		The *`tenor`* attribute of the input swaption volatility curve is used.

Table 4.8 Data Extraction Settings Map for IR_HW_NF (Continued)

Map Key	Type Code	Description	Constraints	Default Value
`anCalibSwptnLength`	AN	(Optional) Swap lengths (in months) to use in the calibration.	Only swap lengths that match ordinates of the input swaption volatility curve are used.	If omitted or if no curve ordinates are matched, all swap lengths present in the input swaption volatility curve are used.

4.3.5 Trade Information Map (IR_HW_NF)

The `TradeInfo` member of the model preferences map refers to another map that specifies information about the portfolio as a whole and other trade-related information. The following table defines the members of a trade information map for the single-currency multifactor Hull-White model.

Table 4.9 Trade Information Map for IR_HW_NF

Map Key	Type Code	Description	Constraints	Default Value
`dtLastCashflow`	D	Last date on which a cash flow occurs for any trade in the portfolio.		
`dtLastRequiredDF`	D	Last date on which a discount factor is required for any trade in the portfolio.		
`g1dtExercise`	GD	Swaption expiry dates to use for selecting calibration instruments. Applies only when the calibrator is `QModelCalibration_IR_HW_NF_PWC _SwaptionDiagonal` and the volatilities are obtained from a `SwaptionVolCube` curve.		
`g1rStrike`	GR	Strike to use for selecting calibration instruments at each expiry date. Applies only when the calibrator is `QModelCalibration_IR_HW_NF_PWC _SwaptionDiagonal` and the volatilities are obtained from a `SwaptionVolCube` curve.	Same number of elements as `g1dtExercise`.	
`strInterp`	S	Interpolation method to use in extracting swaption volatilities. Applies if the data extractor is `QDataExtraction_IR_HW_NF_PWC_S waptionDiagonal`.	See Table B.3 on page 328.	`lin`
`strExtrap`	S	Extrapolation method to use in extracting swaption volatilities. Applies if the data extractor is `QDataExtraction_IR_HW_NF_PWC_S waptionDiagonal`.	See Table B.3 on page 328.	`near`

Chapter 5

Multicurrency Single-Factor Hull-White Model

The multicurrency single-factor Hull-White interest rate model (FX_IR_HW_1F) uses a single-currency Hull-White model for each short rate and a log-normal Garman-Kohlhagen-type model for each spot foreign exchange (FX) rate. It treats both the short rate volatilities and spot FX volatilities as piecewise constant functions in time.

The simulation is done in the forward measure and an exact simulation method is used.

For information about the methodology of the FX_IR_HW_1F model, see the following chapter in *Markit Analytics Model Framework Mathematical Reference*: “Multi-Currency Single Factor Hull-White Model”.

5.1 Module (FX_IR_HW_1F)

The Model Framework module that implements the multicurrency single-factor Hull-White interest rate model (FX_IR_HW_1F) is as follows:

```
quic_model_fx_ir_hw_1f:3.0
```

Combine this module name with the module component names identified in this chapter to form a complete module reference. For example, if the component is `QModel_FX_IR_HW_1F_PWC`, the complete module reference is as follows:

```
QModel_FX_IR_HW_1F_PWC@quic_model_fx_ir_hw_1f:3.0
```

5.2 Market Data Generator Parameters (FX_IR_HW_1F)

A market data generator parameters set for the Model Framework market data generator includes certain parameters whose value depends on the particular model. These include some parameters that are used directly by the generator itself and others that are used only by the Model Framework model that it invokes (in particular by the model's simulator component). For descriptions of the direct generator parameters, see the *Markit Analytics Simulation Framework User Guide*. The parameters that are used by Model Framework simulators are described in "Model Framework Simulator Settings" on page 28.

Some of the simulator settings are used by all models and others are used only by certain models. For the latter subset of settings, the information below shows which ones are used by this model.

Generator Parameter: `strSimulatorMFWKReference`

The parameter `strSimulatorMFWKReference` specifies the simulator plug-in for the model. The following values of this parameter are available for the FX_IR_HW_1F model:

- Exact simulation algorithm under the forward measure:

  `QMCSimulator_FX_IR_HW_1F_PWC_FM@quic_model_fx_ir_hw_1f:3.0`
- Simulation algorithm under the risk-neutral measure:

  `QMCSimulator_FX_IR_HW_1F_PWC_RNM@quic_model_fx_ir_hw_1f:3.0`

Applicability of Simulator Settings

The following table identifies which simulator plug-ins (if any) support the specified simulator settings.

Table 5.1 Support for Simulator Settings (FX_IR_HW_1F)

Parameter	Simulators That Support the Parameter
`bStepOnDFDates`	• `QMCSimulator_FX_IR_HW_1F_PWC_FM` • `QMCSimulator_FX_IR_HW_1F_PWC_RNM`
`bUseEuler`	• `QMCSimulator_FX_IR_HW_1F_PWC_FM` • `QMCSimulator_FX_IR_HW_1F_PWC_RNM`
`bPrecalculateCovariances`	Not applicable
`bUseEigenSym` and `bUsePCA`	Not applicable

Table 5.1 Support for Simulator Settings (FX_IR_HW_1F) (Continued)

Parameter	Simulators That Support the Parameter
bCholesky	Not applicable
strDecomposition	Not applicable
bUseStartEndNumeraireCalc	QMCSimulator_FX_IR_HW_1F_PWC_RNM
bUseForeignQuantoAdjustment	Not applicable
bUseDeterministicFXDrifts	Not applicable
bUseDeterministicInflationDrifts	Not applicable
bApproximateXIntegral	Not applicable

5.3 Model Preferences (FX_IR_HW_1F)

You specify the settings for the model in a model preferences map and in the subsidiary maps that it references. For a general description of a model preferences map, see "Model Preferences Map" on page 32.

You can include credit modeling in this model by specifying additional inputs in the model preferences map and its subsidiary maps. These additional inputs are described in "Adding Credit Support to a Non-Credit Model" on page 36.

5.3.1 Components (FX_IR_HW_1F)

The following table identifies the available plug-ins (components of the FX_IR_HW_1F module) that implement the model. You specify these as values of members of the model preferences map in the form of full module references.

Table 5.2 Model Plug-In Components (FX_IR_HW_1F)

Model Preference	Available Components of the Module
Model	QModel_FX_IR_HW_1F_PWC
CalibrationMethod	QModelCalibration_FX_IR_HW_1F_PWC
DataExtractionMethod	QDataExtraction_FX_IR_HW_1F_PWC

In addition, you must specify the maps that are identified by the other members of the model preferences map. The remainder of this chapter defines these subsidiary maps.

Example

The following figure shows a sample model preferences map that specifies components for this model. In the model preferences file, each map member occupies a single line.

```
FX_IR_HW_1F_ModelPrefs, {
  Model, S, QModel_FX_IR_HW_1F_PWC@quic_model_fx_ir_hw_1f:3.0
  CalibrationMethod, S, QModelCalibration_FX_IR_HW_1F_PWC@quic_model_fx_ir_hw_1f:3.0
  CalibrationSettings, L, FX_IR_HW_1F_CalibrationSettings
  CurveNames, L, FX_IR_HW_1F_CurveNames
  DataExtractionMethod, S, QDataExtraction_FX_IR_HW_1F_PWC@quic_model_fx_ir_hw_1f:3.0
  DataExtractionSettings, L, FX_IR_HW_1F_DataExtractionSettings
  TradeInfo, L, PORTFOLIO_INFO
}
```

5.3.2 Calibration Settings (FX_IR_HW_1F)

The `CalibrationSettings` member of a model preferences map refers to another map that specifies parameters for the model calibration process. The following table defines the elements of a calibration settings map for the FX_IR_HW_1F model.

Table 5.3 Calibration Settings Map for FX_IR_HW_1F

Map Key	Type Code	Description	Constraints	Default Value
`astrCCY`	AS	Names of the model currencies. Must be the same number of names as the number of IR curves passed to the data extractor. The first name is the domestic currency.	Standard 3-character currency identifiers	
`ampCalibrationSettingsIR`	AL	Names of maps, one for each model currency, that specify the IR calibration settings. For the definition of these maps, see "IR Calibration Settings (FX_IR_HW_1F)" on page 78.	Referenced maps must exist in the model preferences file. To use the defaults for all settings, provide an empty map.	
`ampCalibrationSettingsFX`	AL	Names of maps, one for each foreign currency, that specify FX calibration settings. For the definition of these maps, see "FX Calibration Settings (FX_IR_HW_1F)" on page 80.	Referenced maps must exist in the model preferences file. To use the defaults for all settings, provide an empty map.	
`astrBasisCurve`	AS	Nicknames of the interest rate curves used for additive LIBOR basis adjustment.	Include a nickname for each of the curves, in order, specified by the `aBasisCurve` member of the market data map.	

Table 5.3 Calibration Settings Map for FX_IR_HW_1F (Continued)

Map Key	Type Code	Description	Constraints	Default Value
`bOutputFitResults`	B	Whether to report the results of the calibration (comparison of the prices of calibrating instruments from the calibrated model and calculated analytically from market data).	One of: • TRUE • FALSE	FALSE
`strOutputFile`	S	(Optional) File path of the CSV file to which calibration results are written (if requested by `bOutputFitResults`).		Results are displayed in the audit pane only.
`strModelParametersOutputFile`	S	(Optional) File path of the HDF5 file to which the calculated model parameters are written. This file has the same format as a file for externally calibrated parameters. Typically used only for troubleshooting. If omitted, no file is produced.		
`strModelParametersOutputName`	S	(Optional) Name to give this model parameters set in the file specified by `strModelParametersOutputFile`.		`mpModelParams`
`bOutputCalibrationData`	B	Whether to include the calibration data in the HDF5 file specified by `strModelParametersOutputFile`. Typically used only for troubleshooting because it may significantly increase the size of the file.	One of: • TRUE • FALSE	FALSE

Example

```
FX_IR_HW_1F_CalibrationSettings, {
  astrCCY, AS, USD, EUR, JPY, GBP
  ampCalibrationSettingsIR, AL, IR_USD_CalibSettings, IR_EUR_CalibSettings, EMPTY_MAP,
    EMPTY_MAP
  ampCalibrationSettingsFX, AL, void, UseNegativeSpotVols, UseNegativeSpotVols,
    UseNegativeSpotVols
  astrBasisCurve, AS, USDLibor3M, EURLibor3M
}
```

5.3.2.1 IR Calibration Settings (FX_IR_HW_1F)

The ampCalibrationSettingsIR member of a calibration settings map refers to other maps that each specify settings for the calibration of the interest rate model for one currency. The following table defines the members of an IR calibration settings map for the FX_IR_HW_1F model.

Table 5.4 IR Calibration Settings Map for FX_IR_HW_1F

Map Key	Type Code	Description	Constraints	Default Value
strCCYDom	S	Name of the domestic currency.	Standard 3-character currency identifier	
bUseCapletFormula	B	Whether to use the caplet formula. If set to TRUE, but the input calibrating instruments are swaptions, this setting reverts to FALSE.	One of: • TRUE • FALSE	FALSE
rNotional	R	Notional amount to use when calculating prices during calibration.		1.0
mpRootFindSettings	L	Name of a map of settings for the root-finding procedure.	Referenced map must exist in the model preferences file.	Empty map
bAllowNegativeMR	B	Whether to allow the calibration process to generate a negative mean reversion parameter.	One of: • TRUE • FALSE	FALSE
strBasisCurveCalib	S	(Optional) Nickname of the interest rate curve to use for additive LIBOR basis adjustment during calibration.	Must be one of the names in astrBasisCurve in the main calibration settings map.	The LIBOR basis adjustment is not performed.
bUseBasisCurveForCalibDiscounting	B	Whether to use the basis curve, if specified by strBasisCurveCalib, for both discounting and forecasting in the calibration (TRUE) or just for forecasting (FALSE).	One of: • TRUE • FALSE	FALSE
strBasisCurveCalibDisc	S	(Optional) Nickname of the interest rate curve to use for discounting during calibration. Ignored if bUseBasisCurveForCalibDiscounting is set to TRUE.	Must be one of the names in astrBasisCurve in the main calibration settings map.	Interest rate curve for the currency of this map, specified by the market data map member aIRCurve.
bNormalVolatilities	B	Whether to assume normal (TRUE) or log-normal (FALSE) volatilities.	One of: • TRUE • FALSE	FALSE

Example

```
IR_USD_CalibrationSettings, {
  strBasisCurveCalib, S, USDLibor3M
}

IR_EUR_CalibrationSettings, {
  strBasisCurveCalib, S, EURLibor3M
```

5.3.2.1.1 Root-Finding Settings (FX_IR_HW_1F)

The `mpRootFindSettings` member of an IR calibration settings map refers to another map that specifies settings for the root-finding process. Most of these settings specify various numerical tolerances. Normally, the default values are suitable.

The following table defines the members of a root-finding settings map for the FX_IR_HW_1F model.

Table 5.5 Root-Finding Settings Map for FX_IR_HW_1F

Map Key	Type Code	Description	Constraints	Default Value
`rVolSensTol`	R	Volatility sensitivity tolerance		0.001
`rSigmaConst`	R	Sigma used in initial guess for root find (units are per annum). If all calibrating instruments are removed, this value is used as the Hull-White volatility parameter.		0.01
`rErrorTol`	R	Error tolerance for root find to match market prices.		1.0e–14
`rRelTolNR`	R	Relative tolerance in Newton-Raphson method for root find to match market prices.		1.0e–13
`nMaxIterNR`	N	Maximum number of iterations in Newton-Raphson method for root find to match market prices.		100
`nMaxIterBracket`	N	Maximum number of iterations used in bracketing for root find to match market prices.		20
`rBracketLow`	R	Low value for bracketing for root find to match market prices.		1.0e–10
`rBracketHigh`	R	High value for bracketing for root find to match market prices.		1.0e–1
`nMaxDiv`	N	Maximum number of divisions in bisection for root find to match market prices.		100
`rRootGuessJam`	R	Initial guess for root in Jamshidian decomposition.		0.0

Table 5.5 Root-Finding Settings Map for FX_IR_HW_1F (Continued)

Map Key	Type Code	Description	Constraints	Default Value
`rErrorTolJam`	R	Error tolerance in Jamshidian decomposition.		1.0e–13
`rRelTolNRJam`	R	Relative tolerance in Newton-Raphson method for root find in Jamshidian decomposition.		1.0e–15
`nMaxIterNRJam`	N	Maximum number of iterations in Newton-Raphson method for root find in Jamshidian decomposition.		100
`rMinXJam`	R	Minimum X value in bracketing for Jamshidian decomposition.		–0.1
`rMaxXJam`	R	Maximum X value in bracketing for Jamshidian decomposition.		0.1
`nMaxDivJam`	N	Maximum number of iterations in bisection for root find in Jamshidian decomposition.		100

5.3.2.2 FX Calibration Settings (FX_IR_HW_1F)

The `ampCalibrationSettingsFX` member of a calibration settings map refers to other maps that each specify settings for the calibration of the exchange rate model for one pair of currencies. The following table defines the members of an FX calibration settings map for the FX_IR_HW_1F model.

Table 5.6 FX Calibration Settings Map for FX_IR_HW_1F

Map Key	Type Code	Description	Constraints	Default Value
`bUseNegativeSpotVols`	B	Whether to add negative FX spot volatilities to the calibrated values during the calibration procedure.	One of: • TRUE • FALSE	FALSE

Example

```
UseNegativeSpotVols, {
  bUseNegativeSpotVols, B, TRUE
}
```

5.3.3 Market Data Inputs (FX_IR_HW_1F)

The CurveNames member of a model preferences map refers to a map that identifies the market data curves that are required for pricing, simulation, and if applicable, internal model calibration. The following table defines the elements of a market data map for the FX_IR_HW_1F model.

Table 5.7 Market Data Map for FX_IR_HW_1F

Map Key	Type Code	Description	Constraints	Default Value
`aIRCurve`	AS or AL	Either: • Names of curves for discounting (of type `DiscountFactor`, `Yield`, or `FwdLibor`), one for each currency. • Names of lists that specify a set of curves to use in bootstrapping the discount factor, one for each currency. The first curve or list of curves is for the domestic currency, and the remainder are for the foreign currencies. For details about the lists of curves for bootstrapping, see "Specifying the Data to Use in Bootstrapping" on page 34.	Referenced curves must exist in the market data HDF5 file, or referenced lists must exist in an auxiliary transaction data file. The number of elements in the array must equal the number of currencies. Ordinates of a `Yield` curve must be >0.	
`aBasisCurve`	AS	Names of curves (of type `DiscountFactor`, `Yield`, or `FwdLibor`) that specify the forecasting interest rates to use for LIBOR basis adjustments for all relevant currencies.	Referenced curves must exist in the market data HDF5 file. Ordinates of a `Yield` curve must be >0.	
`aMeanReversionCurve`	AS	Names of mean reversion curves (of type `MeanReversion`), one for each currency, in the same order as the IR curves.	Referenced curves must exist in the market data HDF5 file.	
`aCapletVolCurve`	AS	Names of caplet volatility curves (of type `CapletVol`), one for each currency, in the same order as the IR curves. Each currency must have either a caplet volatility curve or a swaption volatility curve.	Referenced curves must exist in the market data HDF5 file. A value can be `void` if the model for that currency is calibrated to swaption volatilities.	
`aSwaptionVolCurve`	AS	Names of swaption volatility matrix curves (of type `SwaptionVolMtx`), one for each currency, in the same order as the IR curves. Each currency must have either a caplet volatility curve or a swaption volatility curve.	Referenced curves must exist in the market data HDF5 file. A value can be `void` if the model for that currency is calibrated to caplet volatilities.	
`aSpotFXCurve`	AS	Names of domestic/foreign spot FX curves (of type `Exchange`), one for each currency, in the same order as the IR curves.	The first name, corresponding to the domestic currency, must be `void`. Referenced curves must exist in the market data HDF5 file.	

Table 5.7 Market Data Map for FX_IR_HW_1F (Continued)

Map Key	Type Code	Description	Constraints	Default Value
aFXImpliedVolCurve	AS	Names of FX option volatility curves (of type ImpliedVol), one for each spot FX rate, in the same order as the FX curves. The first name, matching the domestic currency itself, can be left blank.	Referenced curves must exist in the market data HDF5 file.	
aCorrelationCurve	AS	Names of correlation curves (of type CorrelBlock) that give the correlations between model risk factors. For more detail, see the description that follows this table.	Referenced curves must exist in the market data HDF5 file.	

Correlation Curves

Construct the correlation curves specified by aCorrelationCurve according to the following scheme:

- A model with n currencies has $2n - 1$ risk factors: n short rate risk factors and n–1 FX risk factors.
- Let R_i be the risk factors of the model.
- The n risk factors from i=0 to i=n–1 are the short rate risk factors in the same order as the IR curves.
- The n–1 risk factors from i=n to i=2n–2 are the FX risk factors in the same order as the spot FX curves (omitting the first which is trivial).
- The first 2n–2 correlations are the correlations between R_0 and $R_1,\ldots, R_{2n-2}$.
- The next 2n–3 correlations are the correlations between R_1 and $R_2,\ldots, R_{2n-2}$.
- The next 2n–4 correlations are the correlations between R_2 and $R_3,\ldots, R_{2n-2}$, and so on.

Example

```
FX_IR_HW_1F_CurveNames, {
  aMeanReversionCurve, AS, USD.MeanReversion.USD, EUR.MeanReversion.EUR
  ..., JPY.MeanReversion.JPY, GBP.MeanReversion.GBP
  aIRCurve, AS, USD.Yield.USD, EUR.Yield.EUR, JPY.Yield.JPY
  ..., GBP.Yield.GBP
  aSwaptionVolCurve, AS, USD.SwaptionVolMtx.USD, EUR.SwaptionVolMtx.EUR
  ..., JPY.SwaptionVolMtx.JPY, GBP.SwaptionVolMtx.GBP
  aSpotFXCurve, AS, void, EUR.Exchange.USD, JPY.Exchange.USD
  ..., GBP.Exchange.USD
  aFXImpliedVolCurve, AS, void, EUR.ImpliedVol.USD
  ..., JPY.ImpliedVol.USD, GBP.ImpliedVol.USD
  aCorrelationCurve, AS
  ..., ShortRateUSD.CorrelBlock.ShortRateEUR_1F
  ..., ShortRateUSD.CorrelBlock.ShortRateJPY_1F
  ..., ShortRateUSD.CorrelBlock.ShortRateGBP_1F
  ..., ShortRateUSD.CorrelBlock.FXEUR_1F
  ..., ShortRateUSD.CorrelBlock.FXJPY_1F
  ..., ShortRateUSD.CorrelBlock.FXGBP_1F

  ..., ShortRateEUR.CorrelBlock.ShortRateJPY_1F
  ..., ShortRateEUR.CorrelBlock.ShortRateGBP_1F
  ..., ShortRateEUR.CorrelBlock.FXEUR_1F
```

```
  ..., ShortRateEUR.CorrelBlock.FXJPY_1F
  ..., ShortRateEUR.CorrelBlock.FXGBP_1F

  ..., ShortRateJPY.CorrelBlock.ShortRateGBP_1F
  ..., ShortRateJPY.CorrelBlock.FXEUR_1F
  ..., ShortRateJPY.CorrelBlock.FXJPY_1F
  ..., ShortRateJPY.CorrelBlock.FXGBP_1F

  ..., ShortRateGBP.CorrelBlock.FXEUR_1F
  ..., ShortRateGBP.CorrelBlock.FXJPY_1F
  ..., ShortRateGBP.CorrelBlock.FXGBP_1F

  ..., FXEUR.CorrelBlock.FXJPY_1F
  ..., FXEUR.CorrelBlock.FXGBP_1F

  ..., FXJPY.CorrelBlock.FXGBP_1F
}
```

5.3.4 Data Extraction Settings (FX_IR_HW_1F)

The `DataExtractionSettings` member of a model preferences map refers to another map that specifies parameters for the data extraction process. The following table defines the members of a data extraction settings map for the FX_IR_HW_1F model.

Table 5.8 Data Extraction Settings Map for FX_IR_HW_1F

Map Key	Type Code	Description	Constraints	Default Value
`ampIRCurveSettings`	`AL`	Names of maps, one for each model currency, that specify settings for extracting interest rates. For the definition of these maps, see “Interest Rate Extraction Settings Map” on page 35.	Referenced maps must exist in the model preferences file.	An array of empty maps, one for each currency.
`ampBasisCurveSettings`	`AL`	Names of maps of settings for the basis data extraction, one for each interest rate provider specified by `aBasisCurve` in the market data map. The settings in these maps are listed in “Interest Rate Extraction Settings Map” on page 35.	Referenced maps must exist in the auxiliary transaction data file.	The settings specified by `ampIRCurveSettings` are used.
`ampDataExtractionSettingsIR`	`AL`	Names of maps, one for each model currency, that specify IR data extraction settings for purposes of calibration. For the definition of these maps, see “IR Calibration Data Extraction Settings (FX_IR_HW_1F)” on page 84	Referenced maps must exist in the model preferences file. To use the defaults for all settings, provide an empty map.	

Table 5.8 Data Extraction Settings Map for FX_IR_HW_1F (Continued)

Map Key	Type Code	Description	Constraints	Default Value
`ampDataExtractionSettingsFX`	AL	Names of maps, one for each foreign currency, that specify FX data extraction settings for purposes of calibration. In the current release, FX calibration data extraction has no settings.	Referenced maps must exist in the model preferences file. Provide an empty map for each foreign currency.	
`bExtrapolateDF`	B	Whether to extrapolate discount factors.	One of: • TRUE • FALSE	FALSE
`nMonthsExtrapDFEnd`	N	Number of months after the calibration date in which to extrapolate the discount factors.		0

5.3.4.1 IR Calibration Data Extraction Settings (FX_IR_HW_1F)

The `ampDataExtractionSettingsIR` member of a data extraction settings map refers to other maps that each specify settings for IR calibration data extraction for one currency. The following table defines the members of an IR calibration data extraction settings map for the FX_IR_HW_1F model.

Table 5.9 IR Calibration Data Extraction Settings Map for FX_IR_HW_1F

Map Key	Type Code	Description	Constraints	Default Value
`strMethod`	S	Type of calibration data. Provide the appropriate member of the market data map depending on the method: • For `Caplet`, provide `aCapletVolCurve`. • For `Swaption`, `SwaptionColumn`, and `SelectedSwaptions`, provide `aSwaptionVolCurve`. Also, for `SwaptionColumn`, provide `nLengthMonths` in the trade information map.	One of: • `Caplet` • `Swaption` • `SwaptionColumn` • `SelectedSwaptions`	

Table 5.9 IR Calibration Data Extraction Settings Map for FX_IR_HW_1F (Continued)

Map Key	Type Code	Description	Constraints	Default Value
`rSwaptionShift`	R	(Optional) If specified, the market swaption price in the calibration of the model is calculated under the assumption that the swap rate has a shifted log-normal distribution with the specified shift size. In this case, the swaption price in the calibration is calculated using Black's formula with the adjusted swap rate and strike obtained by subtracting `rSwaptionShift` from the original swap rate and strike of the calibrating swaptions.		0
`strDaycountFixed`	S	(Optional) Day count convention in the fixed leg of the calibrating swaptions.	See Table B.2 on page 327.	The *`dayCountConv`* attribute of the input swaption volatility curve is used.
`nSwapTenorFixed`	N	(Optional) Coupon frequency (in months) in the fixed leg of the calibrating swaptions.		The *`tenor`* attribute of the input swaption volatility curve is used.
Use the additional inputs in this section only when `strMethod` is `SelectedSwaptions`				
`astrSwaptionExpiry`	AS	(Optional) Time to expiry to specify the swaption volatilities for extraction from the input swaption volatility curve, in the same units as the expiry ordinates in the curve.		The times to expiry are assumed to be the expiry ordinate values of the input swaption volatility curve.
`anSwaptionLength`	AN	(Optional) Lengths in months of the swaptions to specify the volatility for extraction from the input swaption volatility curve, one for each expiry date specified by `astrSwaptionExpiry`. Ignored if `astrSwaptionExpiry` is omitted.	Same number of elements as `astrSwaptionExpiry`.	The co-terminal swaption volatility is extracted for all expiry dates specified in `astrSwaptionExpiry`.

Table 5.9 IR Calibration Data Extraction Settings Map for FX_IR_HW_1F (Continued)

Map Key	Type Code	Description	Constraints	Default Value
`arSwaptionStrike`	AR	(Optional) Swaption strike to specify the volatility for extraction from the input swaption volatility curve, one for each expiry date specified by `astrSwaptionExpiry`. Ignored if `astrSwaptionExpiry` is omitted. Used only when the swaption volatility curve is of type `SwaptionVolCube`.	Same number of elements as `astrSwaptionExpiry`.	The at-the-money strike is used for all expiry dates specified in `astrSwaptionExpiry`.
`strSwaptionStrikeType`	S	(Optional) Type of the strikes specified in `arSwaptionStrike`. Ignored if `arSwaptionStrike` is omitted. Used only when the swaption volatility curve is of type `SwaptionVolCube`.	One of: • `ABSOLUTE` • `F-K` • `K-F` • `F/K` • `K/F` F is the underlying par swap rate for the swaption period. `ABSOLUTE` means that values represent the strike K. The remaining strike types mean that values are specified in relative terms.	`ABSOLUTE`
`idxBasisCurveCalib`	N	(Optional) Index of the interest rate curve to use for additive LIBOR basis adjustment in the calculation of the swap rate during the extraction of the ATM volatility.	Integer between 0 and n–1, where n is the number of curves specified by the market data map member `aBasisCurve`.	The LIBOR basis adjustment is not performed.
`idxBasisCurveCalibDisc`	N	(Optional) Index of the interest rate curve to use for discounting in the calculation of the swap rate during the extraction of the ATM volatility. Ignored if `bUseBasisCurveForCalibDiscounting` is set to TRUE.	Integer between 0 and n–1, where n is the number of curves specified by the market data map member `aBasisCurve`.	Interest rate curve for the currency of this map, specified by the market data map member `aIRCurve`.
`bUseBasisCurveForCalibDiscounting`	B	Whether to use the basis curve, if specified by `idxBasisCurveCalib`, for both discounting and forecasting in the calculation of the swap rate (`TRUE`) or just for forecasting (`FALSE`).	One of: • `TRUE` • `FALSE`	`FALSE`

Example

```
FX_IR_HW_1F_DataExtractionSettings, {
  ampDataExtractionSettingsIR, AL, Swaption_DataExtractionSetting
  ..., Swaption_DataExtractionSetting, Swaption_DataExtractionSetting
  ..., Swaption_DataExtractionSetting
```

```
  ampDataExtractionSettingsFX, AL, EMPTY_MAP, EMPTY_MAP, EMPTY_MAP
  ..., EMPTY_MAP
  bExtrapolateDF, B, TRUE
  nMonthsExtrapDFEnd, N, 10
}

Swaption_DataExtractionSetting, {
  strMethod, S, Swaption
}
```

5.3.5 Trade Information (FX_IR_HW_1F)

The `TradeInfo` member of a model preferences map refers to another map that specifies information about the trade portfolio. The following table defines the members of a trade information map for the FX_IR_HW_1F model.

Table 5.10 Trade Information Map for FX_IR_HW_1F

Map Key	Type Code	Description	Constraints	Default Value
`dtLastCashflow`	`D`	Last date on which a cash flow occurs for any trade in the portfolio.		
`dtLastRequiredDF`	`D`	Last date on which a discount factor is required for any trade in the portfolio.		
`nLengthMonths`	`N`	Swap length, in months, of the swaption volatilities to extract when the extraction method is `SwaptionColumn`.		

Example

```
PORTFOLIO_INFO, {
  dtLastCashflow, D, 2059/12/02
  dtLastRequiredDF, D, 2059/12/02
}
```

Chapter 6

Multicurrency Multifactor Hull-White Model

The multicurrency multifactor Hull-White interest rate model (FX_IR_HW_NF) uses a single-currency multifactor Hull-White model for each short rate and a log-normal Garman-Kohlhagen-type model for each spot foreign exchange rate. (Each exchange rate is modelled with one driving factor.) The model treats both the short rate volatilities and spot FX volatilities as piecewise constant functions in time.

The calibration of each IR model is independent. Although the term structure of each IR model has independent discretization in time, the model assumes a combined common time discretization for the volatilities of each short rate and each spot exchange rate. Therefore, the entire correlation structure also has the common time discretization.

This model assumes that the single-currency models for all currencies are calibrated on the same date.

For information about the methodology of the FX_IR_HW_NF model, see the following chapter in *Markit Analytics Model Framework Mathematical Reference*: “Hybrid Equity Multi-Currency Multi-Factor Hull-White Interest Rate Model”.

This chapter describes the inputs that control data extraction and calibration for the FX_IR_HW_NF model.

6.1 Module (FX_IR_HW_NF)

The Model Framework module that implements the multicurrency multifactor Hull-White interest rate model (FX_IR_HW_NF) is as follows:

```
quic_model_fx_ir_hw_nf:3.0
```

Combine this module name with the module component names identified in this chapter to form a complete module reference. For example, if the component is `QModel_FX_IR_HW_NF_PWC`, the complete module reference is as follows:

```
QModel_FX_IR_HW_NF_PWC@quic_model_fx_ir_hw_nf:3.0
```

6.2 Market Data Generator Parameters (FX_IR_HW_NF)

A market data generator parameters set for the Model Framework market data generator includes certain parameters whose value depends on the particular model. These include some parameters that are used directly by the generator itself and others that are used only by the Model Framework model that it invokes (in particular by the model's simulator component). For descriptions of the direct generator parameters, see the *Markit Analytics Simulation Framework User Guide*. The parameters that are used by Model Framework simulators are described in "Model Framework Simulator Settings" on page 28.

Some of the simulator settings are used by all models and others are used only by certain models. For the latter subset of settings, the information below shows which ones are used by this model.

Generator Parameter: `strSimulatorMFWKReference`

The parameter `strSimulatorMFWKReference` specifies the simulator plug-in for the model. The following values of this parameter are available for the FX_IR_HW_NF model:

- Exact simulation algorithm under the forward measure:

  `QMCSimulator_FX_IR_HW_NF_PWC_FM@quic_model_fx_ir_hw_nf:3.0`
- Simulation algorithm under the risk-neutral measure:

  `QMCSimulator_FX_IR_HW_NF_PWC_RNM@quic_model_fx_ir_hw_nf:3.0`

Applicability of Simulator Settings

The following table identifies which simulator plug-ins (if any) support the specified simulator settings.

Table 6.1 Support for Simulator Settings (FX_IR_HW_NF)

Parameter	Simulators That Support the Parameter
bStepOnDFDates	• QMCSimulator_FX_IR_HW_NF_PWC_FM • QMCSimulator_FX_IR_HW_NF_PWC_RNM
bUseEuler	• QMCSimulator_FX_IR_HW_NF_PWC_FM • QMCSimulator_FX_IR_HW_NF_PWC_RNM
bPrecalculateCovariances	• QMCSimulator_FX_IR_HW_NF_PWC_FM • QMCSimulator_FX_IR_HW_NF_PWC_RNM

Table 6.1 Support for Simulator Settings (FX_IR_HW_NF) (Continued)

Parameter	Simulators That Support the Parameter
bUseEigenSym and bUsePCA	• QMCSimulator_FX_IR_HW_NF_PWC_FM • QMCSimulator_FX_IR_HW_NF_PWC_RNM
bCholesky	Not applicable
strDecomposition	Not applicable
bUseStartEndNumeraireCalc	• QMCSimulator_FX_IR_HW_NF_PWC_RNM
bUseForeignQuantoAdjustment	Not applicable
bUseDeterministicFXDrifts	Not applicable
bUseDeterministicInflationDrifts	Not applicable
bApproximateXIntegral	Not applicable

6.3 Model Preferences (FX_IR_HW_NF)

You specify the settings for the model in a model preferences map and in the subsidiary maps that it references. For a general description of a model preferences map, see "Model Preferences Map" on page 32.

You can include credit modeling in this model by specifying additional inputs in the model preferences map and its subsidiary maps. These additional inputs are described in "Adding Credit Support to a Non-Credit Model" on page 36.

6.3.1 Components (FX_IR_HW_NF)

The following table identifies the available plug-ins (components of the FX_IR_HW_NF module unless otherwise noted) that implement the model. You specify these as values of members of the model preferences map in the form of full module references.

Table 6.2 Model Plug-In Components (FX_IR_HW_NF)

Model Preference	Available Components of the Module
Model	QModel_FX_IR_HW_NF_PWC
CalibrationMethod	One of: • QModelCalibration_FX_IR_HW_NF_PWC For internal calibration. • QModelCalibration_FX_IR_HW_NF_PWC_ExtCal For external calibration.

Table 6.2 Model Plug-In Components (FX_IR_HW_NF) (Continued)

Model Preference	Available Components of the Module
`DataExtractionMethod`	One of: • `QDataExtraction_FX_IR_HW_NF_PWC` For internal calibration. • `QDataExtraction_FX_IR` (in module `quic_model_framework`) For external calibration.

In addition, you must specify the maps that are identified by the other members of the model preferences map. The remainder of this chapter defines these subsidiary maps.

Example

The following figure shows a sample model preferences map that specifies components for this model. In the model preferences file, each map member occupies a single line.

```
FX_IR_HW_NF_ModelPrefs, {
  Model, S, QModel_FX_IR_HW_NF_PWC@quic_model_fx_ir_hw_nf:3.0
  CalibrationMethod, S,
    QModelCalibration_FX_IR_HW_NF_PWC@quic_model_fx_ir_hw_nf:3.0
  CalibrationSettings, L, FX_IR_HW_NF_CalibrationSettings
  CurveNames, L, FX_IR_HW_NF_MarketData
  DataExtractionMethod, S, QDataExtraction_FX_IR_HW_NF_PWC@quic_model_fx_ir_hw_nf:3.0
  DataExtractionSettings, L, FX_IR_HW_NF_DataExtractionSettings
  TradeInfo, L, PORTFOLIO_INFO
}
```

6.3.2 Calibration Settings (FX_IR_HW_NF)

The `CalibrationSettings` member of the model preferences map refers to another map that specifies parameters related to calibration of the model. The table below defines the members of a calibration settings map for the multicurrency multifactor Hull-White model (FX_IR_HW_NF). The descriptions of these parameters use the following notation:

- H is the number of currencies. Hence, H–1 is the number of exchange rates.
- K_i is the number of factors in the interest rate model for currency i.
- M is the number of intervals over which the piecewise constant functions are defined.

The symbols in the Equation Symbol column refer to the following chapter in *Markit Analytics Model Framework Mathematical Reference*: “Hybrid Equity Multi-Currency Multi-Factor Hull-White Interest Rate Model”.

Table 6.3 Calibration Settings Map for FX_IR_HW_NF

Map Key	Type Code	Description	Constraints	Default Value	Equation Symbol
The inputs in this section are common to all the calibration methods.					
`astrCCY`	AS	Names of the *H* currencies. The first name is the domestic currency.	Standard 3-character currency identifiers		
`strModelParametersOutputFile`	S	(Optional) File path of the HDF5 file to which the calculated model parameters are written. This file has the same format as a file for externally calibrated parameters. Typically used only for troubleshooting.			No file is produced.
`strModelParametersOutputName`	S	(Optional) Name to give this model parameters set in the file specified by `strModelParametersOutputFile`.		`mpModelParams`	
`bOutputCalibrationData`	B	Whether to include the calibration data in the HDF5 file specified by `strModelParametersOutputFile`. Typically used only for troubleshooting because it may significantly increase the size of the file.	One of: • TRUE • FALSE	FALSE	
Use the inputs in this section only when `CalibrationMethod` is `QModelCalibration_FX_IR_HW_NF_PWC`					
`ampCalibrationSettingsIR`	AL	Names of maps, one for each model currency, that specify the IR calibration settings. For the definition of these maps, see “IR Calibration Settings (FX_IR_HW_NF)” on page 98.	Referenced maps must exist in the model preferences file. To use the defaults for all settings, provide an empty map.		
`ampCalibrationSettingsFX`	AL	Names of maps, one for each foreign currency, that specify FX calibration settings. For the definition of these maps, see “FX Calibration Settings (FX_IR_HW_NF)” on page 101.	Referenced maps must exist in the model preferences file. To use the defaults for all settings, provide an empty map.		

Table 6.3 Calibration Settings Map for FX_IR_HW_NF (Continued)

Map Key	Type Code	Description	Constraints	Default Value	Equation Symbol
`astrBasisCurve`	AS	Nicknames of the interest rate curves used for additive LIBOR basis adjustment.	Include a nickname for each of the curves, in order, specified by the `aBasisCurve` member of the market data map.		
`bCorrOrdinatesInMonths`	B	Whether input correlation blocks have ordinates in months.	One of: • TRUE • FALSE	FALSE	
`bOutputFitResults`	B	Whether to report the results of the calibration (comparison of the prices of calibrating instruments from the calibrated model and calculated analytically from market data).	One of: • TRUE • FALSE	FALSE	
`strOutputFile`	S	(Optional) File path of the CSV file to which calibration results are written (if requested by `bOutputFitResults`).		Results are displayed in the audit pane only.	
`mpOutputSettings`	L	(Optional) Name of a map of settings to control the output of calibration results.	Referenced map must exist in the auxiliary transaction data file.	Empty map	
`mpOptimizationSettings`	L	(Optional) Name of a map of settings for optimizing the fit of model parameters to market-observed quantities. See "Optimization Settings (FX_IR_HW_NF)" on page 97.	Referenced map must exist in the auxiliary transaction data file.		
Use the inputs in this section only when `CalibrationMethod` is `QModelCalibration_FX_IR_HW_NF_PWC_ExtCal`					
`g1dtEta`	GD	Ascending sequence of M+1 dates that define the intervals of the volatility functions.	The first date must be the calibration date.		
`ag1rA`	AL	Names of lists (of type GR) that specify the K_i daily-based mean-reversion parameters. Each list specifies the parameters for one currency.	Referenced lists must exist in the auxiliary transaction data file. The array is of length H.		a_i

Table 6.3 Calibration Settings Map for FX_IR_HW_NF (Continued)

Map Key	Type Code	Description	Constraints	Default Value	Equation Symbol
`ag2rEta`	AL	Names of lists (of type AL) for each currency. Each currency list specifies names of lists (of type GR) for each of its K_i factors. Each currency-factor list specifies the value of the IR volatility parameter (eta), expressed as a daily value, in each of the M time intervals defined by `g1dtEta`. For a given factor, the value in interval m applies from `g1dtEta`$_m$ up to but not including `g1dtEta`$_{m+1}$. The value in the last interval is also used on the last date and beyond the last date (constant extrapolation).	Referenced lists must exist in the auxiliary transaction data file. The array is of length H.		$\tilde{\eta}_i(t)$
`ag1rEtaFX`	AL	Names of lists (of type GR) that specify, for each currency, the value of the FX volatility parameter (eta) in each of the M time intervals defined by `g1dtEta`, expressed as a daily value. For a given factor, the value in interval m applies from `g1dtEta`$_m$ up to but not including `g1dtEta`$_{m+1}$. The value in the last interval is also used on the last date and beyond the last date (constant extrapolation).	Referenced lists must exist in the auxiliary transaction data file. The array is of length H. The first array element must be void.		$\eta_k^{FX}(t)$

Table 6.3 Calibration Settings Map for FX_IR_HW_NF (Continued)

Map Key	Type Code	Description	Constraints	Default Value	Equation Symbol
`g3rCorrMtx`	AL	Names of lists (of type `AL`) for each factor. Each factor list specifies names of lists (of type `GR`) for each pairing with other factors. Each factor-pair list specifies the value of their pairwise correlation, specified as a piecewise function of time over the intervals defined by `g1dtEta`. The correlations include those between the factors within one IR model, between the factors of different IR models, and between the factors of an IR model and an FX model. For details, see the note that follows this table. For a given pair of factors, the value in interval m applies from `g1dtEta`$_m$ up to but not including `g1dtEta`$_{m+1}$. The value in the last interval is also used on the last date and beyond the last date (constant extrapolation).	$-1 \leq \tilde{\rho} \leq 1$		$\tilde{\rho}_{i,j}(t)$

Note: Construction of Correlation Matrices

Consider a 2-D slice of the `g3CorrMtx` grid along the `eta` axis (that is, for a given time). This 2-D factor correlation matrix is square and of length $\sum_i K_i + (H-1)$ in each dimension. It is symmetric, so we consider the construction in only one dimension. First come the K_0 factors of the interest rate for currency 0 (the domestic currency), then the K_1 factors of the interest rate for currency 1, and so on for the H currencies. Finally come the $(H–1)$ factors of the exchange rates.

Example

The following figure shows a sample calibration parameters map when there are 5 currencies, volatilities are defined in 5 intervals (with 6 dates), and the model has 10 factors.

```
FX_IR_HW_NF_CalibrationSettings, {
  astrCCY, AS, USD, AUD, BRL, CAD, CHF
  ag1rA, AL, g1rA_USD, g1rA_AUD, g1rA_BRL, g1rA_CAD, g1rA_CHF
  ag2rEta, AL, g2rEta_USD, g2rEta_AUD, g2rEta_BRL, g2rEta_CAD
  ..., g2rEta_CHF
  ag1rEtaFX, AL, g1rEtaFX_AUD, g1rEtaFX_BRL, g1rEtaFX_CAD, g1rEtaFX_CHF
  g1dtEta, GD, 2010/03/01, 2010/06/01, 2010/09/01, 2010/12/01
  ..., 2011/03/01, 2011/06/01
  g3rCorrMtx, AL, g2rCorrMtx_factor0, g2rCorrMtx_factor1
  ..., g2rCorrMtx_factor2, g2rCorrMtx_factor3, g2rCorrMtx_factor4
  ..., g2rCorrMtx_factor5, g2rCorrMtx_factor6, g2rCorrMtx_factor7
  ..., g2rCorrMtx_factor8, g2rCorrMtx_factor9
}
```

6.3.2.1 Optimization Settings (FX_IR_HW_NF)

The `mpOptimizationSettings` member of the calibration settings map refers to another map that specifies settings for the optimization procedure.

The following table defines the members of the optimization settings map for the multicurrency multifactor Hull-White model. (This applies to the `QModelCalibration_FX_IR_HW_NF_PWC` calibrator only.)

Table 6.4 Optimization Settings Map for FX_IR_HW_NF

Map Key	Type Code	Description	Constraints	Default Value
`OPTIMIZATIONMETHOD`	S	Name of a function that performs the optimization: One of: • `minmd_f` (an Engine operator) • `Simplex` (an MA Script function in the module `quic_numerical_methods`) The remaining members of this map are the settings for the selected function.	One of: • `minmd_f` • `Simplex`	`minmd_f`
The inputs in this section are the supported options for the `minmd_f` optimization method.				

`MXFCAL`
`MXITER`
`AFCTOL`
`RFCTOL`
`LMAX0`
`SCTOL`
`LMAXS`
`XCTOL`
`XFTOL`
		For detailed descriptions, constraints, and default values see the `minmd_f` page in the online *Markit Analytics Script Reference*.		

The inputs in this section are the options for the `Simplex` optimization method.				
`MXITER`	N	Maximum number of iterations.		200
`AFCTOL`	R	Tolerance for convergence.		1e-8
`LAMBDA`	R	Parameter for creating the initial simplex.		0.1

Table 6.4 Optimization Settings Map for FX_IR_HW_NF (Continued)

Map Key	Type Code	Description	Constraints	Default Value
RESTART	B	Whether to apply a restart.	One of: • TRUE • FALSE	TRUE
RHO	R	Reflection coefficient.		1.0
CHI	R	Expansion coefficient.		2.0
GAMMA	R	Contraction coefficient.		0.5
SIGMA	R	Shrinkage coefficient.		0.5
EPSILON	R	Small number used in the convergence calculation.		1e-12

6.3.2.2 IR Calibration Settings (FX_IR_HW_NF)

The `ampCalibrationSettingsIR` member of a calibration settings map refers to other maps that each specify settings for the calibration of the interest rate model for one currency. The following table defines the members of an IR calibration settings map for the FX_IR_HW_NF model.

Table 6.5 IR Calibration Settings Map for FX_IR_HW_NF

Map Key	Type Code	Description	Constraints	Default Value
strCCYDom	S	Name of the domestic currency.	Standard 3-character currency identifier	
bUseCapletFormula	B	Whether to use the caplet formula. If set to TRUE, but the input calibrating instruments are swaptions, this setting reverts to FALSE.	One of: • TRUE • FALSE	FALSE
rNotional	R	Notional amount to use when calculating prices during calibration.		1.0
mpRootFindSettings	L	Name of a map of settings for the root-finding procedure.	Referenced map must exist in the model preferences file.	Empty map
bAllowNegativeMR	B	Whether to allow the calibration process to generate a negative mean reversion parameter.	One of: • TRUE • FALSE	FALSE
strBasisCurveCalib	S	(Optional) Nickname of the interest rate curve to use for additive LIBOR basis adjustment during calibration.	Must be one of the names in `astrBasisCurve` in the main calibration settings map.	The LIBOR basis adjustment is not performed.

Table 6.5 IR Calibration Settings Map for FX_IR_HW_NF (Continued)

Map Key	Type Code	Description	Constraints	Default Value
`bUseBasisCurveForCalibDiscounting`	B	Whether to use the basis curve, if specified by `strBasisCurveCalib`, for both discounting and forecasting in the calibration (TRUE) or just for forecasting (FALSE).	One of: • TRUE • FALSE	FALSE
`strBasisCurveCalibDisc`	S	(Optional) Nickname of the interest rate curve to use for discounting during calibration. Ignored if `bUseBasisCurveForCalibDiscounting` is set to TRUE.	Must be one of the names in `astrBasisCurve` in the main calibration settings map.	Interest rate curve for the currency of this map, specified by the market data map member `aIRCurve`.
`bNormalVolatilities`	B	Whether to assume normal (TRUE) or log-normal (FALSE) volatilities.	One of: • TRUE • FALSE	FALSE

Example

```
IR_USD_CalibrationSettings, {
  strBasisCurveCalib, S, USDLibor3M
}

IR_EUR_CalibrationSettings, {
  strBasisCurveCalib, S, EURLibor3M
}
```

6.3.2.2.1 Root-Finding Settings (FX_IR_HW_NF)

The `mpRootFindSettings` member of an IR calibration settings map refers to another map that specifies settings for the root-finding process. Most of these settings specify various numerical tolerances. Normally, the default values are suitable.

The following table defines the members of a root-finding settings map for the FX_IR_HW_NF model.

Table 6.6 Root-Finding Settings Map for FX_IR_HW_NF

Map Key	Type Code	Description	Constraints	Default Value
`rVolSensTol`	R	Volatility sensitivity tolerance		0.001
`rSigmaConst`	R	Sigma used in initial guess for root find (units are per annum). If all calibrating instruments are removed, this value is used as the Hull-White volatility parameter.		0.01
`rErrorTol`	R	Error tolerance for root find to match market prices.		1.0e–14

Table 6.6 Root-Finding Settings Map for FX_IR_HW_NF (Continued)

Map Key	Type Code	Description	Constraints	Default Value
`rRelTolNR`	R	Relative tolerance in Newton-Raphson method for root find to match market prices.		1.0e–13
`nMaxIterNR`	N	Maximum number of iterations in Newton-Raphson method for root find to match market prices.		100
`nMaxIterBracket`	N	Maximum number of iterations used in bracketing for root find to match market prices.		20
`rBracketLow`	R	Low value for bracketing for root find to match market prices.		1.0e–10
`rBracketHigh`	R	High value for bracketing for root find to match market prices.		1.0e–1
`nMaxDiv`	N	Maximum number of divisions in bisection for root find to match market prices.		100
`rRootGuessJam`	R	Initial guess for root in Jamshidian decomposition.		0.0
`rErrorTolJam`	R	Error tolerance in Jamshidian decomposition.		1.0e–13
`rRelTolNRJam`	R	Relative tolerance in Newton-Raphson method for root find in Jamshidian decomposition.		1.0e–15
`nMaxIterNRJam`	N	Maximum number of iterations in Newton-Raphson method for root find in Jamshidian decomposition.		100
`rMinXJam`	R	Minimum X value in bracketing for Jamshidian decomposition.		–0.1
`rMaxXJam`	R	Maximum X value in bracketing for Jamshidian decomposition.		0.1
`nMaxDivJam`	N	Maximum number of iterations in bisection for root find in Jamshidian decomposition.		100

6.3.2.3 FX Calibration Settings (FX_IR_HW_NF)

The `ampCalibrationSettingsFX` member of a calibration settings map refers to other maps that each specify settings for the calibration of the exchange rate model for one pair of currencies. The following table defines the members of an FX calibration settings map for the FX_IR_HW_NF model.

Table 6.7 FX Calibration Settings Map for FX_IR_HW_NF

Map Key	Type Code	Description	Constraints	Default Value
`bUseNegativeSpotVols`	B	Whether to add negative FX spot volatilities to the calibrated values during the calibration procedure.	One of: • TRUE • FALSE	FALSE

Example

```
UseNegativeSpotVols, {
  bUseNegativeSpotVols, B, TRUE
}
```

6.3.2.4 Calibration Results Output Settings (FX_IR_HW_NF)

The `mpOutputSettings` member of a Hull-White calibration settings map refers to another map that specifies settings for controlling the output of calibration results. The present output process does not use any settings.

6.3.3 Market Data Inputs (FX_IR_HW_NF)

The CurveNames member of the model preferences map refers to a map that identifies the market data curves that are required for pricing, simulation, and if applicable, internal model calibration. The following table defines the members of this market data map for the multicurrency multifactor Hull-White model (FX_IR_HW_NF).

Table 6.8 Market Data Map for FX_IR_HW_NF

Map Key	Type Code	Description	Constraints	Default Value
aIRCurve	AS or AL	Either: • Names of curves for discounting (of type DiscountFactor, Yield, or FwdLibor), one for each currency. • Names of lists that specify a set of curves to use in bootstrapping the discount factor, one for each currency. The first curve or list of curves is for the domestic currency, and the remainder are for the foreign currencies. For details about the lists of curves for bootstrapping, see "Specifying the Data to Use in Bootstrapping" on page 34.	Referenced curves must exist in the market data HDF5 file, or referenced lists must exist in an auxiliary transaction data file. The number of elements in the array must equal the number of currencies. Ordinates of a Yield curve must be >0.	
aSpotFXCurve	AS	Names of domestic/foreign spot FX curves (of type Exchange), one for each currency, in the same order as the IR curves.	The first name, corresponding to the domestic currency, must be void. Referenced curves must exist in the market data HDF5 file.	
Use the inputs in this section only when DataExtractionMethod is QDataExtraction_FX_IR_HW_NF_PWC				
aBasisCurve	AS	Names of curves (of type DiscountFactor, Yield, or FwdLibor) that specify the forecasting interest rates to use for LIBOR basis adjustments for all relevant currencies.	Referenced curves must exist in the market data HDF5 file. Ordinates of a Yield curve must be >0.	
aSwaptionVolCurve	AS	Names of swaption volatility matrix curves (of type SwaptionVolMtx), one for each currency, in the same order as the IR curves.	Referenced curves must exist in the market data HDF5 file.	
aFXImpliedVolCurve	AS	Names of FX option volatility curves (of type ImpliedVol), one for each spot FX rate, in the same order as the FX curves. The first name, matching the domestic currency itself, can be left blank.	Referenced curves must exist in the market data HDF5 file.	

Table 6.8 Market Data Map for FX_IR_HW_NF (Continued)

Map Key	Type Code	Description	Constraints	Default Value
`aCorrelationCurve`	AS	Names of correlation curves (of type `CorrelBlock`) that give the correlations between model risk factors. For more detail, see the description that follows this table.	Referenced curves must exist in the market data HDF5 file.	

Note: Correlation Curves

The correlation curves specified by `aCorrelationCurve` must be listed in the order described below. The currencies must be in the same order as the IR curves.

- The first correlation curve specifies the correlation matrix between the K_0 IR risk factors of the domestic currency.
- Each additional currency i adds 1 + i + (i+1) + (i–1) + (i–1) = 4i correlation curves, as follows:
  - 1: correlation matrix between K_i IR risk factors of the i^{th} currency
  - i: correlation matrices between K_i short rate risk factors of the i^{th} currency and K_j IR risk factors of the j^{th} currency for j=0,...,i–1
  - i+1: correlation vectors between the FX risk factor of the i^{th} currency and K_j IR risk factors of the j^{th} currency for j=0,...,i
  - i–1: correlation vectors between K_i IR risk factors of the i^{th} currency and the FX risk factor of the j^{th} currency for j=1,...,i–1
  - i–1: scalar correlations between the FX risk factor of the i^{th} currency and the FX risk factor of the j^{th} currency for j=1,...,i–1

The following example shows the required sequence of correlation curve names for a 2-factor Hull-White model with these 4 currencies: USD (domestic), EUR, JPY, and GBP:

```
aCorrelationCurve, AS
// USD (0th CCY - domestic)
  ..., ShortRateUSD.CorrelBlock.ShortRateUSD
// EUR (1st CCY)
  ..., ShortRateEUR.CorrelBlock.ShortRateEUR
  ..., ShortRateUSD.CorrelBlock.ShortRateEUR
  ..., ShortRateUSD.CorrelBlock.FXEUR
  ..., ShortRateEUR.CorrelBlock.FXEUR
// JPY (2nd CCY)
  ..., ShortRateJPY.CorrelBlock.ShortRateJPY
  ..., ShortRateUSD.CorrelBlock.ShortRateJPY
  ..., ShortRateEUR.CorrelBlock.ShortRateJPY
  ..., ShortRateUSD.CorrelBlock.FXJPY
  ..., ShortRateEUR.CorrelBlock.FXJPY
  ..., ShortRateJPY.CorrelBlock.FXJPY
  ..., ShortRateJPY.CorrelBlock.FXEUR
  ..., FXEUR.CorrelBlock.FXJPY
// GBP (3rd CCY)
  ..., ShortRateGBP.CorrelBlock.ShortRateGBP
  ..., ShortRateUSD.CorrelBlock.ShortRateGBP
  ..., ShortRateEUR.CorrelBlock.ShortRateGBP
  ..., ShortRateJPY.CorrelBlock.ShortRateGBP
  ..., ShortRateUSD.CorrelBlock.FXGBP
  ..., ShortRateEUR.CorrelBlock.FXGBP
```

```
  ..., ShortRateJPY.CorrelBlock.FXGBP
  ..., ShortRateGBP.CorrelBlock.FXGBP
  ..., ShortRateGBP.CorrelBlock.FXEUR
  ..., ShortRateGBP.CorrelBlock.FXJPY
  ..., FXEUR.CorrelBlock.FXGBP
  ..., FXJPY.CorrelBlock.FXGBP
```

Example

```
SampleHWCalibrationData, {
  aIRCurve, AS, USD.Yield.USD, EUR.Yield.EUR
  aSpotFXCurve, AS, void, EUR.Exchange.USD
}
```

6.3.4 Data Extraction Settings (FX_IR_HW_NF)

The `DataExtractionSettings` member of the model preferences map refers to another map that specifies parameters for the data extraction process. The following table defines the members of a data extraction settings map for the multicurrency multifactor Hull-White model (FX_IR_HW_NF).

Table 6.9 Data Extraction Settings Map for FX_IR_HW_NF

Map Key	Type Code	Description	Constraints	Default Value
`ampIRCurveSettings`	AL	Names of maps, one for each model currency, that specify settings for extracting interest rates. For the definition of these maps, see "Interest Rate Extraction Settings Map" on page 35.	Referenced maps must exist in the model preferences file.	An array of empty maps, one for each currency.
`ampDataExtractionSettingsIR`	AL	Names of maps, one for each model currency, that specify IR data extraction settings for purposes of calibration. For the definition of these maps, see "IR Calibration Data Extraction Settings (FX_IR_HW_NF)" on page 105.	Referenced maps must exist in the model preferences file. To use the defaults for all settings, provide an empty map.	
`ampDataExtractionSettingsFX`	AL	Names of maps, one for each foreign currency, that specify FX data extraction settings for purposes of calibration. In the current release, FX calibration data extraction has no settings.	Referenced maps must exist in the model preferences file. Provide an empty map for each foreign currency.	

Table 6.9 Data Extraction Settings Map for FX_IR_HW_NF (Continued)

Map Key	Type Code	Description	Constraints	Default Value
`ampBasisCurveSettings`	AL	Names of maps of settings for the basis data extraction, one for each interest rate provider specified by `aBasisCurve` in the market data map. The settings in these maps are listed in "Interest Rate Extraction Settings Map" on page 35.	Referenced maps must exist in the model references file.	The settings specified by `ampIRCurveSettings` are used.
`bExtrapolateDF`	B	Controls whether to extrapolate discount factors.	One of: • TRUE • FALSE	FALSE
`nMonthsExtrapDFEnd`	N	Number of months after the calibration date in which to extrapolate the discount factors.		0

6.3.4.1 IR Calibration Data Extraction Settings (FX_IR_HW_NF)

The `ampDataExtractionSettingsIR` member of the data extraction settings map refers to other maps that each specify settings for IR calibration data extraction for one currency. The following table defines the members of an IR calibration data extraction settings map for the multicurrency multifactor Hull-White model.

Table 6.10 IR Calibration Data Extraction Settings Map for FX_IR_HW_NF

Map Key	Type Code	Description	Constraints	Default Value
`strMethod`	S	Type of calibration data. Only `Swaption` is supported in this release.	One of: • `Swaption`	
`strDaycountFixed`	S	(Optional) Day count convention in the fixed leg of the calibrating swaptions.	See Table B.2 on page 327.	If omitted, the *`dayCountConv`* attribute of the input swaption volatility curve is used.
`nSwapTenorFixed`	N	(Optional) Coupon frequency (in months) in the fixed leg of the calibrating swaptions.		If omitted, the *`tenor`* attribute of the input swaption volatility curve is used.

Example

```
FX_IR_HW_NF_DataExtractionSettings, {
  ampDataExtractionSettingsIR, AL, Swaption_DataExtractionSetting
  ..., Swaption_DataExtractionSetting, Swaption_DataExtractionSetting
  ..., Swaption_DataExtractionSetting
```

```
  ampDataExtractionSettingsFX, AL, EMPTY_MAP, EMPTY_MAP, EMPTY_MAP
  ..., EMPTY_MAP
  bExtrapolateDF, B, TRUE
  nMonthsExtrapDFEnd, N, 10
}

Swaption_DataExtractionSetting, {
  strMethod, S, Swaption
}
```

6.3.5 Trade Information (FX_IR_HW_NF)

The TradeInfo member of a model preferences map refers to another map that specifies information about the trade portfolio. The following table defines the members of a trade information map for the FX_IR_HW_NF model.

Table 6.11 Trade Information Map for FX_IR_HW_NF

Map Key	Type Code	Description	Constraints	Default Value
dtLastCashflow	D	Last date on which a cash flow occurs for any trade in the portfolio.		
dtLastRequiredDF	D	Last date on which a discount factor is required for any trade in the portfolio.		

Example

```
PORTFOLIO_INFO, {
  dtLastCashflow, D, 2059/12/02
  dtLastRequiredDF, D, 2059/12/02
}
```

Chapter 7

Inflation Multicurrency Multifactor Hull-White Model

The inflation multicurrency multifactor Hull-White interest rate model (FX_IF_IR_HW_NF) uses a single-currency multifactor Hull-White model for the nominal interest rate for each currency. In addition, the spread between the nominal and real interest rates of each currency is also modelled as a single-currency multifactor Hull-White model. For each spot foreign exchange rate and inflation index, the log-normal model is used. (Each exchange rate and each inflation index is modelled with one driving factor.)

The calibration of each IR model is independent. Although the term structure of each IR model has independent discretization in time, the model assumes a combined common time discretization for the volatilities of each interest rate, spread, inflation index, and spot exchange rate. Therefore, the entire correlation structure also has the common time discretization.

This model assumes that the single-currency models for all currencies are calibrated on the same date.

For information about the methodology of the FX_IF_IR_HW_NF model, see the following chapter in *Markit Analytics Model Framework Mathematical Reference*: “Hybrid Equity Inflation Multi-Currency Multi-Factor Hull-White Interest Rate Model”.

7.1 Module (FX_IF_IR_HW_NF)

The Model Framework module that implements the inflation multicurrency multifactor Hull-White interest rate model (FX_IF_IR_HW_NF) is as follows:

```
quic_model_fx_if_ir_hw_nf:3.0
```

Combine this module name with the module component names identified in this chapter to form a complete module reference. For example, if the component is QModel_FX_IF_IR_HW_NF_PWC, the complete module reference is as follows:

```
QModel_FX_IF_IR_HW_NF_PWC@quic_model_fx_if_ir_hw_nf:3.0
```

7.2 Market Data Generator Parameters (FX_IF_IR_HW_NF)

A market data generator parameters set for the Model Framework market data generator includes certain parameters whose value depends on the particular model. These include some parameters that are used directly by the generator itself and others that are used only by the Model Framework model that it invokes (in particular by the model's simulator component). For descriptions of the direct generator parameters, see the *Markit Analytics Simulation Framework User Guide*. The parameters that are used by Model Framework simulators are described in "Model Framework Simulator Settings" on page 28.

Some of the simulator settings are used by all models and others are used only by certain models. For the latter subset of settings, the information below shows which ones are used by this model.

Generator Parameter: strSimulatorMFWKReference

The parameter strSimulatorMFWKReference specifies the simulator plug-in for the model. The following values of this parameter are available for the FX_IF_IR_HW_NF model:

- Exact simulation algorithm under the forward measure:

  QMCSimulator_FX_IF_IR_HW_NF_PWC_FM@quic_model_fx_if_ir_hw_nf:3.0
- Euler simulation algorithm under the forward measure:

  QMCSimulator_FX_IF_IR_HW_NF_PWC_FM_Euler@quic_model_fx_if_ir_hw_nf:3.0
- Simulation algorithm under the risk-neutral measure:

  QMCSimulator_FX_IF_IR_HW_NF_PWC_RNM@quic_model_fx_ir_hw_nf:3.0

Applicability of Simulator Settings

The following table identifies which simulator plug-ins (if any) support the specified simulator settings.

Table 7.1 Support for Simulator Settings (FX_IF_IR_HW_NF)

Parameter	Simulators That Support the Parameter
bStepOnDFDates	• QMCSimulator_FX_IF_IR_HW_NF_PWC_FM • QMCSimulator_FX_IF_IR_HW_NF_PWC_FM_Euler • QMCSimulator_FX_IF_IR_HW_NF_PWC_RNM

Table 7.1 Support for Simulator Settings (FX_IF_IR_HW_NF) (Continued)

Parameter	Simulators That Support the Parameter
bPrecalculateCovariances	Not applicable
bUseEigenSym and bUsePCA	• QMCSimulator_FX_IF_IR_HW_NF_PWC_FM • QMCSimulator_FX_IF_IR_HW_NF_PWC_RNM
bCholesky	Not used. Cholesky decomposition is performed if bUseEigenSym is FALSE (the default value).
strDecomposition	• QMCSimulator_FX_IF_IR_HW_NF_PWC_FM • QMCSimulator_FX_IF_IR_HW_NF_PWC_RNM
bUseStartEndNumeraireCalc	QMCSimulator_FX_IF_IR_HW_NF_PWC_RNM
bUseForeignQuantoAdjustment	QMCSimulator_FX_IF_IR_HW_NF_PWC_RNM
bUseDeterministicFXDrifts	QMCSimulator_FX_IF_IR_HW_NF_PWC_RNM
bUseDeterministicInflationDrifts	QMCSimulator_FX_IF_IR_HW_NF_PWC_RNM
bApproximateXIntegral	QMCSimulator_FX_IF_IR_HW_NF_PWC_RNM

7.3 Model Preferences (FX_IF_IR_HW_NF)

You specify the settings for the model in a model preferences map and in the subsidiary maps that it references. For a general description of a model preferences map, see “Model Preferences Map” on page 32.

You can include credit modeling in this model by specifying additional inputs in the model preferences map and its subsidiary maps. These additional inputs are described in “Adding Credit Support to a Non-Credit Model” on page 36.

7.3.1 Components (FX_IF_IR_HW_NF)

The following table identifies the available plug-ins (components of the FX_IF_IR_HW_NF module) that implement the model. You specify these as values of members of the model preferences map in the form of full module references.

Table 7.2 Model Plug-In Components (FX_IF_IR_HW_NF)

Model Preference	Available Components of the Module
Model	QModel_FX_IF_IR_HW_NF_PWC

Table 7.2 Model Plug-In Components (FX_IF_IR_HW_NF) (Continued)

Model Preference	Available Components of the Module
`CalibrationMethod`	One of: • `QModelCalibration_FX_IF_IR_HW_1F_PWC` For internal calibration. • `QModelCalibration_FX_IF_IR_HW_NF_CV_ExtCal` For external calibration (parameters constant over time). • `QModelCalibration_FX_IF_IR_HW_NF_ExtCal` For external calibration. Supports time-varying parameters.
`DataExtractionMethod`	• `QDataExtraction_FX_IF_IR_HW_1F_PWC` For internal calibration. • `QDataExtraction_FX_IF_IR_HW_NF_PWC` For external calibration.

In addition, you must specify the maps that are identified by the other members of the model preferences map. The remainder of this chapter defines these subsidiary maps.

Example

The following figure shows a sample model preferences map that specifies components for this model. In the model preferences file, each map member occupies a single line.

```
FX_IF_IR_HW_NF_ModelPrefs, {
  Model, S, QModel_FX_IF_IR_HW_NF_PWC@quic_model_fx_if_ir_hw_nf:3.0
  CalibrationMethod, S,
   QModelCalibration_FX_IF_IR_HW_1F_PWC@quic_model_fx_if_ir_hw_nf:3.0
  CalibrationSettings, L, FX_IF_IR_HW_NF_CalibrationSettings
  CurveNames, L, FX_IF_IR_HW_NF_CurveNames
  DataExtractionMethod, S,
   QDataExtraction_FX_IF_IR_HW_1F_PWC@quic_model_fx_if_ir_hw_nf:3.0
  DataExtractionSettings, L, FX_IF_IR_HW_NF_DataExtractionSettings
  TradeInfo, L, PORTFOLIO_INFO
}
```

7.3.2 Calibration Settings (FX_IF_IR_HW_NF)

The `CalibrationSettings` member of the model preferences map refers to another map that specifies parameters related to calibration of the model. The inflation multicurrency multifactor Hull-White Model can be calibrated either internally or externally.

For external calibration, the resulting model parameters are treated as inputs.

For internal calibration, a single-currency single-factor Hull-White model is used for the nominal interest rate for each currency. The spread between the nominal and real interest rates of each currency is also modelled as a single-currency single-factor Hull-While model. The inflation index volatilities can be calibrated against inflation index options similar to the spot FX rate volatilities.

The table below defines the members of a calibration settings map for the inflation multicurrency multifactor Hull-White model (FX_IF_IR_HW_NF). The descriptions of these parameters use the following notation:

- H is the number of currencies. Hence, H–1 is the number of exchange rates.
- I is the number of inflation indexes.
- K is the number of factors in the interest rate and inflation model.
- The symbols in the Equation Symbol column refer to the Markit Analytics methodology paper *Hybrid Equity Inflation Multi-Currency Multi_Factor Hull-White Interest Rate Model*.

Table 7.3 Calibration Settings Map for FX_IF_IR_HW_NF

Map Key	Type Code	Description	Constraints	Default Value	Equation Symbol
The inputs in this section are common to all the calibration methods.					
`astrCCY`	AS	Names of the H currencies. The first name is the domestic currency.	Standard 3-character currency identifiers		
`astrII`	AS	Names of the I inflation indexes.	All index names must be present in the model parameter files identified by `strIRParameterFile` and `strFXParameterFile`.		
`astrIICCY`	AS	Names of the I currencies, corresponding to the inflation indexes in `astrII`.	Standard 3-character currency identifier. All names must be present in `astrCCY`.		
`bCorrectCorrMtx`	B	Whether to ensure that the input correlation matrix is positive semidefinite by using principal components analysis.	One of: • TRUE • FALSE	TRUE	
`rEigenThreshold`	R	If `bCorrectCorrMtx` is TRUE, all eigenvectors associated with eigenvalues less than this threshold times the largest eigenvalue are set to zero.		1e-15	
`strModelParametersOutputFile`	S	(Optional) File path of the HDF5 file to which the calculated model parameters are written. This file has the same format as a file for externally calibrated parameters. Typically used only for troubleshooting. If omitted, no file is produced.			

Table 7.3 Calibration Settings Map for FX_IF_IR_HW_NF (Continued)

Map Key	Type Code	Description	Constraints	Default Value	Equation Symbol
strModelParametersOutputName	S	(Optional) Name to give this model parameters set in the file specified by strModelParametersOutputFile.		mpModelParams	
bOutputCalibrationData	B	Whether to include the calibration data in the HDF5 file specified by strModelParametersOutputFile. Typically used only for troubleshooting because it may significantly increase the size of the file.	One of: • TRUE • FALSE	FALSE	
Use the inputs in this section only when CalibrationMethod is QModelCalibration_FX_IF_IR_HW_1F_PWC					
ampCalibrationSettingsIR	AL	Names of maps, one for each model currency, that specify the IR calibration settings. For the definition of these maps, see "IR Calibration Settings (FX_IF_IR_HW_NF)" on page 118.	Referenced maps must exist in the model preferences file. To use the defaults for all settings, provide an empty map.		
ampCalibrationSettingsFX	AL	Names of maps, one for each foreign currency, that specify FX calibration settings. For the definition of these maps, see "FX Calibration Settings (FX_IF_IR_HW_NF)" on page 121.	Referenced maps must exist in the model preferences file. To use the defaults for all settings, provide an empty map.		
ampCalibrationSettingsII	AL	Names of maps, one for each inflation index, that specify inflation index calibration settings. For the definition of these maps, see "Inflation Index Calibration Settings (FX_IF_IR_HW_NF)" on page 121.	Referenced maps must exist in the model preferences file. To use the defaults for all settings, provide an empty map.		
astrBasisCurve	AS	Nicknames of the interest rate curves used for additive LIBOR basis adjustment.	Include a nickname for each of the curves, in order, specified by the aBasisCurve member of the market data map.		

Table 7.3 Calibration Settings Map for FX_IF_IR_HW_NF (Continued)

Map Key	Type Code	Description	Constraints	Default Value	Equation Symbol
bOutputFitResults	B	Whether to report the results of the calibration (comparison of the prices of calibrating instruments from the calibrated model and calculated analytically from market data).	One of: • TRUE • FALSE	FALSE	
strOutputFile	S	(Optional) File path of the CSV file to which calibration results are written (if requested by bOutputFitResults).		Results are displayed in the audit pane only.	
Use the inputs in this section only when CalibrationMethod is QModelCalibration_FX_IF_IR_HW_NF_CV_ExtCal					
strIRParameterFile	S	File path of the CSV file that specifies the mean reversion rates and volatilities for interest rates and spreads between nominal and real interest rates for different currencies. For details, see "IR Parameters (strIRParameterFile)" on page 122			First H lines: $a_{k,i}, \eta_{k,i}$ Second I lines: $\alpha_{k,i}, \nu_{k,i}$
strFXParameterFile	S	File path of the CSV file that specifies the volatility of the FX rates and inflation indexes. For details, see "FX and Inflation Volatilities (strFXParameterFile)" on page 123			First H–1 lines: η_k^{FX} Second H lines: η_k^I
strCorrFile	S	Correlations between all risk factors of the model. For details, see "Correlations (strCorrFile)" on page 123			ρ
Use the inputs in this section only when CalibrationMethod is QModelCalibration_FX_IF_IR_HW_NF_ExtCal and risk factor parameters are specified directly (to specify using CSV files, see page 116)					
g1dtEta	GD	Ascending sequence of M+1 dates that define the intervals of the volatility functions.	The first date must be the calibration date.		
ag1rA	AL	Names of lists (of type GR) that specify the H mean-reversion parameters. Each list specifies the parameters for one currency.	Number of elements must be H. Referenced lists must exist in the auxiliary transaction data file.		$a_{k,i}$

Table 7.3 Calibration Settings Map for FX_IF_IR_HW_NF (Continued)

Map Key	Type Code	Description	Constraints	Default Value	Equation Symbol
`ag1rAlpha`	AL	Names of lists (of type GR) that specify the mean-reversion parameters for inflation spreads. Each list specifies the parameter for one spread between nominal and real interest rates for an inflation index.	Number of elements must be I. Referenced lists must exist in the auxiliary transaction data file.		$\alpha_{k,i}$
`ag2rEta`	AL	Names of lists (of type AL) for each currency. Each currency list specifies names of lists (of type GR) for each of its K factors. Each currency-factor list specifies the value of the IR volatility parameter (eta) in each of the M time intervals defined by `g1dtEta`. For a given currency-factor pair, the value in interval m applies from `g1dtEta`$_m$ up to but not including `g1dtEta`$_{m+1}$. The value in the last interval is also used on the last date and beyond the last date (constant extrapolation).	Number of elements must be H. Referenced lists must exist in the auxiliary transaction data file.		$\eta_{k,i}(t)$
`ag2rNu`	AL	Names of lists (of type AL) for each spread between nominal and real interest rates for an inflation index. Each spread list specifies names of lists (of type GR) for each of its K factors. Each spread index-factor list specifies the value of the IR volatility parameter (eta) in each of the M time intervals defined by `g1dtEta`. For a given factor, the value in interval m applies from `g1dtEta`$_m$ up to but not including `g1dtEta`$_{m+1}$. The value in the last interval is also used on the last date and beyond the last date (constant extrapolation).	Number of elements must be I. Referenced lists must exist in the auxiliary transaction data file.		$\nu_{k,i}(t)$

Table 7.3 Calibration Settings Map for FX_IF_IR_HW_NF (Continued)

Map Key	Type Code	Description	Constraints	Default Value	Equation Symbol
`ag1rEtaFX`	AL	Names of lists (of type `GR`) that specify, for each currency, the value of the FX volatility parameter (`eta`) in each of the M time intervals defined by `g1dtEta`. For a given currency, the value in interval m applies from `g1dtEta`$_m$ up to but not including `g1dtEta`$_{m+1}$. The value in the last interval is also used on the last date and beyond the last date (constant extrapolation).	Number of elements must be H–1. Referenced lists must exist in the auxiliary transaction data file.		$\eta_k^{FX}(t)$
`ag1rEtaIF`	AL	Names of lists (of type `GR`) that specify, for each inflation index, the value of the inflation index volatility parameter (eta) in each of the M time intervals defined by `g1dtEta`. For a given inflation index, the value in interval m applies from `g1dtEta`$_m$ up to but not including `g1dtEta`$_{m+1}$. The value in the last interval is also used on the last date and beyond the last date (constant extrapolation).	Number of elements must be I. Referenced lists must exist in the auxiliary transaction data file.		$\eta_k^I(\mathrm{t})$
`g3rCorrMtx`	AL	Names of lists (of type `AL`) for each factor. Each factor list specifies names of lists (of type `GR`) for each pairing with other factors. Each factor-pair list specifies the value of their pairwise correlation, specified as a piecewise function of time over the intervals defined by `g1dtEta`. For a given pair of factors, the value in interval m applies from `g1dtEta`$_m$ up to but not including `g1dtEta`$_{m+1}$. The value in the last interval is also used on the last date and beyond the last date (constant extrapolation). For details, see the note that follows this table.	$-1 \leq \rho \leq 1$		$\rho(t)$

Table 7.3 Calibration Settings Map for FX_IF_IR_HW_NF (Continued)

Map Key	Type Code	Description	Constraints	Default Value	Equation Symbol
Use the inputs in this section only when `CalibrationMethod` is `QModelCalibration_FX_IF_IR_HW_NF_ExtCal` and risk factor parameters are specified through CSV files					
`bExtractCSVModelParameters`	B	Whether to look for risk factor parameters in CSV files.	One of: • TRUE • FALSE	FALSE	
`strDateFile`	S	File path of the CSV file that specifies the ascending sequence of dates that define the intervals of the volatility functions. For details, see "Dates (`strDateFile`)" on page 124.			
`strIRMRParameterFile`	S	File path of the CSV file that specifies the mean reversion rates for currencies and the mean reversion rates for the spread between nominal and real interest rates for inflation indexes. For details, see "IR Mean-Reversion Parameters (`strIRMRParameterFile`)" on page 125.			First H lines: $a_{k,i}$ Next I lines: $\alpha_{k,i}$
`strIRVolParameterFile`	S	File path of the CSV file that specifies the volatilities (eta) of the interest rates for currencies and the volatilities (eta) of the spread between nominal and real interest rates for inflation indexes in each of the M time intervals defined in `strDateFile`. For details, see "IR Volatility Parameters (`strIRVolParameterFile`)" on page 125.			First K*H lines: $\eta_{k,i}(t)$ Next K*I lines: $\nu_{k,i}(t)$
`strFXIFParameterFile`	S	File path of the CSV file that specifies the volatilities of the FX rates between domestic and foreign currencies as well as the inflation index volatilities in each of the M time intervals defined in `strDateFile`. For details, see "FX Volatility Parameters (`strFXIFParameterFile`)" on page 126.			First H–1 lines: $\eta_k^{FX}(t)$ Next I lines: $\eta_k^{I}(t)$

Table 7.3 Calibration Settings Map for FX_IF_IR_HW_NF (Continued)

Map Key	Type Code	Description	Constraints	Default Value	Equation Symbol
`strCorrFile`	S	File path of the CSV file that specifies the value of each factor pair's correlation, specified as a piecewise function of time over the intervals defined in `strDateFile`. See the note that follows this table. For details, see "Correlations (`strCorrFile`)" on page 126.			$\rho(t)$

Note: Construction of g3CorrMtx

The correlations include those between the factors within one IR model, between the factors of different IR models, between the factors of an IR model and an FX model, between the factors of an IR model and a spread, between nominal and real interest rates for an inflation index, and between the factors of an IR model and an inflation model.

Consider a 2-D slice of the g3CorrMtx grid along the eta axis (this is, for a given time). This 2-D factor correlation matrix is square and of length $\sum_{i=0}^{H-1} K_i + (H-1) + \sum_{j=1}^{I} K_j^I + I$ in each dimension. It is symmetric, so we consider the construction in only one dimension. The risk factors should be placed in the following order:

- K_0 factors of the interest rate for currency 0 (the domestic currency), then the K_1 factors of the interest rate for currency 1, and so on for the H currencies
- $(H–1)$ factors of the exchange rates
- K_1^I factors of the spread between the nominal and real short rate for the first inflation index, then the K_2^I factors of the spread for the second inflation index, and so on for the I inflation indexes
- I factors of the inflation index

Note that this is a slightly different order than when specifying correlations using `strCorrFile` when the `CalibrationMethod` is `QModelCalibration_FX_IF_IR_HW_NF_CV_ExtCal`.

Examples

The first example is for the external calibration method with time-varying parameters specified directly under the calibration settings.

```
FX_IF_IR_HW_NF_CallibrationSeetings_ExtCal, {
g1dtEta, GD, 2005/10/11, 2005/11/11
       astrCCY, AS, EUR, USD
       ag1rA, AL, g1rA_EUR, g1rA_USD
       ag2rEta, AL, ag1rEta_EUR, ag1rEta_USD
       ag1rEtaFX, AL, g1rEtaFX_USD
       astrII, AS, I01
       ag1rAlpha, AL, g1rAlpha_I01
       ag2rNu, AL, ag1rNu_I01
       ag1rEtaIF, AL, g1rEtaIF_I01
       astrIICCY, AS, EUR
       g3rCorrMtx, AL
            ..., ag1rCorrMtx_EUR_factor0, ag1rCorrMtx_EUR_factor1
            ..., ag1rCorrMtx_EUR_factor2
            ..., ag1rCorrMtx_USD_factor0, ag1rCorrMtx_USD_factor1
            ..., ag1rCorrMtx_USD_factor2
            ..., ag1rCorrMtx_FX_Vol_USD
            ..., ag1rCorrMtx_I01_factor0, ag1rCorrMtx_I01_factor1
            ..., ag1rCorrMtx_I01_factor2
            ..., ag1rCorrMtx_II_Vol_I01
       bCorrectCorrMtx, B, false
}
```

The second example is for the external calibration method with time-varying parameters specified through CSV files. Examples for the contents of the files can be found in the sub-sections of “Externally Calibrated Model Parameters (Time-Varying)” on page 124.

```
FX_IF_IR_HW_NF_CallibrationSeetings_ExtCal, {
    bExtractCSVModelParameters, B, true
    strDateFile, S, Dates_ExtCal_Via_CSV.csv
    strIRMRParameterFile, S, IRMRParams_ExtCal_Via_CSV.csv
    strIRVolParameterFile, S, IRVolParams_ExtCal_Via_CSV.csv
    strFXIFParameterFile, S, FXIFParams_ExtCal_Via_CSV.csv
    strCorrFile, S, Correlation_ExtCal_Via_CSV.csv
}
```

7.3.2.1 IR Calibration Settings (FX_IF_IR_HW_NF)

The `ampCalibrationSettingsIR` member of a calibration settings map refers to other maps that each specify settings for the calibration of the interest rate model for one currency. The following table defines the members of an IR calibration settings map for the FX_IF_IR_HW_NF model.

Table 7.4 IR Calibration Settings Map for FX_IF_IR_HW_NF

Map Key	Type Code	Description	Constraints	Default Value
`strCCYDom`	S	Name of the domestic currency.	Standard 3-character currency identifier	
`bUseCapletFormula`	B	Whether to use the caplet formula. If set to TRUE, but the input calibrating instruments are swaptions, this setting reverts to FALSE.	One of: • TRUE • FALSE	FALSE
`rNotional`	R	Notional amount to use when calculating prices during calibration.		1.0
`mpRootFindSettings`	L	Name of a map of settings for the root-finding procedure.	Referenced map must exist in the model preferences file.	Empty map
`bAllowNegativeMR`	B	Whether to allow the calibration process to generate a negative mean reversion parameter.	One of: • TRUE • FALSE	FALSE
`strBasisCurveCalib`	S	(Optional) Nickname of the interest rate curve to use for additive LIBOR basis adjustment during calibration. If omitted, the LIBOR basis adjustment is not performed.	Must be one of the names in `astrBasisCurve` in the main calibration settings map.	
`bUseBasisCurveForCalibDiscounting`	B	Whether to use the basis curve, if specified by `strBasisCurveCalib`, for both discounting and forecasting in the calibration (TRUE) or just for forecasting (FALSE).	One of: • TRUE • FALSE	FALSE
`strBasisCurveCalibDisc`	S	(Optional) Nickname of the interest rate curve to use for discounting during calibration. Ignored if `bUseBasisCurveForCalibDiscounting` is set to TRUE.	Must be one of the names in `astrBasisCurve` in the main calibration settings map.	Interest rate curve for the currency of this map, specified by the market data map member `aIRCurve`.
`bNormalVolatilities`	B	Whether to assume normal (TRUE) or log-normal (FALSE) volatilities.	One of: • TRUE • FALSE	FALSE

Example

```
IR_USD_CalibrationSettings, {
  strBasisCurveCalib, S, USDLibor3M
}

IR_EUR_CalibrationSettings, {
  strBasisCurveCalib, S, EURLibor3M
}
```

7.3.2.1.1 Root-Finding Settings (FX_IF_IR_HW_NF)

The `mpRootFindSettings` member of an IR calibration settings map refers to another map that specifies settings for the root-finding process. Most of these settings specify various numerical tolerances. Normally, the default values are suitable.

The following table defines the members of a root-finding settings map for the FX_IF_IR_HW_NF model.

Table 7.5 Root-Finding Settings Map for FX_IF_IR_HW_NF

Map Key	Type Code	Description	Constraints	Default Value
`rVolSensTol`	R	Volatility sensitivity tolerance		0.001
`rSigmaConst`	R	Sigma used in initial guess for root find (units are per annum). If all calibrating instruments are removed, this value is used as the Hull-White volatility parameter.		0.01
`rErrorTol`	R	Error tolerance for root find to match market prices.		1.0e–14
`rRelTolNR`	R	Relative tolerance in Newton-Raphson method for root find to match market prices.		1.0e–13
`nMaxIterNR`	N	Maximum number of iterations in Newton-Raphson method for root find to match market prices.		100
`nMaxIterBracket`	N	Maximum number of iterations used in bracketing for root find to match market prices.		20
`rBracketLow`	R	Low value for bracketing for root find to match market prices.		1.0e–10
`rBracketHigh`	R	High value for bracketing for root find to match market prices.		1.0e–1
`nMaxDiv`	N	Maximum number of divisions in bisection for root find to match market prices.		100
`rRootGuessJam`	R	Initial guess for root in Jamshidian decomposition.		0.0

Table 7.5 Root-Finding Settings Map for FX_IF_IR_HW_NF (Continued)

Map Key	Type Code	Description	Constraints	Default Value
`rErrorTolJam`	R	Error tolerance in Jamshidian decomposition.		1.0e–13
`rRelTolNRJam`	R	Relative tolerance in Newton-Raphson method for root find in Jamshidian decomposition.		1.0e–15
`nMaxIterNRJam`	N	Maximum number of iterations in Newton-Raphson method for root find in Jamshidian decomposition.		100
`rMinXJam`	R	Minimum X value in bracketing for Jamshidian decomposition.		–0.1
`rMaxXJam`	R	Maximum X value in bracketing for Jamshidian decomposition.		0.1
`nMaxDivJam`	N	Maximum number of iterations in bisection for root find in Jamshidian decomposition.		100

7.3.2.2 FX Calibration Settings (FX_IF_IR_HW_NF)

The `ampCalibrationSettingsFX` member of a calibration settings map refers to other maps that each specify settings for the calibration of the exchange rate model for one pair of currencies. The following table defines the members of an FX calibration settings map for the FX_IF_IR_HW_NF model.

Table 7.6 FX Calibration Settings Map for FX_IF_IR_HW_NF

Map Key	Type Code	Description	Constraints	Default Value
`bUseNegativeSpotVols`	B	Whether to add negative FX spot volatilities to the calibrated values during the calibration procedure.	One of: • TRUE • FALSE	FALSE

Example

```
UseNegativeSpotVols, {
  bUseNegativeSpotVols, B, TRUE
}
```

7.3.2.3 Inflation Index Calibration Settings (FX_IF_IR_HW_NF)

The `ampCalibrationSettingsII` member of a calibration settings map refers to other maps that each specify settings for the calibration of the inflation index model for one inflation index. The following table defines the elements of a calibration settings maps for the FX_IF_IR_HW_NF model.

Table 7.7 Inflation Index Calibration Settings Map for FX_IF_IR_HW_NF

Map Key	Type Code	Description	Constraints	Default Value
bCalibrateToIIOptions	B	Whether to calibrate inflation index volatilities from inflation index options.	If set to FALSE in any of the inflation index calibration settings maps, you must provide aSpotIIVolCurve in the market data map. If set to TRUE in any of the inflation index calibration settings maps, you must provide aSpotImpliedVolCurve in the market data map.	TRUE
bUseNegativeSpotVols	B	(Optional) Whether to add negative inflation index spot volatilities to the calibrated values during the calibration procedure. This input only applies when bCalibrateToIIOptions is set to TRUE.	One of: • TRUE • FALSE	FALSE

7.3.2.4 Externally Calibrated Model Parameters (Constant Over Time)

When using QModelCalibration_FX_IF_IR_HW_NF_CV_ExtCal, you specify the externally calibrated model parameters in the 3 CSV files identified in the calibration settings map by the keys strIRParameterFile, strFXParameterFile, and strCorrFile. In the current implementation, we assume that all interest rates and spreads have the same number of factors.

7.3.2.4.1 IR Parameters (strIRParameterFile)

The CSV file identified by strIRParameterFile specifies the interest rates and the spreads between the nominal and real interest rates. The file contains H+I lines. The first H lines specify the mean reversion rates and the volatilities of the interest rates of the H currencies. The next I lines specify the mean reversion rates and the volatilities of the spreads between nominal and real interest rates to simulate inflation indexes. The first currency is interpreted as the domestic currency.

The first element of each line is a string that identifies the currency or inflation index. Next comes a list of $2K$ positive values. The first K values specify the mean reversion rates of the interest rate or spread. The next K values specify the volatilities of the interest rate or spread.

Example

The sample CSV file (identified by `strIRParameterFile`) in the figure below shows the required format. It specifies the parameters for a 3-factor model with 4 currencies and 2 inflation indexes, where EUR is the domestic currency.

```
// currency ID, IR mean reversion rates, IR volatilities
EUR, 0.0999768, 0.0555563, 0.0968013, 0.0440524, 0.0161914, 0.0209815
USD, 0.0246619, 0.026417, 0.0881347, 0.0683505, 0.090142, 0.0993792
GBP, 0.0961729, 0.0514096, 0.0260791, 0.09655, 0.0716406, 0.0835421
JPY, 0.0692773, 0.0181097, 0.0824264, 0.0469075, 0.0513712, 0.062902
//
// inflation index ID, spread mean reversion rates, spread volatilities
I1, 0.0110639, 0.0693063, 0.056372, 0.0198876, 0.0799084, 0.0257757
I2, 0.064581, 0.0703877, 0.0397624, 0.0418855, 0.0273468, 0.0381594
```

7.3.2.4.2 FX and Inflation Volatilities (`strFXParameterFile`)

The CSV file identified by `strFXParameterFile` specifies the volatilities of the FX rates between domestic and foreign currencies, and the inflation index volatilities. The file contains $2H–1$ lines. The first $H–1$ lines specify the volatilities of the FX rates between the domestic currency and the $H–1$ foreign currencies. The next H lines specify the volatilities of the inflation indexes (one index per currency). The order and the identifiers of the currencies and inflation indexes in `strFXParameterFile` must be the same as in `strIRParameterFile`.

The first element of each line is the string that identifies the foreign currency or the inflation index. The second element of the line is a real value that specifies the volatility of the FX rate or inflation index.

Example

The sample CSV file (identified by `strFXParameterFile`) in the figure below shows the required format. It specifies the parameters for the 4 currencies and 2 inflation indexes in the previous example, where EUR is the domestic currency.

```
// currency ID, FX volatility
EUR, 0.449118
USD, 0.193081
GBP, 0.193413
JPY, 0.498023
//
// inflation index ID, inflation index volatility
I1, 0.433921
I2, 0.113395
```

7.3.2.4.3 Correlations (`strCorrFile`)

The CSV file identified by `strCorrFile` specifies the correlations between all risk factors of the model. Each line of the file contains a row of the correlation matrix. The values in the row are separated with commas. The correlation matrix is square and of size $KH+KI+(H–1)+I$ in each dimension. It is symmetric, so we describe the construction in only one dimension. The risk factors comes in the following order:

- K factors of the interest rate for currency 0 (the domestic currency), then the K factors of the interest rate for currency 1, and so on for the H currencies

- K factors of the spread between the nominal and real short rate for the first inflation index, then the K factors of the spread the second inflation index, and so on for the I inflation indexes
- (H–1) factors of the exchange rates
- I factors of the inflation index

The order of the currencies and inflation indexes must be the same as in `strIRParameterFile` and `strFXParameterFile`.

Example

The sample CSV file (identified by `strCorrFile`) in the figure below shows the required format. It specifies the correlation matrix for a 2-factor 2-currency 2-inflation-index model.

```
// correlation matrix
1.00, 0.61, 0.37, 0.22, 0.14, 0.08, 0.05, 0.03, 0.02, 0.01, 0.01
0.61, 1.00, 0.61, 0.37, 0.22, 0.14, 0.08, 0.05, 0.03, 0.02, 0.01
0.37, 0.61, 1.00, 0.61, 0.37, 0.22, 0.14, 0.08, 0.05, 0.03, 0.02
0.22, 0.37, 0.61, 1.00, 0.61, 0.37, 0.22, 0.14, 0.08, 0.05, 0.03
0.14, 0.22, 0.37, 0.61, 1.00, 0.61, 0.37, 0.22, 0.14, 0.08, 0.05
0.08, 0.14, 0.22, 0.37, 0.61, 1.00, 0.61, 0.37, 0.22, 0.14, 0.08
0.05, 0.08, 0.14, 0.22, 0.37, 0.61, 1.00, 0.61, 0.37, 0.22, 0.14
0.03, 0.05, 0.08, 0.14, 0.22, 0.37, 0.61, 1.00, 0.61, 0.37, 0.22
0.02, 0.03, 0.05, 0.08, 0.14, 0.22, 0.37, 0.61, 1.00, 0.61, 0.37
0.01, 0.02, 0.03, 0.05, 0.08, 0.14, 0.22, 0.37, 0.61, 1.00, 0.61
0.01, 0.01, 0.02, 0.03, 0.05, 0.08, 0.14, 0.22, 0.37, 0.61, 1.00
```

7.3.2.5 Externally Calibrated Model Parameters (Time-Varying)

When using `QModelCalibration_FX_IF_IR_HW_NF_ExtCal`, you can specify the risk factor parameters externally in the five CSV files identified in the calibration settings map by the keys `strDateFile`, `strIRMRParameterFile`, `strIRVolParameterFile`, `strFXIFParameterFile`, and `strCorrFile`.

7.3.2.5.1 Dates (`strDateFile`)

The CSV file identified by `strDateFile` specifies the ascending sequence of dates that define the intervals of the volatility functions. The file contains one line and M+1 values. The first date must be the calibration date and all dates must be in the *`YYYY/MM/DD`* format.

Example

The sample CSV file (identified by `strDateFile`) in the figure below shows the required format.

```
2013/12/12, 2013/12/13, 2013/12/17, 2013/12/23
```

7.3.2.5.2 IR Mean-Reversion Parameters (strIRMRParameterFile)

The CSV file identified by strIRMRParameterFile specifies the mean reversion rates for currencies and the mean reversion rates for the spread between nominal and real interest rates for inflation indexes.

The file contains H+ I lines. The first H lines specify the mean reversion rates for the H currencies. The next I lines specify the mean-reversion rates for the spread between nominal and real interest rates for the I inflation indexes.

The first element of each line is a string that identifies the currency or inflation index. Next comes a list of the K parameters. The order and names of the first element of each line must be consistent with astrCCY and astrII. The first currency is interpreted as the domestic currency.

Example

The sample CSV file (identified by strIRMRParameterFile) in the figure below shows the required format. It specifies the parameters for a 2-factor model with 3 currencies and 2 inflation indexes

```
EUR, 0.042741, 0.04
USD, 0.0331989, 0.03
DKK, 0.0523398, 0.05
I01, 0.042741, 0.04
I03, 0.042741, 0.04
```

7.3.2.5.3 IR Volatility Parameters (strIRVolParameterFile)

The CSV file identified by strIRVolParameterFile specifies the volatilities (eta) of the interest rates for currencies and the volatilities (eta) of the spread between nominal and real interest rates for inflation indexes in each of the M time intervals defined in strDateFile.

The file contains K*H + K*I lines. The first K*H lines specify the volatilities for the K factors for the H currencies. The next K*I lines specify the volatilities for the K factors of the spread between nominal and real interest rates for the I inflation indexes. Each K factor line in the file specifies the M volatilities for one currency or inflation index.

The first element of each line is a string that identifies the currency or inflation index. Next comes a list of the M parameters for the K factor. The order and names of the first element of each line must be consistent with astrCCY and astrII.

Example

The sample CSV file (identified by strIRVolParameterFile) in the figure below shows the required format. It specifies the parameters for a 2-factor model with 3 currencies, 2 inflation indexes, and 3 time intervals

```
EUR, 0.00927385, 0.00927385, 0.00927385
EUR, 0.009, 0.009, 0.009
USD, 0.0120213, 0.0120213, 0.0120213
USD, 0.012, 0.012, 0.012
DKK, 0.0126505, 0.0126505, 0.0126505
DKK, 0.012, 0.012, 0.012
I01, 0.00789928, 0.00789928, 0.00789928
I01, 0.0078, 0.0078, 0.0078
I03, 0.00789928, 0.00789928, 0.00789928
I03, 0.0078, 0.0078, 0.0078
```

7.3.2.5.4 FX Volatility Parameters (strFXIFParameterFile)

The CSV file identified by `strFXIFParameterFile` specifies the volatilities of the FX rates between domestic and foreign currencies as well as the inflation index volatilities in each of the M time intervals defined in `strDateFile`.

The file contains $(H–1)+I$ lines. The first $H–1$ lines specify the volatilities of the FX rates between the domestic currency and the $H–1$ foreign currencies. The next I lines specify the volatilities for the I inflation indexes. Each line in the file specifies the M volatilities for one currency or inflation index.

The first element of each line is a string that identifies the foreign currency or inflation index. Next comes a list of the M parameters. The order and names of the first element of each line must be consistent with `astrCCY` and `astrII`.

Example

The sample CSV file (identified by `strFXIFParameterFile`) in the figure below shows the required format. It specifies the parameters for the 3 currencies and 2 inflation indexes in the previous example (for 3 time intervals), where EUR is the domestic currency.

```
USD, 0.0704675, 0.0704675, 0.0683415
DKK, 0.00910566, 0.00910566, 0.00846446
I01, 0.0087063, 0.0087063, 0.0087063
I03, 0.00871357, 0.00871357, 0.00871357
```

7.3.2.5.5 Correlations (strCorrFile)

The CSV file identified by `strCorrFile` specifies the value of each factor pair's correlation, specified as a piecewise function of time over the intervals defined in `strDateFile`.

Each line in the file specifies the M correlations for one factor pair. The first element of each line specifies the name of the factor pair and it is not validated. It is for your convenience when specifying factor pairs. The order of the risk factor pairs must be as specified in “Note: Construction of g3CorrMtx” on page 117.

Example

The sample CSV file (identified by `strCorrFile`) in the figure below shows the required format. It specifies the correlation matrix for a 3-time-interval, 2-factor, 3-currency, 2-inflation-index model.

```
EUR_factor0_EUR_factor0, 1, 1, 1
EUR_factor0_EUR_factor1, 0.5, 0.5, 0.5
EUR_factor0_USD_factor0, 0.659956, 0.659956, 0.659956
EUR_factor0_USD_factor1, 0.5, 0.5, 0.5
EUR_factor0_DKK_factor0, 0.96511, 0.96511, 0.96511
EUR_factor0_DKK_factor1, 0.5, 0.5, 0.5
EUR_factor0_FX_Vol_USD, -0.426101, -0.426101, -0.426101
EUR_factor0_FX_Vol_DKK, -0.100783, -0.100783, -0.100783
EUR_factor0_I01_factor0, 0.99463, 0.99463, 0.99463
EUR_factor0_I01_factor1, 0.5, 0.5, 0.5
EUR_factor0_I03_factor0, 0.99463, 0.99463, 0.99463
EUR_factor0_I03_factor1, 0.5, 0.5, 0.5
EUR_factor0_II_Vol_I01, 0, 0, 0
EUR_factor0_II_Vol_I03, 0, 0, 0
EUR_factor1_EUR_factor0, ...
EUR_factor1_EUR_factor1, ...
... ...
```

7.3.3 Market Data Inputs (FX_IF_IR_HW_NF)

The `CurveNames` member of the model preferences map refers to a curves name map that identifies the market data curves that are required for pricing, simulation, and if applicable, internal model calibration. The following table defines the members of a market data map for the inflation multicurrency multifactor Hull-White model (FX_IF_IR_HW_NF).

Table 7.8 Market Data Map for FX_IF_IR_HW_NF

Map Key	Type Code	Description	Constraints	Default Value
`aIRCurve`	AS or AL	Either: • Names of curves for discounting (of type `DiscountFactor`, `Yield`, or `FwdLibor`), one for each currency. • Names of lists that specify a set of curves to use in bootstrapping the discount factor, one for each currency. The first curve or list of curves is for the domestic currency, and the remainder are for the foreign currencies. For details about the lists of curves for bootstrapping, see “Specifying the Data to Use in Bootstrapping” on page 34.	Referenced curves must exist in the market data HDF5 file, or referenced lists must exist in an auxiliary transaction data file. The number of elements in the array must equal the number of currencies. Ordinates of a `Yield` curve must be >0.	

Table 7.8 Market Data Map for FX_IF_IR_HW_NF (Continued)

Map Key	Type Code	Description	Constraints	Default Value
aINFCurve	AS	Names of curves (of type DiscountFactor, Yield, or InflationRate) that specify the inflation-bond-related interest rate for each currency, in the same order as the inflation indexes.	Referenced curves must exist in the market data HDF5 file. The number of elements in the array must equal the number of inflation indexes. Ordinates of a Yield curve must be >0.	
aSpotIICurve	AS	Names of curves (of type InflationIndex) that specify the inflation index for each currency, in the same order as the inflation indexes. Must be provided when bCalibrateToIIOptions is set to TRUE.	Referenced curves must exist in the market data HDF5 file. The number of elements in the array must equal the number of inflation indexes.	
aSpotFXCurve	AS	Names of domestic/foreign spot FX curves (of type Exchange), one for each currency, in the same order as the IR curves.	The first name, corresponding to the domestic currency, must be void. Referenced curves must exist in the market data HDF5 file.	
Use the inputs in this section only when DataExtractionMethod is QDataExtraction_FX_IF_IR_HW_1F_PWC				
aINFMeanReversionCurve	AS	Names of mean reversion curves (of type MeanReversion), one for the spread between nominal and real interest rates for each currency, in the same order as the inflation indexes.	Referenced curves must exist in the market data HDF5 file.	
aINFVolCurve	AS	Names of volatility curves (of type ImpliedVol), one for the spread between nominal and real interest rates for each currency, in the same order as the inflation indexes.	Referenced curves must exist in the market data HDF5 file.	
aSpotIIVolCurve	AS	Names of inflation index volatility curves (of type ImpliedVol), one for each inflation index, in the same order as the inflation indexes.	Must be provided when bCalibrateToIIOption is set to False. Referenced curves must exist in the market data HDF5 file.	
aSpotIIImpliedVolCurve	AS	Names of inflation index option implied volatility curves (of type ImpliedVol), one for each inflation index, in the same order as the inflation indexes.	Must be provided when bCalibrateToIIOptions is set to TRUE. Referenced curves must exist in the market data HDF5 file.	

Table 7.8 Market Data Map for FX_IF_IR_HW_NF (Continued)

Map Key	Type Code	Description	Constraints	Default Value
`aBasisCurve`	AS	Names of curves (of type `DiscountFactor`, `Yield`, or `FwdLibor`) that specify the forecasting interest rates to use for LIBOR basis adjustments for all relevant currencies.	Referenced curves must exist in the market data HDF5 file. Ordinates of a `Yield` curve must be >0.	
`aMeanReversionCurve`	AS	Names of mean reversion curves (of type `MeanReversion`), one for each currency, in the same order as the IR curves.	Referenced curves must exist in the market data HDF5 file.	
`aCapletVolCurve`	AS	Names of caplet volatility curves (of type `CapletVol`), one for each currency, in the same order as the IR curves. Each currency must have either a caplet volatility curve or a swaption volatility curve.	Referenced curves must exist in the market data HDF5 file. A value can be `void` if the model for that currency is calibrated to swaption volatilities.	
`aSwaptionVolCurve`	AS	Names of swaption volatility matrix curves (of type `SwaptionVolMtx`), one for each currency, in the same order as the IR curves. Each currency must have either a caplet volatility curve or a swaption volatility curve.	Referenced curves must exist in the market data HDF5 file. A value can be `void` if the model for that currency is calibrated to caplet volatilities.	
`aFXImpliedVolCurve`	AS	Names of FX option volatility curves (of type `ImpliedVol`), one for each spot FX rate, in the same order as the FX curves. The first name, matching the domestic currency itself, can be left blank.	Referenced curves must exist in the market data HDF5 file.	
`aCorrelationCurve`	AS	Names of correlation curves (of type `CorrelBlock`) that give the correlations between model risk factors. For more detail, see the description that follows this table.	Referenced curves must exist in the market data HDF5 file.	

Correlation Curves

Construct the correlation curves specified by `aCorrelationCurve` according to the following scheme:

- A model with n currencies and m inflation indexes has $2n-1+2m$ risk factors: n IR risk factors and $n-1$ FX risk factors, m spread risk factors associated with inflation indexes and m inflation index risk factors.
- Let R_i be the risk factors of the model.
- The n risk factors from $i=0$ to $i=n-1$ are the IR risk factors in the same order as the IR curves.
- The $n-1$ risk factors from $i=n$ to $i=2n-2$ are the FX risk factors in the same order as the spot FX curves (omitting the first which is trivial).
- The m risk factors from $i=2n-1$ to $i=2n+m-2$ are the spread risk factors in the same order as the inflation indexes.

- The m risk factors from i=2n+m-1 to i=2n+2m-2 are the inflation index risk factors in the same order as the inflation indexes.
- The first 2n+2m–2 correlations are the correlations between R_0 and R_1,..., $R_{2n+2m-2}$.
- The next 2n+2m–3 correlations are the correlations between R_1 and R_2,..., $R_{2n+2m-2}$.
- The next 2n+2m–4 correlations are the correlations between R_2 and R_3,..., $R_{2n+2m-2}$, and so on.

Example

```
FX_IF_IR_HW_1F_CurveNames_, {
  aIRCurve, AS, EUR.Yield.EUR, USD.Yield.USD
  aINFCurve, AS, EUR_INF.Yield.EUR
  aSpotIICurve, AS, I_EUR.InflationIndex.EUR
  aSpotFXCurve, AS, void, USD.Exchange.EUR
  aINFMeanReversionCurve, AS, IRR.MeanReversion.EUR
  aINFVolCurve, AS, IRR.ImpliedVol.EUR
  aSpotIIVolCurve, AS, IIVol.ImpliedVol.EUR
  aSpotIIImpliedVolCurve, AS, IIImplied.ImpliedVol.EUR
  aMeanReversionCurve, AS, EURMR.MeanReversion.EUR, USDMR.MeanReversion.USD
  aSwaptionVolCurve, AS, SemiannualSwapVol.SwaptionVolMtx.EUR
  ..., SemiannualSwapVol.SwaptionVolMtx.USD
  aFXImpliedVolCurve, AS, void, USD.ImpliedVol.EUR
  aCorrelationCurve, AS
  ..., ShortRateUSD.CorrelBlock.ShortRateEUR
  ..., ShortRateEUR.CorrelBlock.SpotFXEUR
  ..., ShortRateEUR.CorrelBlock.IRREUR
  ..., ShortRateEUR.CorrelBlock.IIEUR
  ..., ShortRateUSD.CorrelBlock.SpotFXEUR
  ..., ShortRateUSD.CorrelBlock.IRREUR
  ..., ShortRateUSD.CorrelBlock.IIEUR
  ..., SpotFXEUR.CorrelBlock.IRREUR
  ..., SpotFXEUR.CorrelBlock.IIEUR
  ..., IRREUR.CorrelBlock.IIEUR
}
```

7.3.4 Data Extraction Settings (FX_IF_IR_HW_NF)

The `DataExtractionSettings` member of the model preferences map refers to another map that specifies parameters for the data extraction process. The following table defines the members of a data extraction settings map for the inflation multicurrency multifactor Hull-White model (FX_IF_IR_HW_NF).

Table 7.9 Data Extraction Settings Map for FX_IF_IR_HW_NF

Map Key	Type Code	Description	Constraints	Default Value
ampIRCurveSettings	AL	Names of maps, one for each model currency, that specify settings for extracting interest rates. For the definition of these maps, see “Interest Rate Extraction Settings Map” on page 35.	Referenced maps must exist in the model preferences file.	An array of empty maps, one for each currency.
ampBasisCurveSettings	AL	Names of maps of settings for the basis data extraction, one for each interest rate provider specified by aBasisCurve in the market data map. The settings in these maps are listed in “Interest Rate Extraction Settings Map” on page 35.	Referenced maps must exist in the model preferences file.	The settings specified by ampIRCurveSettings are used.
ampIFCurveSettings	AL	Names of maps, one for each inflation index, that specify the settings for extracting the inflation-bond-related interest rate.	Referenced maps must exist in the model preferences file.	An array of empty maps, one for each inflation index.
bExtrapolateDF	B	Controls whether to extrapolate discount factors and inflation discount factors.	One of: • TRUE • FALSE	FALSE
nMonthsExtrapDFEnd	N	Number of months after the calibration date in which to extrapolate the discount factors.		0
Use the inputs in this section only when DataExtractionMethod is QDataExtraction_FX_IF_IR_HW_1F_PWC				
ampDataExtractionSettingsIR	AL	Names of maps, one for each model currency, that specify IR data extraction settings for purposes of calibration. For the definition of these maps, see “IR Calibration Data Extraction Settings (FX_IF_IR_HW_NF)” on page 132.	Referenced maps must exist in the model preferences file. To use the defaults for all settings, provide an empty map.	
ampDataExtractionSettingsFX	AL	Names of maps, one for each foreign currency, that specify FX data extraction settings for purposes of calibration. In the current release, FX calibration data extraction has no settings.	Referenced maps must exist in the model preferences file. Provide an empty map for each foreign currency.	

Table 7.9 Data Extraction Settings Map for FX_IF_IR_HW_NF (Continued)

Map Key	Type Code	Description	Constraints	Default Value
ampDataExtractionSettingsII	AL	Names of maps, one for each inflation index, that specify inflation index data extraction settings for the purpose of calibration. In the current release, inflation index calibration data extraction has no settings.	Referenced maps must exist in the model preferences file. Provide an empty map for each inflation index.	

7.3.4.1 IR Calibration Data Extraction Settings (FX_IF_IR_HW_NF)

The `ampDataExtractionSettingsIR` member of the data extraction settings map refers to other maps that each specify settings for IR calibration data extraction for one currency. The following table defines the members of an IR calibration data extraction settings map for the FX_IF_IR_HW_NF model.

Table 7.10 IR Calibration Data Extraction Settings Map for FX_IF_IR_HW_NF

Map Key	Type Code	Description	Constraints	Default Value
strMethod	S	Type of calibration data.	One of: • `Swaption` • `SelectedSwaptions`	
rSwaptionShift	R	(Optional) If specified, the market swaption price in the calibration of the model is calculated under the assumption that the swap rate has a shifted log-normal distribution with the specified shift size. In this case, the swaption price in the calibration is calculated using Black's formula with the adjusted swap rate and strike obtained by subtracting `rSwaptionShift` from the original swap rate and strike of the calibrating swaptions.		0
strDaycountFixed	S	(Optional) Day count convention in the fixed leg of the calibrating swaptions.	See Table B.2 on page 327.	The *`dayCountConv`* attribute of the input swaption volatility curve is used.
nSwapTenorFixed	N	(Optional) Coupon frequency (in months) in the fixed leg of the calibrating swaptions.		The *`tenor`* attribute of the input swaption volatility curve is used.

Table 7.10 IR Calibration Data Extraction Settings Map for FX_IF_IR_HW_NF (Continued)

Map Key	Type Code	Description	Constraints	Default Value
Use the additional inputs in this section only when `strMethod` is `SelectedSwaptions`				
`astrSwaptionExpiry`	AS	(Optional) Time to expiry to specify the swaption volatilities for extraction from the input swaption volatility curve, in the same units as the expiry ordinates in the curve. If not provided, the times to expiry are assumed to be the expiry ordinate values of the input swaption volatility curve.		
`anSwaptionLength`	AN	(Optional) Lengths in months of the swaptions to specify the volatility for extraction from the input swaption volatility curve, one for each expiry date specified by `astrSwaptionExpiry`. If not provided, the co-terminal swaption volatility is extracted for all expiry dates specified in `astrSwaptionExpiry`. Ignored if `astrSwaptionExpiry` is omitted.	Same number of elements as `astrSwaptionExpiry`.	
`arSwaptionStrike`	AR	(Optional) Swaption strike to specify the volatility for extraction from the input swaption volatility curve, one for each expiry date specified by `astrSwaptionExpiry`. If not provided, the at-the-money strike is used for all expiry dates specified in `astrSwaptionExpiry`. Ignored if `astrSwaptionExpiry` is omitted. Used only when the swaption volatility curve is of type `SwaptionVolCube`.	Same number of elements as `astrSwaptionExpiry`.	

Table 7.10 IR Calibration Data Extraction Settings Map for FX_IF_IR_HW_NF (Continued)

Map Key	Type Code	Description	Constraints	Default Value
`strSwaptionStrikeType`	S	(Optional) Type of the strikes specified in `arSwaptionStrike`. Ignored if `arSwaptionStrike` is omitted. Used only when the swaption volatility curve is of type `SwaptionVolCube`.	One of: • ABSOLUTE • F-K • K-F • F/K • K/F F is the underlying par swap rate for the swaption period. ABSOLUTE means that values represent the strike K. The remaining strike types mean that values are specified in relative terms.	ABSOLUTE
`idxBasisCurveCalib`	N	(Optional) Index of the interest rate curve to use for additive LIBOR basis adjustment in the calculation of the swap rate during the extraction of the ATM volatility.	Integer between 0 and n–1, where n is the number of curves specified by the market data map member `aBasisCurve`.	The LIBOR basis adjustment is not performed.
`idxBasisCurveCalibDisc`	N	(Optional) Index of the interest rate curve to use for discounting in the calculation of the swap rate during the extraction of the ATM volatility. Ignored if `bUseBasisCurveForCalibDiscounting` is set to TRUE.	Integer between 0 and n–1, where n is the number of curves specified by the market data map member `aBasisCurve`.	Interest rate curve for the currency of this map, specified by the market data map member `aIRCurve`.
`bUseBasisCurveForCalibDiscounting`	B	Whether to use the basis curve, if specified by `idxBasisCurveCalib`, for both discounting and forecasting in the calculation of the swap rate (TRUE) or just for forecasting (FALSE).	One of: • TRUE • FALSE	FALSE

Example

```
FX_IF_IR_HW_1F_DataExtractionSettings, {
  ampDataExtractionSettingsIR, AL, Swaption_DataExtractionSetting
  ..., Swaption_DataExtractionSetting, Swaption_DataExtractionSetting
  ..., Swaption_DataExtractionSetting
  ampDataExtractionSettingsFX, AL, EMPTY_MAP, EMPTY_MAP, EMPTY_MAP
  ..., EMPTY_MAP
bExtrapolateDF, B, TRUE
nMonthsExtrapDFEnd, N, 10
}

Swaption_DataExtractionSetting, {
  strMethod, S, Swaption
}
```

7.3.5 Trade Information (FX_IF_IR_HW_NF)

The `TradeInfo` member of a model preferences map refers to another map that specifies information about the trade portfolio. The following table defines the members of a trade information map for the FX_IF_IR_HW_NF model.

Table 7.11 Trade Information Map for FX_IF_IR_HW_NF

Map Key	Type Code	Description	Constraints	Default Value
`dtLastCashflow`	D	Last date on which a cash flow occurs for any trade in the portfolio.		
`dtLastRequiredDF`	D	Last date on which a discount factor is required for any trade in the portfolio.		

Example

```
PORTFOLIO_INFO, {
  dtLastCashflow, D, 2059/12/02
  dtLastRequiredDF, D, 2059/12/02
}
```

Chapter 8

Inflation Multicurrency Multifactor Hull-White Model with Derived Inflation Indexes

The inflation multicurrency multifactor Hull-White interest rate model with derived inflation indexes (FX_IF_IR_HW_NF_DI) uses a single-currency multifactor Hull-White model for the nominal interest rate for each currency. In addition, the spread between the nominal and real interest rates of each currency is also modelled as a single-currency multifactor Hull-White model. For each spot foreign exchange rate and inflation index, the log-normal model is used. (Each exchange rate and each inflation index is modelled with one driving factor.)

This model extends the FX_IF_IR_HW_NF model to allow for derived inflation indexes. A derived inflation index has the same driving factors as a core inflation index and inflation index rate curve, but has different inflation index and inflation rate curve starting values.

The model treats the interest rate volatilities, spread volatilities, spot FX volatilities, and inflation index volatilities as piecewise constant functions in time.

The calibration of each IR model is independent. Although the term structure of each IR model has independent discretization in time, the model assumes a combined common time discretization for the volatilities of each interest rate, spread, inflation index, and spot exchange rate. Therefore, the entire correlation structure also has the common time discretization.

This model assumes that the single-currency models for all currencies are calibrated on the same date.

For information about the methodology of the FX_IF_IR_HW_NF_DI model, see the following chapter in *Markit Analytics Model Framework Mathematical Reference*: “Hybrid Equity Inflation Multi-Currency Multi-Factor Hull-White Interest Rate Model”.

8.1 Module (FX_IF_IR_HW_NF_DI)

The Model Framework module that implements the inflation multicurrency multifactor Hull-White interest rate model with derived inflation indexes (FX_IF_IR_HW_NF_DI) is as follows:

```
quic_model_fx_if_ir_hw_nf:3.0
```

Combine this module name with the module component names identified in this chapter to form a complete module reference. For example, if the component is `QModel_FX_IF_IR_HW_NF_PWC_Derived`, the complete module reference is as follows:

```
QModel_FX_IF_IR_HW_NF_PWC_Derived@quic_model_fx_if_ir_hw_nf:3.
0
```

8.2 Market Data Generator Parameters (FX_IF_IR_HW_NF_DI)

A market data generator parameters set for the Model Framework market data generator includes certain parameters whose value depends on the particular model. These include some parameters that are used directly by the generator itself and others that are used only by the Model Framework model that it invokes (in particular by the model’s simulator component). For descriptions of the direct generator parameters, see the *Markit Analytics Simulation Framework User Guide*. The parameters that are used by Model Framework simulators are described in “Model Framework Simulator Settings” on page 28.

Some of the simulator settings are used by all models and others are used only by certain models. For the latter subset of settings, the information below shows which ones are used by this model.

Generator Parameter: `strSimulatorMFWKReference`

The parameter `strSimulatorMFWKReference` specifies the simulator plug-in for the model. The following values of this parameter are available for the FX_IF_IR_HW_NF_DI model:

- Exact simulation algorithm under the forward measure:

  ```
  QMCSimulator_FX_IF_IR_HW_NF_PWC_FM@quic_model_fx_if_ir_hw_nf:3
  .0
  ```

- Euler simulation algorithm under the forward measure:

QMCSimulator_FX_IF_IR_HW_NF_PWC_FM_Euler@quic_model_fx_if_ir_hw_nf:3.0

- Simulation algorithm under the risk-neutral measure:
  QMCSimulator_FX_IF_IR_HW_NF_PWC_RNM@quic_model_fx_ir_hw_nf:3.0

Applicability of Simulator Settings

The following table identifies which simulator plug-ins (if any) support the specified simulator settings.

Table 8.1 Support for Simulator Settings (FX_IF_IR_HW_NF_DI)

Parameter	Simulators That Support the Parameter
bStepOnDFDates	• QMCSimulator_FX_IF_IR_HW_NF_PWC_FM • QMCSimulator_FX_IF_IR_HW_NF_PWC_FM_Euler • QMCSimulator_FX_IF_IR_HW_NF_PWC_RNM
bPrecalculateCovariances	Not applicable
bUseEigenSym and bUsePCA	• QMCSimulator_FX_IF_IR_HW_NF_PWC_FM • QMCSimulator_FX_IF_IR_HW_NF_PWC_RNM
bCholesky	Not used. Cholesky decomposition is performed if bUseEigenSym is FALSE (the default value).
strDecomposition	• QMCSimulator_FX_IF_IR_HW_NF_PWC_FM • QMCSimulator_FX_IF_IR_HW_NF_PWC_RNM
bUseStartEndNumeraireCalc	QMCSimulator_FX_IF_IR_HW_NF_PWC_RNM
bUseForeignQuantoAdjustment	QMCSimulator_FX_IF_IR_HW_NF_PWC_RNM
bUseDeterministicFXDrifts	QMCSimulator_FX_IF_IR_HW_NF_PWC_RNM
bUseDeterministicInflationDrifts	QMCSimulator_FX_IF_IR_HW_NF_PWC_RNM
bApproximateXIntegral	QMCSimulator_FX_IF_IR_HW_NF_PWC_RNM

8.3 Model Preferences (FX_IF_IR_HW_NF_DI)

You specify the settings for the model in a model preferences map and in the subsidiary maps that it references. For a general description of a model preferences map, see “Model Preferences Map” on page 32.

8.3.1 Components (FX_IF_IR_HW_NF_DI)

The following table identifies the available plug-ins (components of the FX_IF_IR_HW_NF_DI module) that implement the model. You specify these as values of members of the model preferences map in the form of full module references.

Table 8.2 Model Plug-In Components (FX_IF_IR_HW_NF_DI)

Model Preference	Available Components of the Module
`Model`	`QModel_FX_IF_IR_HW_NF_PWC_Derived`
`CalibrationMethod`	One of: • `QModelCalibration_FX_IF_IR_HW_NF_CV_ExtCal_Derived` For external calibration (parameters constant over time). • `QModelCalibration_FX_IF_IR_HW_NF_ExtCal_Derived` For external calibration. Supports time-varying parameters.
`DataExtractionMethod`	`QDataExtraction_FX_IF_IR_HW_NF_PWC_Derived`

In addition, you must specify the maps that are identified by the other members of the model preferences map. The remainder of this chapter defines these subsidiary maps.

Example

The following figure shows a sample model preferences map that specifies components for this model. In the model preferences file, each map member occupies a single line.

```
FX_IF_IR_HW_NF_ModelPrefs, {
  Model, S, QModel_FX_IF_IR_HW_NF_PWC_Derived@quic_model_fx_if_ir_hw_nf:3.0
  CalibrationMethod, S,
   QModelCalibration_FX_IF_IR_HW_NF_ExtCal_Derived@quic_model_fx_if_ir_hw_nf:3.0
  CalibrationSettings, L, FX_IF_IR_HW_NF_CalibrationSettings
  CurveNames, L, FX_IF_IR_HW_NF_CurveNames
  DataExtractionMethod, S,
   QDataExtraction_FX_IF_IR_HW_NF_PWC_Derived@quic_model_fx_if_ir_hw_nf:3.0
  DataExtractionSettings, L, FX_IF_IR_HW_NF_DataExtractionSettings
  TradeInfo, L, PORTFOLIO_INFO
}
```

8.3.2 Calibration Settings (FX_IF_IR_HW_NF_DI)

The `CalibrationSettings` member of the model preferences map refers to another map that specifies parameters related to calibration of the model. The actual calibration process is assumed to be done externally, and the resulting model parameters are treated as inputs.

The table below defines the members of a calibration settings map for the inflation multicurrency multifactor Hull-White model with derived inflation indexes. The descriptions of these parameters use the following notation:

- H is the number of currencies. Hence, H–1 is the number of exchange rates.
- I is the number of inflation indexes.
- K is the number of factors in the interest rate and inflation model.

- The symbols in the Equation Symbol column refer to the Markit Analytics methodology paper *Hybrid Equity Inflation Multi-Currency Multi_Factor Hull-White Interest Rate Model*.

Table 8.3 Calibration Settings Map for FX_IF_IR_HW_NF_DI

Map Key	Type Code	Description	Constraints	Default Value	Equation Symbol
The inputs in this section are common to all the calibration methods.					
`astrCCY`	AS	Names of the H currencies. The first name is the domestic currency.	Standard 3-character currency identifiers		
`astrII`	AS	Names of the I core inflation indexes.	All index names must be present in the model parameter files identified by `strIRParameterFile` and `strFXParameterFile`.		
`astrIICCY`	AS	Names of the I currencies, corresponding to the inflation indexes in `astrII`.	Standard 3-character currency identifier. All names must be present in `astrCCY`.		
`astrIIDerived`	AS	Names of the derived inflation indexes.			
`astrIIDerivedFrom`	AS	Names of the core inflation indexes on which the derived indexes are based, one for each derived index.	All names must be present in `astrII`.		
`bCorrectCorrMtx`	B	Whether to ensure that the input correlation matrix is positive semidefinite by using principal components analysis.	One of: • TRUE • FALSE	TRUE	
`rEigenThreshold`	R	If `bCorrectCorrMtx` is TRUE, all eigenvectors associated with eigenvalues less than this threshold times the largest eigenvalue are set to zero.		1e-15	

Table 8.3 Calibration Settings Map for FX_IF_IR_HW_NF_DI (Continued)

Map Key	Type Code	Description	Constraints	Default Value	Equation Symbol
`strModelParametersOutputFile`	S	(Optional) File path of the HDF5 file to which the calculated model parameters are written. This file has the same format as a file for externally calibrated parameters. Typically used only for troubleshooting. If omitted, no file is produced.			
`strModelParametersOutputName`	S	(Optional) Name to give this model parameters set in the file specified by `strModelParametersOutputFile`.		`mpModelParams`	
Use the inputs in this section only when `CalibrationMethod` is `QModelCalibration_FX_IF_IR_HW_NF_CV_ExtCal_Derived`					
`strIRParameterFile`	S	File path of the CSV file that specifies the mean reversion rates and volatilities for interest rates and spreads between nominal and real interest rates for different currencies. For details, see "IR Parameters (`strIRParameterFile`)" on page 147			First H lines: $a_{k,i}, \eta_{k,i}$ Second I lines: $\alpha_{k,i}, \nu_{k,i}$
`strFXParameterFile`	S	File path of the CSV file that specifies the volatility of the FX rates and inflation indexes. For details, see "FX and Inflation Volatilities (`strFXParameterFile`)" on page 148			First H–1 lines: η_k^{FX} Second H lines: η_k^I
`strCorrFile`	S	Correlations between all risk factors of the model. For details, see "Correlations (`strCorrFile`)" on page 148			ρ

Table 8.3 Calibration Settings Map for FX_IF_IR_HW_NF_DI (Continued)

Map Key	Type Code	Description	Constraints	Default Value	Equation Symbol
Use the inputs in this section only when `CalibrationMethod` is `QModelCalibration_FX_IF_IR_HW_NF_ExtCal_Derived`					
`g1dtEta`	GD	Ascending sequence of M+1 dates that define the intervals of the volatility functions.	The first date must be the calibration date.		
`ag1rA`	AL	Names of lists (of type GR) that specify the H mean-reversion parameters. Each list specifies the parameters for one currency.	Number of elements must be H. Referenced lists must exist in the auxiliary transaction data file.		$a_{k,i}$
`ag1rAlpha`	AL	Names of lists (of type `GR`) that specify the mean-reversion parameters for inflation spreads. Each list specifies the parameter for one spread between nominal and real interest rates for an inflation index.	Number of elements must be I. Referenced lists must exist in the auxiliary transaction data file.		$\alpha_{k,i}$
`ag2rEta`	AL	Names of lists (of type `AL`) for each currency. Each currency list specifies names of lists (of type `GR`) for each of its K factors. Each currency-factor list specifies the value of the IR volatility parameter (eta) in each of the M time intervals defined by `g1dtEta`. For a given currency-factor pair, the value in interval m applies from `g1dtEta`$_m$ up to but not including `g1dtEta`$_{m+1}$. The value in the last interval is also used on the last date and beyond the last date (constant extrapolation).	Number of elements must be H. Referenced lists must exist in the auxiliary transaction data file.		$\eta_{k,i}(t)$

Table 8.3 Calibration Settings Map for FX_IF_IR_HW_NF_DI (Continued)

Map Key	Type Code	Description	Constraints	Default Value	Equation Symbol
`ag2rNu`	AL	Names of lists (of type `AL`) for each spread between nominal and real interest rates for an inflation index. Each spread list specifies names of lists (of type `GR`) for each of its K factors. Each spread index-factor list specifies the value of the IR volatility parameter (eta) in each of the M time intervals defined by `g1dtEta`. For a given factor, the value in interval m applies from `g1dtEta`$_m$ up to but not including `g1dtEta`$_{m+1}$. The value in the last interval is also used on the last date and beyond the last date (constant extrapolation).	Number of elements must be I. Referenced lists must exist in the auxiliary transaction data file.		$\nu_{k,i}(t)$
`ag1rEtaFX`	AL	Names of lists (of type `GR`) that specify, for each currency, the value of the FX volatility parameter (`eta`) in each of the M time intervals defined by `g1dtEta`. For a given factor, the value in interval m applies from `g1dtEta`$_m$ up to but not including `g1dtEta`$_{m+1}$. The value in the last interval is also used on the last date and beyond the last date (constant extrapolation).	Number of elements must be H–1. Referenced lists must exist in the auxiliary transaction data file.		$\eta_k^{FX}(t)$

Table 8.3 Calibration Settings Map for FX_IF_IR_HW_NF_DI (Continued)

Map Key	Type Code	Description	Constraints	Default Value	Equation Symbol
`ag1rEtaIF`	AL	Names of lists (of type GR) that specify, for each inflation index, the value of the inflation index volatility parameter (eta) in each of the M time intervals defined by `g1dtEta`. For a given inflation index, the value in interval m applies from `g1dtEta`$_m$ up to but not including `g1dtEta`$_{m+1}$. The value in the last interval is also used on the last date and beyond the last date (constant extrapolation).	Number of elements must be I. Referenced lists must exist in the auxiliary transaction data file.		$\eta_k^I(t)$

Table 8.3 Calibration Settings Map for FX_IF_IR_HW_NF_DI (Continued)

Map Key	Type Code	Description	Constraints	Default Value	Equation Symbol
`g3rCorrMtx`	AL	Names of lists (of type AL) for each factor. Each factor list specifies names of lists (of type GR) for each pairing with other factors. Each factor-pair list specifies the value of their pairwise correlation, specified as a piecewise function of time over the intervals defined by `g1dtEta` The correlations include those between the factors within one IR model, between the factors of different IR models, between the factors of an IR model and an FX model, between the factors of an IR model and a spread between nominal and real interest rates for an inflation index, and between the factors of an IR model and an inflation model. For details, see the note that follows this table. For a given pair of factors, the value in interval m applies from `g1dtEta`$_m$ up to but not including `g1dtEta`$_{m+1}$. The value in the last interval is also used on the last date and beyond the last date (constant extrapolation). See the note that follows this table.	$-1 \le \rho \le 1$		$\rho(t)$

Note: Construction of g3CorrMtx

Consider a 2-D slice of the `g3CorrMtx` grid along the eta axis (that is, for a given time). This 2-D factor correlation matrix is square and of length $KH+(H-1)+KI+I$ in each dimension. It is symmetric, so we consider the construction in only one dimension. The risk factors should be placed in the following order:

- K factors of the interest rate for currency 0 (the domestic currency), then the
- K factors of the interest rate for currency 1, and so on for the H currencies
- $(H–1)$ factors of the exchange rates

- K factors of the spread between the nominal and real short rate for the first inflation index, then the K factors of the spread the second inflation index, and so on for the I inflation indexes
- I factors of the inflation index

Note that this is a slightly different order than when specifying correlations using `strCorrFile`.

Example

This example uses the time-varying parameter calibration.

```
FX_IF_IR_HW_NF_CallibrationSeetings_ExtCal_Derived, {
g1dtEta, GD, 2005/10/11, 2005/11/11
        astrCCY, AS, EUR, USD
        ag1rA, AL, g1rA_EUR, g1rA_USD
        ag2rEta, AL, ag1rEta_EUR, ag1rEta_USD
        ag1rEtaFX, AL, g1rEtaFX_USD
        astrII, AS, I01
        ag1rAlpha, AL, g1rAlpha_I01
        ag2rNu, AL, ag1rNu_I01
        ag1rEtaIF, AL, g1rEtaIF_I01
        astrIICCY, AS, EUR
        g3rCorrMtx, AL
             ..., ag1rCorrMtx_EUR_factor0, ag1rCorrMtx_EUR_factor1
             ..., ag1rCorrMtx_EUR_factor2
             ..., ag1rCorrMtx_USD_factor0, ag1rCorrMtx_USD_factor1
             ..., ag1rCorrMtx_USD_factor2
             ..., ag1rCorrMtx_FX_Vol_USD
             ..., ag1rCorrMtx_I01_factor0, ag1rCorrMtx_I01_factor1
             ..., ag1rCorrMtx_I01_factor2
             ..., ag1rCorrMtx_II_Vol_I01
        astrIIDerived, AS, I01d1
        astrIIDerivedFrom, AS, I01
        bCorrectCorrMtx, B, false
}
```

8.3.2.1 Externally Calibrated Model Parameters (Constant Over Time)

When using `QModelCalibration_FX_IF_IR_HW_NF_CV_ExtCal_Derived`, you specify the externally calibrated model parameters in the 3 CSV files identified in the calibration settings map by the keys `strIRParameterFile`, `strFXParameterFile`, and `strCorrFile`. In the current implementation, we assume that all interest rates and spreads have the same number of factors.

8.3.2.1.1 IR Parameters (`strIRParameterFile`)

The CSV file identified by `strIRParameterFile` specifies the interest rates and the spreads between the nominal and real interest rates. The file contains H+I lines. The first H lines specify the mean reversion rates and the volatilities of the interest rates of the H currencies. The next I lines specify the mean reversion rates and the volatilities of the spreads between nominal and real interest rates to simulate inflation indexes. The first currency is interpreted as the domestic currency.

The first element of each line is a string that identifies the currency or inflation index. Next comes a list of 2K positive values. The first K values specify the mean reversion rates of the interest rate or spread. The next K values specify the volatilities of the interest rate or spread.

Example

The sample CSV file (identified by `strIRParameterFile`) in the figure below shows the required format. It specifies the parameters for a 3-factor model with 4 currencies and 2 inflation indexes, where EUR is the domestic currency.

```
// currency ID, IR mean reversion rates, IR volatilities
EUR, 0.0999768, 0.0555563, 0.0968013, 0.0440524, 0.0161914, 0.0209815
USD, 0.0246619, 0.026417, 0.0881347, 0.0683505, 0.090142, 0.0993792
GBP, 0.0961729, 0.0514096, 0.0260791, 0.09655, 0.0716406, 0.0835421
JPY, 0.0692773, 0.0181097, 0.0824264, 0.0469075, 0.0513712, 0.062902
//
// inflation index ID, spread mean reversion rates, spread volatilities
I1, 0.0110639, 0.0693063, 0.056372, 0.0198876, 0.0799084, 0.0257757
I2, 0.064581, 0.0703877, 0.0397624, 0.0418855, 0.0273468, 0.0381594
```

8.3.2.1.2 FX and Inflation Volatilities (`strFXParameterFile`)

The CSV file identified by `strFXParameterFile` specifies the volatilities of the FX rates between domestic and foreign currencies, and the inflation index volatilities. The file contains $2H–1$ lines. The first $H–1$ lines specify the volatilities of the FX rates between the domestic currency and the $H–1$ foreign currencies. The next H lines specify the volatilities of the inflation indexes (one index per currency). The order and the identifiers of the currencies and inflation indexes in `strFXParameterFile` must be the same as in `strIRParameterFile`.

The first element of each line is the string that identifies the foreign currency or the inflation index. The second element of the line is a real value that specifies the volatility of the FX rate or inflation index.

Example

The sample CSV file (identified by `strFXParameterFile`) in the figure below shows the required format. It specifies the parameters for the 4 currencies and 2 inflation indexes in the previous example, where EUR is the domestic currency.

```
// currency ID, FX volatility
EUR, 0.449118
USD, 0.193081
GBP, 0.193413
JPY, 0.498023
//
// inflation index ID, inflation index volatility
I1, 0.433921
I2, 0.113395
```

8.3.2.1.3 Correlations (`strCorrFile`)

The CSV file identified by `strCorrFile` specifies the correlations between all risk factors of the model. Each line of the file contains a row of the correlation matrix. The values in the row are separated with commas. The correlation matrix is square and of size $KH+KI+(H–1)+I$ in each dimension. It is symmetric, so we describe the construction in only one dimension. The risk factors comes in the following order:

- K factors of the interest rate for currency 0 (the domestic currency), then the K factors of the interest rate for currency 1, and so on for the H currencies
- K factors of the spread between the nominal and real short rate for the first inflation index, then the K factors of the spread the second inflation index, and so on for the I inflation indexes
- (H–1) factors of the exchange rates
- I factors of the inflation index

The order of the currencies and inflation indexes must be the same as in `strIRParameterFile` and `strFXParameterFile`.

Example

The sample CSV file (identified by `strCorrFile`) in the figure below shows the required format. It specifies the correlation matrix for a 2-factor 2-currency 2-inflation-index model.

```
// correlation matrix
1.00, 0.61, 0.37, 0.22, 0.14, 0.08, 0.05, 0.03, 0.02, 0.01, 0.01
0.61, 1.00, 0.61, 0.37, 0.22, 0.14, 0.08, 0.05, 0.03, 0.02, 0.01
0.37, 0.61, 1.00, 0.61, 0.37, 0.22, 0.14, 0.08, 0.05, 0.03, 0.02
0.22, 0.37, 0.61, 1.00, 0.61, 0.37, 0.22, 0.14, 0.08, 0.05, 0.03
0.14, 0.22, 0.37, 0.61, 1.00, 0.61, 0.37, 0.22, 0.14, 0.08, 0.05
0.08, 0.14, 0.22, 0.37, 0.61, 1.00, 0.61, 0.37, 0.22, 0.14, 0.08
0.05, 0.08, 0.14, 0.22, 0.37, 0.61, 1.00, 0.61, 0.37, 0.22, 0.14
0.03, 0.05, 0.08, 0.14, 0.22, 0.37, 0.61, 1.00, 0.61, 0.37, 0.22
0.02, 0.03, 0.05, 0.08, 0.14, 0.22, 0.37, 0.61, 1.00, 0.61, 0.37
0.01, 0.02, 0.03, 0.05, 0.08, 0.14, 0.22, 0.37, 0.61, 1.00, 0.61
0.01, 0.01, 0.02, 0.03, 0.05, 0.08, 0.14, 0.22, 0.37, 0.61, 1.00
```

8.3.3 Market Data Inputs (FX_IF_IR_HW_NF_DI)

The `CurveNames` member of the model preferences map refers to a map that identifies the market data curves that are required for pricing, simulation, and if applicable, internal model calibration. The following table defines the members of a market data map for the inflation multicurrency multifactor Hull-White interest rate model with derived inflation indexes.

Table 8.4 Market Data Map for FX_IF_IR_HW_NF_DI

Map Key	Type Code	Description	Constraints	Default Value
`aIRCurve`	AS or AL	Either: • Names of curves for discounting (of type `DiscountFactor`, `Yield`, or `FwdLibor`), one for each currency. • Names of lists that specify a set of curves to use in bootstrapping the discount factor, one for each currency. The first curve or list of curves is for the domestic currency, and the remainder are for the foreign currencies. For details about the lists of curves for bootstrapping, see “Specifying the Data to Use in Bootstrapping” on page 34.	Referenced curves must exist in the market data HDF5 file, or referenced lists must exist in an auxiliary transaction data file. The number of elements in the array must equal the number of currencies. Ordinates of a `Yield` curve must be >0.	
`aINFCurve`	AS	Names of curves (of type `DiscountFactor`, `Yield`, or `InflationRate`) that specify the inflation-bond-related interest rate for each currency, in the same order as the inflation indexes.	Referenced curves must exist in the market data HDF5 file. The number of elements in the array must equal the number of currencies. Ordinates of a `Yield` curve must be >0.	
`aSpotIICurve`	AS	Names of curves (of type `InflationIndex`) that specify the inflation index for each currency, in the same order as the inflation indexes.	Referenced curves must exist in the market data HDF5 file. The number of elements in the array must equal the number of inflation indexes.	
`aINFDerivedCurve`	AS	Names of curves (of type `Yield`) that specify the inflation-bond-related interest rate for the currency of each derived inflation index, in the same order in which the indexes are listed in the `astrIIDerived` parameter in the calibration settings map.	Referenced curves must exist in the market data HDF5 file. The number of elements in the array must equal the number of inflation indexes. Ordinates of a `Yield` curve must be >0.	
`aSpotIIDerivedCurve`	AS	Names of curves (of type `InflationIndex`) that specify the initial value of each derived inflation index, in the same order in which the indexes are listed in the `astrIIDerived` parameter in the calibration settings map.	Referenced curves must exist in the market data HDF5 file. The number of elements in the array must equal the number of derived indexes.	

Table 8.4 Market Data Map for FX_IF_IR_HW_NF_DI (Continued)

Map Key	Type Code	Description	Constraints	Default Value
aSpotFXCurve	AS	Names of domestic/foreign spot FX curves (of type Exchange), one for each currency, in the same order as the IR curves.	The first name, corresponding to the domestic currency, must be void. Referenced curves must exist in the market data HDF5 file.	

Example

In the following example, a single derived inflation index is assumed to be based on a core index whose currency is USD.

```
SampleHWCalibrationData, {
  aIRCurve, AS, USD.Yield.USD, EUR.Yield.EUR
  aINFCurve, AS, USD_Inf.Yield.USD, EUR_Inf.Yield.EUR
  aSpotIICurve, AS, I_USD.InflationIndex.USD, I_EUR.InflationIndex.USD
  aINFDerivedCurve, AS, USD_Inf.Yield.USD
  aSpotIIDerivedCurve, AS, I_USD.InflationIndex.USD
  aSpotFXCurve, AS, void, EUR.Exchange.USD
}
```

8.3.4 Data Extraction Settings (FX_IF_IR_HW_NF_DI)

The DataExtractionSettings member of the model preferences map refers to another map that specifies parameters for the data extraction process. The following table defines the members of a data extraction settings map for the inflation multicurrency multifactor Hull-White interest rate model with derived inflation indexes.

Table 8.5 Data Extraction Settings Map for FX_IF_IR_HW_NF_DI

Map Key	Type Code	Description	Constraints	Default Value
ampIRCurveSettings	AL	Names of maps, one for each model currency, that specify settings for extracting interest rates. For the definition of these maps, see "Interest Rate Extraction Settings Map" on page 35.	Referenced maps must exist in the model preferences file.	An array of empty maps, one for each currency.
ampIFCurveSettings	AL	Names of maps, one for each inflation index, that specify the settings for extracting the inflation-bond-related interest rate.	Referenced maps must exist in the model preferences file.	An array of empty maps, one for each inflation index.

Table 8.5 Data Extraction Settings Map for FX_IF_IR_HW_NF_DI (Continued)

Map Key	Type Code	Description	Constraints	Default Value
ampIFDerivedCurveSettings	AL	Names of maps, one for each derived inflation index, that specify the settings for extracting the inflation-bond-related interest rate.	Referenced maps must exist in the model preferences file.	An array of empty maps, one for each derived inflation index.
bExtrapolateDF	B	Controls whether to extrapolate discount factors and inflation discount factors.	One of: • TRUE • FALSE	FALSE
nMonthsExtrapDFEnd	N	Number of months after the calibration date in which to extrapolate the discount factors.		0

Example

```
FX_IF_IR_HW_NF_DataExtractionSettings, {
 bExtrapolateDF, B, TRUE
 nMonthsExtrapDFEnd, N, 10
}
```

8.3.5 Trade Information (FX_IF_IR_HW_NF_DI)

The TradeInfo member of a model preferences map refers to another map that specifies information about the trade portfolio. The following table defines the members of a trade information map for the FX_IF_IR_HW_NF_DI model.

Table 8.6 Trade Information Map for FX_IF_IR_HW_NF_DI

Map Key	Type Code	Description	Constraints	Default Value
dtLastCashflow	D	Last date on which a cash flow occurs for any trade in the portfolio.		
dtLastRequiredDF	D	Last date on which a discount factor is required for any trade in the portfolio.		

Example

```
PORTFOLIO_INFO, {
  dtLastCashflow, D, 2059/12/02
  dtLastRequiredDF, D, 2059/12/02
}
```

Chapter 9

Hybrid Credit Equity Inflation Multicurrency Model

In the hybrid credit equity inflation multicurrency extension of the multifactor Hull-White interest rate model (CR_EQ_FX_IF_IR_HW_NF_BK_1F), a single-currency multifactor Hull-White model is used for the nominal interest rate for each currency. In addition, the spread between the nominal and real interest rates of each currency is also modelled as a single-currency multifactor Hull-White model. For each spot foreign exchange rate, spot equity price, and inflation index, the log-normal model is used. (Each exchange rate, each spot equity price, and each inflation index is modelled with one driving factor.) For credit modelling, the dynamics of the hazard rate for each credit name is modelled by a single-factor log-normal Black-Karasinski model.

This model also supports derived inflation indexes. A derived inflation index has the same driving factors as a core inflation index and inflation index rate curve, but has different inflation index and inflation rate curve starting values.

For information about the methodology of the CR_EQ_FX_IF_IR_HW_NF_BK_1F model, see the following chapter in *Markit Analytics Model Framework Mathematical Reference*: “Hybrid Credit Equity Inflation Multi-Currency Model with Multi-Factor Hull-White Models for Interest Rates and Single Factor Black-Karasinski Models for Hazard Rates”.

9.1 Module (CR_EQ_FX_IF_IR_HW_NF_BK_1F)

The Model Framework module that implements the hybrid credit equity inflation multicurrency extension of the multifactor Hull-White interest rate model (CR_EQ_FX_IF_IR_HW_NF_BK_1F) is as follows:

```
quic_model_cr_eq_fx_if_ir_hw_nf_bk_1f:3.0
```

Combine this module name with the module component names identified in this chapter to form a complete module reference. For example, if the component is `QModel_CR_EQ_FX_IF_IR_HW_NF_BK_1F`, the complete module reference is as follows:

```
QModel_CR_EQ_FX_IF_IR_HW_NF_BK_1F@quic_model_cr_eq_fx_if_ir_hw
_nf_bk_1f:3.0
```

9.2 Market Data Generator Parameters (CR_EQ_FX_IF_IR_HW_NF_BK_1F)

A market data generator parameters set for the Model Framework market data generator includes certain parameters whose value depends on the particular model. These include some parameters that are used directly by the generator itself and others that are used only by the Model Framework model that it invokes (in particular by the model's simulator component). For descriptions of the direct generator parameters, see the *Markit Analytics Simulation Framework User Guide*. The parameters that are used by Model Framework simulators are described in "Model Framework Simulator Settings" on page 28.

Some of the simulator settings are used by all models and others are used only by certain models. For the latter subset of settings, the information below shows which ones are used by this model.

Generator Parameter: `strSimulatorMFWKReference`

The parameter `strSimulatorMFWKReference` specifies the simulator plug-in for the model. The following values of this parameter are available for the CR_EQ_FX_IF_IR_HW_NF_BK_1F model:

- Simulation algorithm under the risk-neutral measure:

  ```
  QMCSimulator_CR_EQ_FX_IF_IR_HW_NF_BK_1F_RNM@quic_model_cr_eq_f
  x_if_ir_hw_nf_bk_1f:3.0
  ```

- Euler simulation algorithm under the risk-neutral measure:

  ```
  QMCSimulator_CR_EQ_FX_IF_IR_HW_NF_BK_1F_RNM_Euler@quic_model_c
  r_eq_fx_if_ir_hw_nf_bk_1f:3.0
  ```

Applicability of Simulator Settings

The following table identifies which simulator plug-ins (if any) support the specified simulator settings.

Table 9.1 Support for Simulator Settings (CR_EQ_FX_IF_IR_HW_NF_BK_1F)

Parameter	Simulators That Support the Parameter
bStepOnDFDates	QMCSimulator_CR_EQ_FX_IF_IR_HW_NF_BK_1F_RNM
bPrecalculateCovariances	QMCSimulator_CR_EQ_FX_IF_IR_HW_NF_BK_1F_RNM
bUseEigenSym and bUsePCA	QMCSimulator_CR_EQ_FX_IF_IR_HW_NF_BK_1F_RNM
bCholesky	Not applicable
strDecomposition	QMCSimulator_CR_EQ_FX_IF_IR_HW_NF_BK_1F_RNM
bUseStartEndNumeraireCalc	QMCSimulator_CR_EQ_FX_IF_IR_HW_NF_BK_1F_RNM
bUseForeignQuantoAdjustment	Not applicable
bUseDeterministicFXDrifts	Not applicable
bUseDeterministicInflationDrifts	Not applicable
bApproximateXIntegral	Not applicable

9.3 Model Preferences (CR_EQ_FX_IF_IR_HW_NF_BK_1F)

You specify the settings for the model in a model preferences map and in the subsidiary maps that it references. For a general description of a model preferences map, see “Model Preferences Map” on page 32.

9.3.1 Components (CR_EQ_FX_IF_IR_HW_NF_BK_1F)

The following table identifies the available plug-ins (components of the CR_EQ_FX_IF_IR_HW_NF_BK_1F module) that implement the model. You specify these as values of members of the model preferences map in the form of full module references.

Table 9.2 Model Plug-In Components (CR_EQ_FX_IF_IR_HW_NF_BK_1F)

Model Preference	Available Components of the Module
Model	QModel_CR_EQ_FX_IF_IR_HW_NF_BK_1F

Table 9.2 Model Plug-In Components (CR_EQ_FX_IF_IR_HW_NF_BK_1F)

Model Preference	Available Components of the Module
CalibrationMethod	One of: • QModelCalibration_CR_EQ_FX_IF_IR_HW_1F_BK_1F For internal calibration. • QModelCalibration_CR_EQ_FX_IF_IR_HW_NF_BK_1F_ExtCal For external calibration. Supports time-varying parameters.
DataExtractionMethod	One of: • QDataExtraction_CR_EQ_FX_IF_IR_HW_1F_BK_1F For internal calibration. • QDataExtraction_CR_EQ_FX_IF_IR_HW_NF_BK_1F_ExtCal For external calibration.

In addition, you must specify the maps that are identified by the other members of the model preferences map. The remainder of this chapter defines these subsidiary maps.

Example

The following figure shows a sample model preferences map that specifies components for this model. In the model preferences file, each map member occupies a single line.

```
CR_EQ_FX_IF_IR_HW_NF_ModelPrefs, {
  Model, S, QModel_CR_EQ_FX_IF_IR_HW_NF_BK_1F@quic_model_cr_eq_fx_if_ir_hw_nf_bk_1f:3.0
  CalibrationMethod, S,
   QModelCalibration_CR_EQ_FX_IF_IR_HW_1F_BK_1F@quic_model_cr_eq_fx_if_ir_hw_nf_bk_1f:3.0
  CalibrationSettings, L, CR_EQ_FX_IF_IR_HW_NF_CalibrationSettings
  CurveNames, L, CR_EQ_FX_IF_IR_HW_NF_CurveNames
  DataExtractionMethod, S,
   QDataExtraction_CR_EQ_FX_IF_IR_HW_1F_BK_1F@quic_model_cr_eq_fx_if_ir_hw_nf_bk_1f:3.0
  DataExtractionSettings, L, CR_EQ_FX_IF_IR_HW_NF_DataExtractionSettings
  TradeInfo, L, PORTFOLIO_INFO
}
```

9.3.2 Calibration Settings (CR_EQ_FX_IF_IR_HW_NF_BK_1F)

The CalibrationSettings member of the model preferences map refers to another map that specifies parameters related to calibration of the model.

The parameters of the IR, FX, equity, and inflation models can be calibrated either internally or externally. For external calibration, the resulting model parameters are treated as inputs. For internal calibration, a single-currency single-factor Hull-White model is used for the nominal interest rate for each currency. The spread between the nominal and real interest rates of each currency is also modelled as a single-currency single-factor Hull-While model. The inflation index volatilities can be calibrated against inflation index options similar to the spot FX rate volatilities.

The credit model is calibrated internally to the market data to reproduce the initial CDS prices.

The table below defines the members of a calibration settings map for the CR_EQ_FX_IF_IR_HW_NF_BK_1F model. The descriptions of these parameters use the following notation:

- H is the number of currencies. Hence, H–1 is the number of exchange rates.
- E is the number of equities.
- I is the number of inflation indexes.
- C is the number of credit names.
- K is the number of factors in the interest rate and inflation model.

The symbols in the Equation Symbol column refer to the Markit Analytics methodology paper *Hybrid Credit Equity Inflation Multi-Currency Model with Multi-Factor Hull-White Models for Interest Rates and Single Factor Black-Karasinski Models for Hazard Rates*.

Table 9.3 Calibration Settings Map for CR_EQ_FX_IF_IR_HW_NF_BK_1F

Map Key	Type Code	Description	Constraints	Default Value	Equation Symbol
The inputs in this section are common to all the calibration methods.					
`astrCCY`	AS	Names of the H currencies. The first name is the domestic currency.	Standard 3-character currency identifiers		
`astrEquity`	AS	Names of the E equities.			
`astrEquityCCY`	AS	Names of the E currencies, corresponding to the equities in `astrEquity`.	Standard 3-character currency identifier. All names must be present in `astrCCY`.		
`astrName`	AS	Credit names.	Number of elements must be C.		
`arRecoveryRate`	AR	(Optional) Recovery rates to use for each credit name. Overrides the recovery rate attribute of the input par credit spread curves (if provided).	Number of elements must be C.	If a survival probability curve is input for a name, the value defaults to 0.4.	
`rDaysPerAnnumCR`	R	Number of days per annum to convert the credit model parameters specified in `arKappa` and `aoSigma`, to daily units.		365.25 [dy]	
`arKappa`	AR	Mean reversion parameters for the hazard rates simulation.	Number of elements must be C.		κ_m

Table 9.3 Calibration Settings Map for CR_EQ_FX_IF_IR_HW_NF_BK_1F (Continued)

Map Key	Type Code	Description	Constraints	Default Value	Equation Symbol
aoSigma	AR or AL	Volatility parameters for the hazard rates simulation. Can be provided in either of the following formats. • Array of C real values. Each element specifies the constant volatility for one credit name. • Array of C names of lists of type AR. Each list specifies the piece-wise constant volatility for one credit name for the tenor points provided in aanTTMSigma.	Referenced lists (in the AL case) must exist in the model preferences file.		η_m^{CR}
aanTTMSigma	AL	Array of C names of lists of types AN. Each list specifies the tenor points (in units specified by strSigmaTTMUnits) for the volatility provided in aoSigma for one credit name. Omit this input if you specify constant volatilities.			
strSigmaTTMUnits	S	Units of the tenors of the hazard rate volatility parameter specified by aanTTMSigma.	One of: • months • days	months	
astrII	AS	Names of the I inflation indexes.			
astrIICCY	AS	Names of the I currencies, corresponding to the inflation indexes in astrII.	Standard 3-character currency identifier. All names must be present in astrCCY.		
astrIIDerived	AS	(Optional) Names of the derived inflation indexes.			
astrIIDerivedFrom	AS	(Optional) Names of the core inflation indexes on which the derived indexes are based, one for each derived index. Required if astrIIDerived is specified.	All names must be present in astrII.		
bCorrectCorrMtx	B	Whether to ensure that the input correlation matrix is positive semidefinite by using principal components analysis.	One of: • TRUE • FALSE	TRUE	

Table 9.3 Calibration Settings Map for CR_EQ_FX_IF_IR_HW_NF_BK_1F (Continued)

Map Key	Type Code	Description	Constraints	Default Value	Equation Symbol
`rEigenThreshold`	R	If `bCorrectCorrMtx` is TRUE, all eigenvectors associated with eigenvalues less than this threshold times the largest eigenvalue are set to zero.		1e-15	
`strModelParametersOutputFile`	S	(Optional) File path of the HDF5 file to which the calculated model parameters are written. This file has the same format as a file for externally calibrated parameters. Typically used only for troubleshooting. If omitted, no file is produced.			
`strModelParametersOutputName`	S	(Optional) Name to give this model parameters set in the file specified by `strModelParametersOutputFile`.		`mpModelParams`	
`bOutputCalibrationData`	B	Whether to include the calibration data in the HDF5 file specified by `strModelParametersOutputFile`. Typically used only for troubleshooting because it may significantly increase the size of the file.	One of: • TRUE • FALSE	FALSE	
`ampCalibrationSettingsCR`	AL	Names of maps, one for each credit name, that specify credit calibration settings. For the definition of these maps, see "Credit Calibration Settings (CR_EQ_FX_IF_IR_HW_NF_BK_1F)" on page 164	Referenced maps must exist in the model preferences file. To use the defaults for all settings, provide an empty map.	An array of empty maps, one for each credit name.	
Use the inputs in this section only when `CalibrationMethod` is `QModelCalibration_CR_EQ_FX_IF_IR_HW_1F_BK_1F`					
`ampCalibrationSettingsIR`	AL	Names of maps, one for each model currency, that specify the IR calibration settings. For the definition of these maps, see "IR Calibration Settings (CR_EQ_FX_IF_IR_HW_NF_BK_1F)" on page 166.	Referenced maps must exist in the model preferences file. To use the defaults for all settings, provide an empty map.		

Table 9.3 Calibration Settings Map for CR_EQ_FX_IF_IR_HW_NF_BK_1F (Continued)

Map Key	Type Code	Description	Constraints	Default Value	Equation Symbol
ampCalibrationSettingsFX	AL	Names of maps, one for each foreign currency, that specify FX calibration settings. For the definition of these maps, see "FX Calibration Settings (CR_EQ_FX_IF_IR_HW_NF_BK_1F)" on page 168.	Referenced maps must exist in the model preferences file. To use the defaults for all settings, provide an empty map.		
ampCalibrationSettingsEQ	AL	Names of maps, one for each equity, that specify equity calibration settings. For the definition of these maps, see "Equity Calibration Settings (CR_EQ_FX_IF_IR_HW_NF_BK_1F)" on page 168.	Referenced maps must exist in the model preferences file. To use the defaults for all settings, provide an empty map.	An array of empty maps, one for each equity.	
ampCalibrationSettingsII	AL	Names of maps, one for each inflation index, that specify inflation index calibration settings. For the definition of these maps, see "Inflation Index Calibration Settings (CR_EQ_FX_IF_IR_HW_NF_BK_1F)" on page 169.	Referenced maps must exist in the model preferences file. To use the defaults for all settings, provide an empty map.	An array of empty maps, one for each inflation index.	
astrBasisCurve	AS	Nicknames of the interest rate curves used for additive LIBOR basis adjustment.	Include a nickname for each of the curves, in order, specified by the aBasisCurve member of the market data map.		
bOutputFitResults	B	Whether to report the results of the calibration (comparison of the prices of calibrating instruments from the calibrated model and calculated analytically from market data).	One of: • TRUE • FALSE	FALSE	
strOutputFile	S	(Optional) File path of the CSV file to which calibration results are written (if requested by bOutputFitResults).		Results are displayed in the audit pane only.	
Use the inputs in this section only when CalibrationMethod is QModelCalibration_CR_EQ_FX_IF_IR_HW_NF_BK_1F_ExtCal					
g1dtEta	GD	Ascending sequence of M+1 dates that define the intervals of the volatility functions.	The first date must be the calibration date.		

Table 9.3 Calibration Settings Map for CR_EQ_FX_IF_IR_HW_NF_BK_1F (Continued)

Map Key	Type Code	Description	Constraints	Default Value	Equation Symbol
`ag1rA`	AL	Names of lists (of type GR) that specify the mean-reversion parameters. Each list specifies the parameter for one currency.	Number of elements must be H. Referenced lists must exist in the auxiliary transaction data file.		$a_{k,i}$
`ag1rAlpha`	AL	Names of lists (of type GR) that specify the mean-reversion parameters for inflation spreads. Each list specifies the parameter for one spread between nominal and real interest rates for an inflation index.	Number of elements must be I. Referenced lists must exist in the auxiliary transaction data file.		$\alpha_{k,i}$
`ag2rEta`	AL	Names of lists (of type AL) for each currency. Each currency list specifies names of lists (of type GR) for each of its K factors. Each currency-factor list specifies the value of the IR volatility parameter (eta) in each of the M time intervals defined by `g1dtEta`. For a given currency-factor pair, the value in interval m applies from $\texttt{g1dtEta}_m$ up to but not including $\texttt{g1dtEta}_{m+1}$. The value in the last interval is also used on the last date and beyond the last date (constant extrapolation).	Number of elements must be H. Referenced lists must exist in the auxiliary transaction data file.		$\eta_{k,i}(t)$

Table 9.3 Calibration Settings Map for CR_EQ_FX_IF_IR_HW_NF_BK_1F (Continued)

Map Key	Type Code	Description	Constraints	Default Value	Equation Symbol
`ag2rNu`	AL	Names of lists (of type AL) for each spread between nominal and real interest rates for an inflation index. Each spread list specifies names of lists (of type GR) for each of its K factors. Each spread index-factor list specifies the value of the IR volatility parameter (eta) in each of the M time intervals defined by `g1dtEta`. For a given inflation index-factor pair, the value in interval m applies from `g1dtEta`$_m$ up to but not including `g1dtEta`$_{m+1}$. The value in the last interval is also used on the last date and beyond the last date (constant extrapolation).	Number of elements must be I. Referenced lists must exist in the auxiliary transaction data file.		$\nu_{k,i}(t)$
`ag1rEtaFX`	AL	Names of lists (of type GR) that specify, for each currency, the value of the FX volatility parameter (`eta`) in each of the M time intervals defined by `g1dtEta`. For a given currency, the value in interval m applies from `g1dtEta`$_m$ up to but not including `g1dtEta`$_{m+1}$. The value in the last interval is also used on the last date and beyond the last date (constant extrapolation).	Number of elements must be H–1. Referenced lists must exist in the auxiliary transaction data file.		$\eta_k^{FX}(t)$
`ag1rEtaEquity`	AL	Names of lists (of type GR) that specify, for each equity, the value of the volatility parameter (`eta`) in each of the M time intervals defined by `g1dtEta`. For a given equity, the value in interval m applies from `g1dtEta`$_m$ up to but not including `g1dtEta`$_{m+1}$. The value in the last interval is also used on the last date and beyond the last date (constant extrapolation).	Number of elements must be E. Referenced lists must exist in the auxiliary transaction data file.		$\eta_j^{EQ}(t)$

Table 9.3 Calibration Settings Map for CR_EQ_FX_IF_IR_HW_NF_BK_1F (Continued)

Map Key	Type Code	Description	Constraints	Default Value	Equation Symbol
`ag1rEtaIF`	AL	Names of lists (of type GR) that specify, for each inflation index, the value of the inflation index volatility parameter (eta) in each of the M time intervals defined by `g1dtEta`. For a given inflation index, the value in interval m applies from `g1dtEta`$_m$ up to but not including `g1dtEta`$_{m+1}$. The value in the last interval is also used on the last date and beyond the last date (constant extrapolation).	Number of elements must be I. Referenced lists must exist in the auxiliary transaction data file.		$\eta_k^I(t)$
`g3rCorrMtx`	AL	Names of lists (of type AL) for each factor. Each factor list specifies names of lists (of type GR) for each pairing with other factors. Each factor-pair list specifies the value of their pairwise correlation as a piecewise function of time over the intervals defined by `g1dtEta`. For a given pair of factors, the value in interval m applies from `g1dtEta`$_m$ up to but not including `g1dtEta`$_{m+1}$. The value in the last interval is also used on the last date and beyond the last date (constant extrapolation). For details, see the note that follows this table.	$-1 \leq \rho \leq 1$		$\rho(t)$

Note: Construction of g3CorrMtx

The correlations include those between the IR factors (within one currency and between the different currencies), FX factors, equity factors, hazard rate factors, factors of the spread between nominal and real interest rates, and inflation indexes.

Consider a 2-D slice of the g3CorrMtx grid along the eta axis (this is, for a given time). This 2-D factor correlation matrix is square and of length $\sum_{i=1}^{H} K_i + (H-1) + E + C + \sum_{j=1}^{I} K_j^I + I$ in each dimension. It is symmetric, so we consider the construction in only one dimension. Place the risk factors in the following order:

- K_1 factors of the interest rate for currency 1, then the K_2 factors of the interest rate for currency 2, and so on for the H currencies
- $(H–1)$ factors of the exchange rates
- E factors of the spot equity prices

- C factors of the hazard rates
- K_1^I factors of the spread between the nominal and real short rate for the first inflation index, then the K_2^I factors of the spread for the second inflation index, and so on for the I inflation indexes
- I factors of the inflation index

Example

This example uses the time-varying parameter calibration.

```
CR_EQ_FX_IF_IR_HW_NF_BK_1F_CallibrationSettings_ExtCal, {
  g1dtEta, GD, 2005/10/11, 2005/11/11
  astrCCY, AS, EUR, USD
  astrEquity, AS, SPX
  astrCCYEquity, AS, USD
  astrName, AS, CS1, CS2
  ag1rA, AL, g1rA_EUR, g1rA_USD
  ag2rEta, AL, ag1rEta_EUR, ag1rEta_USD
  ag1rEtaFX, AL, g1rEtaFX_USD
  ag1rEtaEquity, AL, g1rEtaEQ_USD
  arKappa, AR, 0.01
  aoSigma, AL, arSigma_CS1, arSigma_CS2
  aanTTMSigma, AL, arTTMSigma_CS1, arTTMSigma_CS2
  astrII, AS, I01
  ag1rAlpha, AL, g1rAlpha_I01
  ag2rNu, AL, ag1rNu_I01
  ag1rEtaIF, AL, g1rEtaIF_I01
  astrIICCY, AS, EUR
  astrIIDerived, AS, I01d1
  astrIIDerivedFrom, AS, I01
  g3rCorrMtx, AL
  ..., ag1rCorrMtx_EUR_factor0, ag1rCorrMtx_EUR_factor1
  ..., ag1rCorrMtx_EUR_factor2
  ..., ag1rCorrMtx_USD_factor0, ag1rCorrMtx_USD_factor1
  ..., ag1rCorrMtx_USD_factor2
  ..., ag1rCorrMtx_FX_Vol_USD
  ..., ag1rCorrMtx_SPX_Vol_USD
  ..., ag1rCorrMtx_CS1
  ..., ag1rCorrMtx_CS2
  ..., ag1rCorrMtx_I01_factor0, ag1rCorrMtx_I01_factor1
  ..., ag1rCorrMtx_I01_factor2
  ..., ag1rCorrMtx_II_Vol_I01
  bCorrectCorrMtx, B, FALSE
}
```

9.3.2.1 Credit Calibration Settings (CR_EQ_FX_IF_IR_HW_NF_BK_1F)

The `ampCalibrationSettingsCR` member of a calibration settings map refers to other maps that each specify settings for the calibration of the credit model for one credit name. The following table defines the members of a credit calibration settings map for the CR_EQ_FX_IF_IR_HW_NF_BK_1F model.

Table 9.4 Credit Calibration Settings Map for CR_EQ_FX_IF_IR_HW_NF_BK_1F

Map Key	Type Code	Description	Constraints	Default Value
`rMaxTimeStep`	R	Maximum time step in the tree calculation when calibrating a credit model.		10[dy]
`nBootStrapIter`	N	Number of bootstrap iterations to use when calibrating a credit model to CDS with correlations.		2
`bUseCreditCorrelations`	B	Whether to take into account credit correlations with IR risk factors when calibrating a credit model to CDS.	One of: • TRUE • FALSE	TRUE
`nMaxIterNR`	N	Maximum number of iterations in Newton-Raphson root finding when calibrating a credit model.		50
`rErrorTol`	R	Error tolerance in Newton-Raphson root finding when calibrating a credit model.		1e-15
`bPruneTree`	B	Whether to prune the tree in the tree calculation when calibrating a credit model.	One of: • TRUE • FALSE	TRUE
`rPruneStdDev`	R	Number of standard deviations to prune tree in the tree calculation when calibrating a credit model.		5
`astrInterpXi`	AS	Interpolation method to use for the calibrated parameter ξ ξ, one for each credit name.	See Table B.3 on page 328. Number of elements must be C.	`lin`
`astrExtrapXi`	AS	Extrapolation method to use for the calibrated parameter ξ ξ, one for each credit name.	See Table B.3 on page 328. Number of elements must be C.	`lin`

Example

```
CS1_CalibrationSettings, {
  rMaxTimeStep, R, 5[dy]
  rPruneStdDev, R, 3
}
```

9.3.2.2 IR Calibration Settings (CR_EQ_FX_IF_IR_HW_NF_BK_1F)

The `ampCalibrationSettingsIR` member of a calibration settings map refers to other maps that each specify settings for the calibration of the interest rate model for one currency. The following table defines the members of an IR calibration settings map for the CR_EQ_FX_IF_IR_HW_NF_BK_1F model.

Table 9.5 IR Calibration Settings Map for CR_EQ_FX_IF_IR_HW_NF_BK_1F

Map Key	Type Code	Description	Constraints	Default Value
strCCYDom	S	Name of the domestic currency.	Standard 3-character currency identifier	
bUseCapletFormula	B	Whether to use the caplet formula. If set to TRUE, but the input calibrating instruments are swaptions, this setting reverts to FALSE.	One of: • TRUE • FALSE	FALSE
rNotional	R	Notional amount to use when calculating prices during calibration.		1.0
mpRootFindSettings	L	Name of a map of settings for the root-finding procedure.	Referenced map must exist in the model preferences file.	Empty map
bAllowNegativeMR	B	Whether to allow the calibration process to generate a negative mean reversion parameter.	One of: • TRUE • FALSE	FALSE
strBasisCurveCalib	S	(Optional) Nickname of the interest rate curve to use for additive LIBOR basis adjustment during calibration. If omitted, the LIBOR basis adjustment is not performed.	Must be one of the names in `astrBasisCurve` in the main calibration settings map.	
bUseBasisCurveForCalibDiscounting	B	Whether to use the basis curve, if specified by `strBasisCurveCalib`, for both discounting and forecasting in the calibration (TRUE) or just for forecasting (FALSE).	One of: • TRUE • FALSE	FALSE
strBasisCurveCalibDisc	S	(Optional) Nickname of the interest rate curve to use for discounting during calibration. Ignored if `bUseBasisCurveForCalibDiscounting` is set to TRUE.	Must be one of the names in `astrBasisCurve` in the main calibration settings map.	Interest rate curve for the currency of this map, specified by the market data map member `aIRCurve`.
bNormalVolatilities	B	Whether to assume normal (TRUE) or log-normal (FALSE) volatilities.	One of: • TRUE • FALSE	FALSE

Example

```
IR_EUR_CalibrationSettings, {
  strBasisCurveCalib, S, EURLibor3M
}
```

9.3.2.2.1 Root-Finding Settings (CR_EQ_FX_IF_IR_HW_NF_BK_1F)

The `mpRootFindSettings` member of an IR calibration settings map refers to another map that specifies settings for the root-finding process. Most of these settings specify various numerical tolerances. Normally, the default values are suitable.

The following table defines the members of a root-finding settings map for the CR_EQ_FX_IF_IR_HW_NF_BK_1F model.

Table 9.6 Root-Finding Settings Map for CR_EQ_FX_IF_IR_HW_NF_BK_1F

Map Key	Type Code	Description	Constraints	Default Value
`rVolSensTol`	R	Volatility sensitivity tolerance		0.001
`rSigmaConst`	R	Sigma used in initial guess for root find (units are per annum). If all calibrating instruments are removed, this value is used as the Hull-White volatility parameter.		0.01
`rErrorTol`	R	Error tolerance for root find to match market prices.		1.0e–14
`rRelTolNR`	R	Relative tolerance in Newton-Raphson method for root find to match market prices.		1.0e–13
`nMaxIterNR`	N	Maximum number of iterations in Newton-Raphson method for root find to match market prices.		100
`nMaxIterBracket`	N	Maximum number of iterations used in bracketing for root find to match market prices.		20
`rBracketLow`	R	Low value for bracketing for root find to match market prices.		1.0e–10
`rBracketHigh`	R	High value for bracketing for root find to match market prices.		1.0e–1
`nMaxDiv`	N	Maximum number of divisions in bisection for root find to match market prices.		100
`rRootGuessJam`	R	Initial guess for root in Jamshidian decomposition.		0.0
`rErrorTolJam`	R	Error tolerance in Jamshidian decomposition.		1.0e–13

Table 9.6 Root-Finding Settings Map for CR_EQ_FX_IF_IR_HW_NF_BK_1F

Map Key	Type Code	Description	Constraints	Default Value
`rRelTolNRJam`	R	Relative tolerance in Newton-Raphson method for root find in Jamshidian decomposition.		1.0e–15
`nMaxIterNRJam`	N	Maximum number of iterations in Newton-Raphson method for root find in Jamshidian decomposition.		100
`rMinXJam`	R	Minimum X value in bracketing for Jamshidian decomposition.		–0.1
`rMaxXJam`	R	Maximum X value in bracketing for Jamshidian decomposition.		0.1
`nMaxDivJam`	N	Maximum number of iterations in bisection for root find in Jamshidian decomposition.		100

9.3.2.3 FX Calibration Settings (CR_EQ_FX_IF_IR_HW_NF_BK_1F)

The `ampCalibrationSettingsFX` member of a calibration settings map refers to other maps that each specify settings for the calibration of the exchange rate model for one pair of currencies. The following table defines the members of an FX calibration settings map for the CR_EQ_FX_IF_IR_HW_NF_BK_1F model.

Table 9.7 FX Calibration Settings Map for CR_EQ_FX_IF_IR_HW_NF_BK_1F

Map Key	Type Code	Description	Constraints	Default Value
`bUseNegativeSpotVols`	B	Whether to add negative FX spot volatilities to the calibrated values during the calibration procedure.	One of: • TRUE • FALSE	FALSE

Example

```
UseNegativeSpotFXVols, {
  bUseNegativeSpotVols, B, TRUE
}
```

9.3.2.4 Equity Calibration Settings (CR_EQ_FX_IF_IR_HW_NF_BK_1F)

The `ampCalibrationSettingsEQ` member of a calibration settings map refers to other maps that each specify settings for the calibration of the equity model for

one equity. The following table defines the members of a calibration settings map for the CR_EQ_FX_IF_IR_HW_NF_BK_1F model.

Table 9.8 Equity Calibration Settings Map for CR_EQ_FX_IF_IR_HW_NF_BK_1F

Map Key	Type Code	Description	Constraints	Default Value
`bUseNegativeSpotVols`	B	(Optional) Whether to add negative equity spot volatilities to the calibrated values during the calibration procedure.	One of: • TRUE • FALSE	FALSE

Example

```
UseNegativeSpotEQVols, {
  bUseNegativeSpotVols, B, TRUE
}
```

9.3.2.5 Inflation Index Calibration Settings (CR_EQ_FX_IF_IR_HW_NF_BK_1F)

The `ampCalibrationSettingsII` member of a calibration settings map refers to other maps that each specify settings for the calibration of the inflation index model for one inflation index. The following table defines the members of a calibration settings map for the CR_EQ_FX_IF_IR_HW_NF_BK_1F model.

Table 9.9 Inflation Index Calibration Settings Map for CR_EQ_FX_IF_IR_HW_NF_BK_1F

Map Key	Type Code	Description	Constraints	Default Value
`bCalibrateToIIOptions`	B	Whether to calibrate inflation index volatilities from inflation index options. If set to FALSE in any of the inflation index calibration settings maps, you must provide `aSpotIIVolCurve` in the Market Data Map. If set to TRUE in any of the inflation index calibration settings maps, you must provide `aSpotIIImpliedVolCurve` in the Market Data Map.	One of: • TRUE • FALSE	TRUE
`bUseNegativeSpotVols`	B	(Optional) Whether to add negative inflation index spot volatilities to the calibrated values during the calibration procedure. This input applies only when `bCalibrateToIIOptions` is set to TRUE.	One of: • TRUE • FALSE	FALSE

Example

```
SampleIICalibrationSettings, {
  bCalibrateToIIOptions, B, TRUE
  bUseNegativeSpotVols, B, TRUE
}
```

9.3.3 Market Data Inputs (CR_EQ_FX_IF_IR_HW_NF_BK_1F)

The CurveNames member of the model preferences map refers to a market data map that identifies the market data curves that are required for pricing, simulation, and if applicable, internal model calibration. The following table defines the members of a market data map for the CR_EQ_FX_IF_IR_HW_NF_BK_1F model.

Table 9.10 Market Data Map for CR_EQ_FX_IF_IR_HW_NF_BK_1F

Map Key	Type Code	Description	Constraints	Default Value
aIRCurve	AS or AL	Either: • Names of curves for discounting (of type DiscountFactor, Yield, or FwdLibor), one for each currency. • Names of lists that specify a set of curves to use in bootstrapping the discount factor, one for each currency. The first curve or list of curves is for the domestic currency, and the remainder are for the foreign currencies. For details about the lists of curves for bootstrapping, see "Specifying the Data to Use in Bootstrapping" on page 34.	Referenced curves must exist in the market data HDF5 file, or referenced lists must exist in an auxiliary transaction data file. The number of elements must equal the number of currencies. Ordinates of a Yield curve must be >0.	
aINFCurve	AS	Names of curves (of type DiscountFactor, Yield, or InflationRate) that specify the inflation-bond-related interest rate for each currency, in the same order as the inflation indexes.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of inflation indexes. Ordinates of a Yield curve must be >0.	

Table 9.10 Market Data Map for CR_EQ_FX_IF_IR_HW_NF_BK_1F (Continued)

Map Key	Type Code	Description	Constraints	Default Value
aSpotIICurve	AS	Names of curves (of type InflationIndex) that specify the inflation index for each currency, in the same order as the inflation indexes. Must be provided when bCalibrateToIIOptions is set to TRUE in the inflation index calibration settings map.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of inflation indexes.	
aINFDerivedCurve	AS	(Optional) Names of curves (of type Yield) that specify the inflation-bond-related interest rate for the currency of each derived inflation index, in the same order in which the indexes are listed in the astrIIDerived parameter in the calibration settings map. Required if the astrIIDerived parameter is specified in the calibration settings map.	Referenced curves must exist in the market data HDF5 file. The number of elements in the array must equal the number of inflation indexes. Ordinates of a Yield curve must be >0.	
aSpotIIDerivedCurve	AS	(Optional) Names of curves (of type InflationIndex) that specify the initial value of each derived inflation index, in the same order in which the indexes are listed in the astrIIDerived parameter in the calibration settings map. Required if the astrIIDerived parameter is specified in the calibration settings map.	Referenced curves must exist in the market data HDF5 file. The number of elements in the array must equal the number of derived indexes.	
aSpotFXCurve	AS	Names of domestic/foreign spot FX curves (of type Exchange), one for each currency, in the same order as the IR curves.	The first name, corresponding to the domestic currency, must be void. Referenced curves must exist in the market data HDF5 file.	
aSpotEQCurve	AS	Names of spot equity curves (of type Equity or EquityIndex), one for each equity, in the same order as the equities.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of equities.	
aEQDividendCurve	AS	Names of equity dividend curves (of type DiscreteAbsoluteDividend or ContinuousYieldDividend), one for each equity, in the same order as the equities.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of equities.	

Table 9.10 Market Data Map for CR_EQ_FX_IF_IR_HW_NF_BK_1F (Continued)

Map Key	Type Code	Description	Constraints	Default Value
aCreditCurve	AS	Names of the CDS curves (of type ParCreditSpread), one for each credit name, in the same order as the credit names.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of credit names.	
Use the inputs in this section only when DataExtractionMethod is QDataExtraction_CR_EQ_FX_IF_IR_HW_1F_BK_1F				
aINFMeanReversionCurve	AS	Names of mean reversion curves (of type MeanReversion), one for the spread between nominal and real interest rates for each currency, in the same order as the inflation indexes.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of currencies.	
aINFVolCurve	AS	Names of volatility curves (of type ImpliedVol), one for the spread between nominal and real interest rates for each currency, in the same order as the inflation indexes.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of currencies.	
aSpotIIVolCurve	AS	Names of inflation index volatility curves (of type ImpliedVol), one for each inflation index, in the same order as the inflation indexes. Must be provided when bCalibrateToIIOptions is set to FALSE in the inflation index calibration settings map.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of inflation indexes.	
aSpotIIImpliedVolCurve	AS	Names of inflation index option implied volatility curves (of type ImpliedVol), one for each inflation index, in the same order as the inflation indexes. Must be provided when bCalibrateToIIOptions is set to TRUE in the inflation index calibration settings map.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of inflation indexes.	
aBasisCurve	AS	Names of curves (of type DiscountFactor, Yield, or FwdLibor) that specify the forecasting interest rates to use for LIBOR basis adjustments for all relevant currencies.	Referenced curves must exist in the market data HDF5 file. Ordinates of a Yield curve must be >0.	
aMeanReversionCurve	AS	Names of mean reversion curves (of type MeanReversion), one for each currency, in the same order as the IR curves.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of currencies.	

Table 9.10 Market Data Map for CR_EQ_FX_IF_IR_HW_NF_BK_1F (Continued)

Map Key	Type Code	Description	Constraints	Default Value
`aCapletVolCurve`	AS	Names of caplet volatility curves (of type `CapletVol`), one for each currency, in the same order as the IR curves. Each currency must have either a caplet volatility curve or a swaption volatility curve. A value can be `void` if the model for that currency is calibrated to swaption volatilities.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of currencies.	
`aSwaptionVolCurve`	AS	Names of swaption volatility curves (of type `SwaptionVolMtx`), one for each currency, in the same order as the IR curves. Each currency must have either a caplet volatility curve or a swaption volatility curve. A value can be `void` if the model for that currency is calibrated to caplet volatilities.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of currencies.	
`aFXImpliedVolCurve`	AS	Names of FX option volatility curves (of type `ImpliedVol`), one for each spot FX rate, in the same order as the FX curves. The first name, matching the domestic currency itself, can be left blank.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of currencies.	
`aEQImpliedVolCurve`	AS	Names of equity option volatility curves (of type `EquityImpliedVol` or `ImpliedVol`), one for each spot equity, in the same order as the equity curves.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of equities.	
`aCorrelationCurve`	AS	Names of correlation curves (of type `CorrelBlock`) that give the correlations between model risk factors. For more detail, see the description that follows this table.	Referenced curves must exist in the market data HDF5 file.	

Correlation Curves

Construct the correlation curves specified by `aCorrelationCurve` according to the following scheme:

- A model with n currencies, e equities, c credit names, and m inflation indexes, has $2n–1+e+c+2m$ risk factors: n interest rate risk factors and $n–1$ FX risk factors, e equity risk factors, c credit risk factors, m spread risk factors associated with inflation indexes, and m inflation index risk factors.
- Let R_i be the risk factors of the model.
- The n risk factors from $i=0$ to $i=n–1$ are the interest rate risk factors in the same order as the IR curves.
- The $n–1$ risk factors from $i=n$ to $i=2n-2$ are the FX risk factors in the same order as the spot FX curves (omitting the first which is trivial).

- The e risk factors from i=2n–1 to i=2n+e–2 are the equity risk factors in the same order as the spot equity curves.
- The c risk factors from i=2n+e–1 to i=2n+e+c–2 are the credit risk factors in the same order as the credit spread curves.
- The m risk factors from i=2n+e+c–1 to i=2n+e+c+m–2 are the spread risk factors in the same order as the inflation indexes.
- The m risk factors from i=2n+e+c+m–1 to i=2n+e+c+2m–2 are the inflation index risk factors in the same order as the inflation indexes.
- The first 2n+e+c+2m–2 correlations are the correlations between R_0 and R_1,..., $R_{2n+e+c+2m-2}$.
- The next 2n+e+c+2m–3 correlations are the correlations between R_1 and R_2,..., $R_{2n+e+c+2m-2}$.
- The next 2n+e+c+2m–4 correlations are the correlations between R_2 and R_3,..., $R_{2n+e+c+2m-2}$, and so on.

Example

```
CR_EQ_FX_IF_IR_HW_1F_BK_1F_CurveNames_, {
  aIRCurve, AS, EUR.Yield.EUR, USD.Yield.USD
  aINFCurve, AS, EUR_INF.Yield.EUR
  aSpotIICurve, AS, I_EUR.InflationIndex.EUR
  aSpotFXCurve, AS, void, USD.Exchange.EUR
  aSpotEQCurve, AS, SPX.EquityIndex.USD
  aCreditCurve, AS, CS1.ParCreditSpread.USD, CS2.ParCreditSpread.EUR
  aINFMeanReversionCurve, AS, IRR.MeanReversion.EUR
  aINFVolCurve, AS, IRR.ImpliedVol.EUR
  aSpotIIVolCurve, AS, IIVol.ImpliedVol.EUR
  aSpotIIImpliedVolCurve, AS, IIImplied.ImpliedVol.EUR
  aMeanReversionCurve, AS, EURMR.MeanReversion.EUR, USDMR.MeanReversion.USD
  aSwaptionVolCurve, AS, SemiannualSwapVol.SwaptionVolMtx.EUR
  ..., SemiannualSwapVol.SwaptionVolMtx.USD
  aFXImpliedVolCurve, AS, void, USD.ImpliedVol.EUR
  aEQImpliedVolCurve, AS, void, SPX.ImpliedVol.USD
  aCorrelationCurve, AS
  ..., ShortRateUSD.CorrelBlock.ShortRateEUR
  ..., ShortRateUSD.CorrelBlock.SpotFXEUR
  ..., ShortRateUSD.CorrelBlock.SPX
  ..., ShortRateUSD.CorrelBlock.CS1
  ..., ShortRateUSD.CorrelBlock.CS2
  ..., ShortRateUSD.CorrelBlock.IRREUR
  ..., ShortRateUSD.CorrelBlock.IIEUR
  ..., ShortRateEUR.CorrelBlock.SpotFXEUR
  ..., ShortRateEUR.CorrelBlock.SPX
  ..., ShortRateEUR.CorrelBlock.CS1
  ..., ShortRateEUR.CorrelBlock.CS2
  ..., ShortRateEUR.CorrelBlock.IRREUR
  ..., ShortRateEUR.CorrelBlock.IIEUR
  ..., SpotFXEUR.CorrelBlock.SPX
  ..., SpotFXEUR.CorrelBlock.CS1
  ..., SpotFXEUR.CorrelBlock.CS2
  ..., SpotFXEUR.CorrelBlock.IRREUR
  ..., SpotFXEUR.CorrelBlock.IIEUR
  ..., SPX.CorrelBlock.CS1
  ..., SPX.CorrelBlock.CS2
  ..., SPX.CorrelBlock.IRREUR
  ..., SPX.CorrelBlock.IIEUR
  ..., CS1.CorrelBlock.CS2
  ..., CS1.CorrelBlock.IRREUR
```

```
  ..., CS1.CorrelBlock.IIEUR
  ..., CS2.CorrelBlock.IRREUR
  ..., CS2.CorrelBlock.IIEUR
  ..., IRREUR.CorrelBlock.IIEUR
}
```

9.3.4 Data Extraction Settings (CR_EQ_FX_IF_IR_HW_NF_BK_1F)

The `DataExtractionSettings` member of the model preferences map refers to another map that specifies parameters for the data extraction process. The following table defines the members of a data extraction settings map for the CR_EQ_FX_IF_IR_HW_NF_BK_1F model.

Table 9.11 Data Extraction Settings Map for CR_EQ_FX_IF_IR_HW_NF_BK_1F

Map Key	Type Code	Description	Constraints	Default Value
`ampIRCurveSettings`	AL	Names of maps, one for each model currency, that specify settings for extracting interest rates. For the definition of these maps, see "Interest Rate Extraction Settings Map" on page 35.	Referenced maps must exist in the model preferences file. To use the defaults for all settings, provide an empty map.	An array of empty maps, one for each currency.
`ampBasisCurveSettings`	AL	Names of maps of settings for the basis data extraction, one for each interest rate curve specified by `aBasisCurve` in the market data map. The settings in these maps are listed in "Interest Rate Extraction Settings Map" on page 35.	Referenced maps must exist in the model preferences file.	The settings specified by `ampIRCurveSettings` are used.
`ampIFCurveSettings`	AL	Names of maps, one for each inflation index, that specify the settings for extracting the inflation-bond-related interest rate. In the current release, inflation index data extraction has no settings.	Referenced maps must exist in the model preferences file.	An array of empty maps, one for each inflation index.
`bExtrapolateDF`	B	Controls whether to extrapolate discount factors and inflation discount factors.	One of: • TRUE • FALSE	FALSE
`nMonthsExtrapDFEnd`	N	Number of months after the calibration date in which to extrapolate the discount factors.		0
`aidxCDSCCY`	AN	Index of the CDS currency for each credit name.	Integers between 0 and the number of foreign currencies of the model.	0

Table 9.11 Data Extraction Settings Map for CR_EQ_FX_IF_IR_HW_NF_BK_1F (Continued)

Map Key	Type Code	Description	Constraints	Default Value
bUseMFWKStripper	B	Whether to use the model's internal survival probability bootstrapper (TRUE), or the external generic survival probability bootstrapper (FALSE).	One of: • TRUE • FALSE	TRUE
ampSettingsCDS	AL	Names of maps, one for each credit name, that specify credit data extraction settings for purposes of calibration. For the definition of these maps, see "CR Calibration Data Extraction Settings (CR_EQ_FX_IF_IR_HW_NF_BK_1F)" on page 177.	Referenced maps must exist in the model preferences file. To use the defaults for all settings, provide an empty map.	An array of empty maps, one for each credit name.
Use the inputs in this section only when DataExtractionMethod is QDataExtraction_CR_EQ_FX_IF_IR_HW_1F_BK_1F				
ampDataExtractionSettingsIR	AL	Names of maps, one for each model currency, that specify IR data extraction settings for purposes of calibration. For the definition of these maps, see "IR Calibration Data Extraction Settings (CR_EQ_FX_IF_IR_HW_NF_BK_1F)" on page 188.	Referenced maps must exist in the model preferences file. To use the defaults for all settings, provide an empty map.	
ampDataExtractionSettingsFX	AL	Names of maps, one for each foreign currency, that specify FX data extraction settings for purposes of calibration. In the current release, FX calibration data extraction has no settings.	Referenced maps must exist in the model preferences file.	An array of empty maps, one for each foreign currency.
ampDataExtractionSettingsEQ	AL	Names of maps, one for each equity, that specify equity data extraction settings for purposes of calibration. In the current release, equity calibration data extraction has no settings.	Referenced maps must exist in the model preferences file.	An array of empty maps, one for each equity.
ampDataExtractionSettingsII	AL	Names of maps, one for each inflation index, that specify inflation index data extraction settings for purposes of calibration. In the current release, inflation index calibration data extraction has no settings.	Referenced maps must exist in the model preferences file.	An array of empty maps, one for each inflation index.

Example

```
CR_EQ_FX_IF_IR_HW_NF_BK_1F_DataExtractionSettings, {
  ampDataExtractionSettingsIR, AL, Swaption_DataExtractionSetting
  ampSettingsCDS, AL, CS1_mpSettingsCDS, CS2_mpSettingsCDS
  aidxCDSCCY, AN, 1, 1
  bExtrapolateDF, B, TRUE
  nMonthsExtrapDFEnd, N, 10
}
```

9.3.4.1 CR Calibration Data Extraction Settings (CR_EQ_FX_IF_IR_HW_NF_BK_1F)

The `ampDataExtractionSettingsCR` member of the data extraction settings map refers to other maps that each specify settings for CR calibration data extraction for one credit name.

You can choose whether to use the model's internal survival probability bootstrapper (`bUseMFWKStripper` = TRUE), or the external generic survival probability bootstrapper (`bUseMFWKStripper` = FALSE).

The model's internal survival probability bootstrapper uses the assumption that defaults occur at the mid-points of each coupon period.

For information about the methodology of the external bootstrapper, see the following Markit Analytics document: *CDS Pricing and Bootstrapping Methodology Notes*.

The sections below define the data extraction settings maps for the internal and external survival probability bootstrappers.

9.3.4.1.1 With the Internal Survival Probability Bootstrapper

The following table defines the members of a CR calibration data extraction settings map for the CR_EQ_FX_IF_IR_HW_NF_BK_1F model when you use the model's internal survival probability bootstrapper.

Table 9.12 CR Calibration Data Extraction Settings Map for CR_EQ_FX_IF_IR_HW_NF_BK_1F (Internal Survival Probability Bootstrapper)

Map Key	Type Code	Description	Constraints	Default Value
`bUseIMMDates`	B	Whether to use IMM dates. If TRUE and the calibration date is not an IMM date, the CDS maturity is taken to be from the next IMM date.	One of: • TRUE • FALSE	TRUE
`bRoundMidPointToNearestDay`	B	Whether to round the coupon period mid points, calculated for accrued interest, to the nearest day.	One of: • TRUE • FALSE	TRUE
`bUseYearFracForAccInt`	B	Whether to use the year fraction in the calculation of the accrued interest using midpoint approximation.	One of: • TRUE • FALSE	TRUE

Table 9.12 CR Calibration Data Extraction Settings Map for CR_EQ_FX_IF_IR_HW_NF_BK_1F (Internal Survival Probability Bootstrapper) (Continued)

Map Key	Type Code	Description	Constraints	Default Value
rDaysPerAnnumAccInt	R	Number of days per annum in the calculation of the accrued interest using midpoint approximation, if bUseYearFracForAccInt is FALSE.		365.25[dy]
rFwdHazardRateFloor	R	Floor value for the forward hazard rate in bootstrapping.		1e-5
bAccInt	B	Whether to use the accrued interest in bootstrapping.	One of: • TRUE • FALSE	TRUE
bTest	B	Whether to perform the round trip test on par credit spread in bootstrapping.	One of: • TRUE • FALSE	FALSE
bBootstrapClean	B	Whether to take into account the accrued rebate for IMM dates in bootstrapping.	One of: • TRUE • FALSE	TRUE for spread quote data. FALSE for upfront fee quote data.
strSPInterpType	S	Survival probability interpolation method: • Log-linear interpolation on survival probabilities (SPLogLin) • Linear interpolation on survival probability yields (SPYieldLin)	One of: • SPLogLin • SPYieldLin	SPLogLin
bUseBisection	B	Whether to use the bisection method for root finding (TRUE) or the Newton-Raphson method (FALSE).	One of: • TRUE • FALSE	FALSE
rNRTol	R	Tolerance value for the Newton-Raphson method of root finding.		1e-8
nNRMaxIter	N	Maximum number of iterations for Newton-Raphson root finding.		50
mpOptionsRootGridX	L	(Optional) Name of a map that specifies settings for root finding by the bisection method.		
rBisectionLB	R	Lower bound used in the bisection method of root finding.		0
rBisectionUB	R	Upper bound used in the bisection method of root finding.		1

Table 9.12 CR Calibration Data Extraction Settings Map for CR_EQ_FX_IF_IR_HW_NF_BK_1F (Internal Survival Probability Bootstrapper) (Continued)

Map Key	Type Code	Description	Constraints	Default Value
`bLastPeriodAccrualEndUnadjusted`	B	Whether to use the unadjusted accrual end date for the last coupon period if `bUseIMMDates` is TRUE.	One of: • TRUE • FALSE	TRUE
`bIMMStepInNext`	B	Whether to use the next date after the calibration date as the IMM step-in date.	One of: • TRUE • FALSE	TRUE
`bFirstPartialIMMCoupon`	B	Whether to use the first partial coupon with IMM dates.	One of: • TRUE • FALSE	FALSE
`bUpfrontFee`	B	Whether the underlying curve data represents upfront fee quotes (TRUE) or par credit spreads (FALSE).	One of: • TRUE • FALSE	FALSE
`oUpfrontFeeFixedCoupon`	R or AR	Fixed coupon rate to use in the calculation when the input credit data is upfront fee quotes. Specify a scalar input (R) if fixed coupons are the same for all maturities, or an array (AR) if fixed coupons are different for different maturities.		0.01
`anUpfrontFeeScheduleMonths`	AN	(Optional) Maturity, as number of months, for each fixed coupon rate for upfront fee quote data. Required when `oUpfrontFeeFixedCoupon` is an array.	Same number of elements as `oUpfrontFeeFixedCoupon`.	
`nSettlementLag`	N	Number of days after which the contract must be settled.		0

Example

```
mpSettingsCDS_ObligorA, {
  bRoundMidpointToNearestDay, B, TRUE
  bUseYearFracForAccInt, B, TRUE
  bAccInt, B, TRUE
  rFwdHazardRateFloor, R, 1e-5
  bUseBisection, B, FALSE
  bTest, B, FALSE
  bBootstrapClean, B, TRUE
  strSPInterpType, S, SPYieldLin
  bUpfrontFee, B, TRUE
  oUpfrontFeeFixedCoupon, R, 0.015
  nSettlementLag, N, 2
}
```

9.3.4.1.1.1 Root-Finding Settings (CR_EQ_FX_IF_IR_HW_NF_BK_1F)

The `mpOptionsRootGridX` member of the CR calibration data extraction settings map above refers to another input map that specifies root-finding settings for the bisection method. These are the options that are parameters of the `RootGridX()` function (for more information see the *QuIC Functions Reference* document which is a set of HTML files included in an Analytics package). The following table defines the members of this map.

Table 9.13 CR Root-Finding Settings Map for CR_EQ_FX_IF_IR_HW_NF_BK_1F

Map Key	Type Code	Description	Constraints	Default Value
`nDivs`	`N`	Number of subdivision operations to perform.		30

Example

```
CRDataExtraction_RootFindingSettings, {
  nDivs, N, 50
}
```

9.3.4.1.2 With the External Survival Probability Bootstrapper

The following table defines the members of a CR calibration data extraction settings map for the CR_EQ_FX_IF_IR_HW_NF_BK_1F model when you use the external generic survival probability bootstrapper.

Table 9.14 CR Calibration Data Extraction Settings Map for CR_EQ_FX_IF_IR_HW_NF_BK_1F (External Survival Probability Bootstrapper)

Map Key	Type Code	Description	Constraints	Default Value
`strSPFrequency`	`S`	(Optional) Frequency of the survival probability dates. If set to `COUPONDATES`, the survival probability is generated at the union of the coupon dates of all the CDS instruments used in the bootstrapping. If omitted, the survival probability is generated on the node points of the input credit curve.	One of: • `COUPONDATES` • `DAILY` • `WEEKLY` • `MONTHLY` • `QUARTERLY` • `SEMIANNUAL` • `ANNUAL`	
`strHolidayListPremiumLeg`	`S`	(Optional) Name of the relevant set of holidays for adjusting the CDS schedule dates for the premium leg. If omitted, no adjustment is performed.	Name must be the key in the holidays HDF5 file.	

Table 9.14 CR Calibration Data Extraction Settings Map for CR_EQ_FX_IF_IR_HW_NF_BK_1F (Continued) (External Survival Probability Bootstrapper) (Continued)

Map Key	Type Code	Description	Constraints	Default Value
strHolidayListProtectionLeg	S	(Optional) Name of the relevant set of holidays for adjusting the CDS schedule dates for the protection leg. If omitted, no adjustment is performed.	Name must be the key in the holidays HDF5 file.	
mpCDSBootstrapperSettings	L	Name of a map that specifies the CDS bootstrapper settings. For a definition of this map, see Table 9.15 on page 182.		
mpCDSPricerSettings	L	(Optional) Name of a map that specifies the CDS pricer settings. For a definition of this map, see Table 9.16 on page 183 and Table 9.17 on page 186. Omit this input if the reference credit curve is of type SurvivalProbability.		
mpCDSPricerScheduleSettings	L	(Optional) Name of a map that specifies the settings for the schedule generation of the CDS pricer. For a definition of this map, see Table 9.18 on page 188. Omit this input if the reference credit curve is of type SurvivalProbability.		

Example

```
DataExtractionSettings_ExternalSPBootstrapper_ObligorA {
  strHolidayListPremiumLeg, S, USD
  strHolidayListProtectionLeg, S, WE
  mpCDSBootstrapperSettings, L, CDSBootstrapper_SPEnd
  mpCDSPricerSettings, L, CDSPricer_RollDefaultDates
  mpCDSPricerScheduleSettings, L, CDSPricerSchedule_IMMDates
}
```

9.3.4.1.2.1 External CDS Bootstrapper Settings

The mpCDSBootstrapperSettings member of the CR calibration data extraction settings map above refers to another input map that specifies survival probability bootstrapper settings. The following table defines the members of this map.

Table 9.15 External CDS Bootstrapper Settings Map

Map Key	Type Code	Description	Constraints	Default Value
strCDSBootstrapper	S	Bootstrapper type.	CDSBootstrapperSinglеNameSPEnd	
bFloor	B	Whether to floor the value of the optimization parameter in bootstrapping.	One of: • TRUE • FALSE	TRUE
bRoundTripTest	B	Whether to perform the round trip test on the CDS price in bootstrapping.	One of: • TRUE • FALSE	FALSE
bUseYearFracSP	B	Whether to use the year fraction in the calculation of the survival probability, yield, or spot hazard rate.	One of: • TRUE • FALSE	FALSE
nNRMaxIter	N	Maximum number of iterations for Newton-Raphson root finding.		50
rFloor	R	Floor value for the optimization parameter in bootstrapping.		1e-15
rNRTol	R	Tolerance value for the Newton-Raphson method of root finding.		1e-15
rSPDaysPerAnnum	R	(Optional) Number of days per annum in the calculation of the survival probability, yield, or spot hazard rate, if bUseYearFracSP is FALSE. If omitted, the relevant attribute of the credit curve is used.		365 (if not available from the credit curve)
strIncorrectSurvProbPoints	S	Method to handle incorrect survival probability points generated in the bootstrapping.	One of: • ignore • exclude • flatExtrap	exclude
strOptimizationObject	S	Object on which to perform the optimization.	One of: • spotHazardRate • SPYield • SP	spotHazardRate
strSPDaycount	S	(Optional) Day count convention in the calculation of the survival probability, yield, or spot hazard rate, if bUseYearFracSP is TRUE. If omitted, the relevant attribute of the credit curve is used.	See Table B.2 on page 327.	ACT365FIXED (if not available from the credit curve)

Table 9.15 External CDS Bootstrapper Settings Map (Continued)

Map Key	Type Code	Description	Constraints	Default Value
`strSPInterpObject`	S	Object to interpolate and extrapolate on (`log-lin` for `SP`; `lin` for `SPYield`).	One of: • `SPYield` • `SP`	`SPYield`
`strSPCompounding`	S	Compounding frequency of the survival probability curve.	One of: • `DAILY` • `WEEKLY` • `MONTHLY` • `QUARTERLY` • `SEMIANNUAL` • `ANNUAL` • `SIMPLE` • `CONTINUOUS`	`CONTINUOUS`
`strSPYieldExtrap`	S	Extrapolation method to use when the interpolation is performed on survival probability yield—that is, `strSPInterpObject` is set to `SPYield`.	See Table B.3 on page 328.	`lin`

Example

```
CDSBootstrapper_SPEnd {
  strCDSBootstrapper, S, CDSBootstrapperSingleNameSPEnd
  strSPInterpObject, S, SPYield
  strSPCompounding, S, ANNUAL
  strOptimizationObject, S, spotHazardRate
}
```

9.3.4.1.2.2 External CDS Pricer Settings: Mid-Point Default Pricer

The `mpCDSPricerSettings` member of the CR calibration data extraction settings map above refers to another input map that specifies CDS pricer settings. The map can be one of two types. The table below defines the members of the setting map for the pricer `CDSPricerSISingleNameMidPointDefault` in which the default date is assumed to be the mid-point of a coupon period.

Table 9.16 External CDS Pricer Settings Map (`CDSPricerSISingleNameMidPointDefault`)

Map Key	Type Code	Description	Constraints	Default Value
`strCDSPricer`	S	CDS pricer type.	`CDSPricerSISingleNameMidPointDefault`	

Table 9.16 External CDS Pricer Settings Map (`CDSPricerSISingleNameMidPointDefault`)

Map Key	Type Code	Description	Constraints	Default Value
`arCDSFixedCoupon`	AR	(Optional) Fixed coupon rate to use in bootstrapping when the input credit data is upfront fee quotes (`bUpfrontFee` is `TRUE` in the `mpCDSPricerScheduleSettings` map), for the CDS names. The first element, which corresponds to the first name, is used.		`0.01`
`arNotional`	AR	Constant notional for the CDS names. The first element, which corresponds to the first name, is used.		`1.0`
`arRecoveryRate`	AR	(Optional) Recovery rate to use in survival probability bootstrapping and in scaling exposures in valuation adjustment, for the CDS names. The first element, which corresponds to the first name, is used.		`0.4`
`bAccInt`	B	Whether to use the accrued interest in bootstrapping.	One of: • TRUE • FALSE	`TRUE`
`bClean`	B	Whether to take into account the accrued rebate for the first coupon in bootstrapping.	One of: • TRUE • FALSE	`TRUE`
`bFirstPartialCoupon`	B	Whether to use the first partial coupon.	One of: • TRUE • FALSE	`FALSE`
`bPayPremium`	B	Whether to pay premiums (buy the insurance).	One of: • TRUE • FALSE	`TRUE`
`bRoundMidPointToNearestDay`	B	Whether to round the coupon period mid points, calculated for accrued interest, to the nearest day.	One of: • TRUE • FALSE	`TRUE`
`bUseYearFracForAccInt`	B	Whether to use the year fraction in the calculation of the accrued interest.	One of: • TRUE • FALSE	`TRUE`

Table 9.16 External CDS Pricer Settings Map (`CDSPricerSISingleNameMidPointDefault`)

Map Key	Type Code	Description	Constraints	Default Value
`rDaysPerAnnumAccInt`	R	(Optional) Number of days per annum in the calculation of the accrued interest, if `bUseYearFracForAccInt` is `FALSE`. If omitted, the relevant attribute of the par credit spread curve is used.		
`strBusDayConvPremiumLeg`	S	Business day convention for adjusting the CDS schedule dates for the premium leg.	See Table B.1 on page 326.	`NA`
`strBusDayConvProtectionLeg`	S	Business day convention for adjusting the CDS schedule dates for the protection leg.	See Table B.1 on page 326.	`strBusDayConvPremiumLeg`
`strDaycount`	S	(Optional) Day count convention in the calculation of the accrued interest, if `bUseYearFracForAccInt` is `TRUE`. If omitted, the relevant attribute of the par credit spread curve is used.	See Table B.2 on page 327.	
`strLastPeriodEndDateType`	S	Type of accrual end date for the last coupon period.	One of: • `adjusted` • `adjustedAddOneDay` • `unadjusted` • `unadjustedAddOneDay`	`unadjustedAddOneDay`

Example

```
SampleCDSPricerSettings_MidpointDefault, {
  strCDSPricer, S, CDSPricerSISingleNameMidPointDefault
  strBusDayConvPremiumLeg, S, MODFOLLOWING
  strBusDayConvProtectionLeg, S, MODFOLLOWING
  bRoundMidPointToNearestDay, B, TRUE
  bClean, B, TRUE
  bUseYearFracForAccInt, B, TRUE
  strDaycount, S, ACT365
  strLastPeriodEndDateType, S, unadjustedAddOneDay
}
```

9.3.4.1.2.3 External CDS Pricer Settings: Roll Default Dates Pricer

The `mpCDSPricerSettings` member of the CR calibration data extraction settings map above refers to another input map that specifies CDS pricer settings. The map can be one of two types. The table below defines the members of the setting map for the pricer `CDSPricerSISingleNameRollDefaultDates` in which the default date is assumed to be a whole number of months from the later of the protection start date or the valuation date.

Table 9.17 External CDS Pricer Settings Map (`CDSPricerSISingleNameRollDefaultDates`)

Map Key	Type Code	Description	Constraints	Default Value
`strCDSPricer`	S	CDS pricer type.	`CDSPricerSISingleNameRollDefaultDates`	
`arCDSFixedCoupon`	AR	(Optional) Fixed coupon rate to use in bootstrapping when the input credit data is upfront fee quotes (`bUpfrontFee` is `TRUE` in the `mpCDSPricerScheduleSettings` map), for the CDS names. The first element, which corresponds to the first name, is used.		`0.01`
`arNotional`	AR	Constant notional for the CDS names. The first element, which corresponds to the first name, is used.		`1.0`
`arRecoveryRate`	AR	(Optional) Recovery rate to use in survival probability bootstrapping and in scaling exposures in valuation adjustment, for the CDS names. The first element, which corresponds to the first name, is used.		`0.4`
`bAccInt`	B	Whether to use the accrued interest in bootstrapping.	One of: • `TRUE` • `FALSE`	`TRUE`
`bClean`	B	Whether to take into account the accrued rebate for the first coupon in bootstrapping.	One of: • `TRUE` • `FALSE`	`TRUE`
`bPayPremium`	B	Whether to pay premiums (buy the insurance).	One of: • `TRUE` • `FALSE`	`TRUE`
`bUseYearFracForAccInt`	B	Whether to use the year fraction in the calculation of the accrued interest.	One of: • `TRUE` • `FALSE`	`TRUE`
`nMonthDefaultPeriod`	N	Interval (in months) between two default dates.		`3`
`rDaysPerAnnumAccInt`	R	(Optional) Number of days per annum in the calculation of the accrued interest, if `bUseYearFracForAccInt` is `FALSE`. If omitted, the relevant attribute of the par credit spread curve is used.		

Table 9.17 External CDS Pricer Settings Map (`CDSPricerSISingleNameRollDefaultDates`)

Map Key	Type Code	Description	Constraints	Default Value
`strBusDayConvPremiumLeg`	S	Business day convention for adjusting the CDS schedule dates for the premium leg.	See Table B.1 on page 326.	NA
`strBusDayConvProtectionLeg`	S	Business day convention for adjusting the CDS schedule dates for the protection leg.	See Table B.1 on page 326.	NA
`strDaycount`	S	(Optional) Day count convention in the calculation of the accrued interest, if `bUseYearFracForAccInt` is `TRUE`. If omitted, the relevant attribute of the par credit spread curve is used.	See Table B.2 on page 327.	
`strFirstPeriodStartDateType`	S	Type of accrual start date for the first coupon period.	One of: • `adjusted` • `unadjusted`	`adjusted`
`strLastDefaultPeriodEndDateType`	S	Type of accrual end date for the last default period.	One of: • `adjusted` • `unadjusted`	`unadjusted`
`strLastPeriodEndDateType`	S	Type of accrual end date for the last coupon period.	One of: • `adjusted` • `adjustedAddOneDay` • `unadjusted` • `unadjustedAddOneDay`	`unadjustedAddOneDay`

Example

```
SampleCDSPricerSettings_RollDefaultDates, {
  strCDSPricer, S, CDSPricerSISingleNameRollDefaultDates
  strBusDayConvPremiumLeg, S, MODFOLLOWING
  strBusDayConvProtectionLeg, S, MODFOLLOWING
  nMonthDefaultPeriod, N, 3
  bClean, B, TRUE
  bUseYearFracForAccInt, B, TRUE
  strDaycount, S, ACT365FIXED
  strLastPeriodEndDateType, S, unadjustedAddOneDay
}
```

9.3.4.1.2.4 External CDS Pricer Schedule Generation Settings

The `mpCDSPricerScheduleSettings` member of the CR calibration data extraction settings map above refers to another input map that specifies settings for the

schedule generation of the CDS pricers. The following table defines the members of this map.

Table 9.18 External CDS Pricer Schedule Generation Settings Map

Map Key	Type Code	Description	Constraints	Default Value
`bUseIMMDates`	B	Whether to use IMM dates. If the valuation date is not an IMM date, the CDS maturity is taken to be from the next IMM date.	One of: • TRUE • FALSE	TRUE
`bIMMStepInNext`	B	Whether to use the next date after the valuation date as the IMM step-in date.	One of: • TRUE • FALSE	TRUE
`bUpfrontFee`	B	Whether the underlying credit curve data represents upfront fee quotes (TRUE) or par credit spreads (FALSE).	One of: • TRUE • FALSE	FALSE

Example

```
CDSPricerSchedule_IMMDates {
 bUseIMMDates, B, TRUE
}
```

9.3.4.2 IR Calibration Data Extraction Settings (CR_EQ_FX_IF_IR_HW_NF_BK_1F)

The `ampDataExtractionSettingsIR` member of the data extraction settings map refers to other maps that each specify settings for IR calibration data extraction for one currency. The following table defines the members of an IR calibration data extraction settings map for the CR_EQ_FX_IF_IR_HW_NF_BK_1F model.

Table 9.19 IR Calibration Data Extraction Settings Map for CR_EQ_FX_IF_IR_HW_NF_BK_1F

Map Key	Type Code	Description	Constraints	Default Value
`strMethod`	S	Type of calibration data.	One of: • `Swaption` • `SelectedSwaptions`	

Table 9.19 IR Calibration Data Extraction Settings Map for CR_EQ_FX_IF_IR_HW_NF_BK_1F

Map Key	Type Code	Description	Constraints	Default Value
`rSwaptionShift`	R	(Optional) If specified, the market swaption price in the calibration of the model is calculated under the assumption that the swap rate has a shifted log-normal distribution with the specified shift size. In this case, the swaption price in the calibration is calculated using Black's formula with the adjusted swap rate and strike obtained by subtracting `rSwaptionShift` from the original swap rate and strike of the calibrating swaptions.		0
`strDaycountFixed`	S	(Optional) Day count convention in the fixed leg of the calibrating swaptions.	See Table B.2 on page 327.	The *`dayCountConv`* attribute of the input swaption volatility curve is used.
`nSwapTenorFixed`	N	(Optional) Coupon frequency (in months) in the fixed leg of the calibrating swaptions.		The *`tenor`* attribute of the input swaption volatility curve is used.
Use the additional inputs in this section only when `strMethod` is `SelectedSwaptions`				
`astrSwaptionExpiry`	AS	(Optional) Time to expiry to specify the swaption volatilities for extraction from the input swaption volatility curve, in the same units as the expiry ordinates in the curve. If not provided, the times to expiry are assumed to be the expiry ordinate values of the input swaption volatility curve.		
`anSwaptionLength`	AN	(Optional) Lengths in months of the swaptions to specify the volatility for extraction from the input swaption volatility curve, one for each expiry date specified by `astrSwaptionExpiry`. If not provided, the co-terminal swaption volatility is extracted for all expiry dates specified in `astrSwaptionExpiry`. Ignored if `astrSwaptionExpiry` is omitted.	Same number of elements as `astrSwaptionExpiry`.	

Table 9.19 IR Calibration Data Extraction Settings Map for CR_EQ_FX_IF_IR_HW_NF_BK_1F

Map Key	Type Code	Description	Constraints	Default Value
`arSwaptionStrike`	AR	(Optional) Swaption strike to specify the volatility for extraction from the input swaption volatility curve, one for each expiry date specified by `astrSwaptionExpiry`. If not provided, the at-the-money strike is used for all expiry dates specified in `astrSwaptionExpiry`. Ignored if `astrSwaptionExpiry` is omitted. Used only when the swaption volatility curve is of type `SwaptionVolCube`.	Same number of elements as `astrSwaptionExpiry`.	
`strSwaptionStrikeType`	S	(Optional) Type of the strikes specified in `arSwaptionStrike`. Ignored if `arSwaptionStrike` is omitted. Used only when the swaption volatility curve is of type `SwaptionVolCube`.	One of: • `ABSOLUTE` • `F-K` • `K-F` • `F/K` • `K/F` F is the underlying par swap rate for the swaption period. ABSOLUTE means that values represent the strike K. The remaining strike types mean that values are specified in relative terms.	`ABSOLUTE`
`idxBasisCurveCalib`	N	(Optional) Index of the interest rate curve to use for additive LIBOR basis adjustment in the calculation of the swap rate during the extraction of the ATM volatility.	Integer between 0 and n–1, where n is the number of curves specified by the market data map member `aBasisCurve`.	The LIBOR basis adjustment is not performed.
`idxBasisCurveCalibDisc`	N	(Optional) Index of the interest rate curve to use for discounting in the calculation of the swap rate during the extraction of the ATM volatility. Ignored if `bUseBasisCurveForCalibDiscounting` is set to TRUE.	Integer between 0 and n–1, where n is the number of curves specified by the market data map member `aBasisCurve`.	Interest rate curve for the currency of this map, specified by the market data map member `aIRCurve`.
`bUseBasisCurveForCalibDiscounting`	B	Whether to use the basis curve, if specified by `idxBasisCurveCalib`, for both discounting and forecasting in the calculation of the swap rate (TRUE) or just for forecasting (FALSE).	One of: • TRUE • FALSE	FALSE

Example

```
Swaption_DataExtractionSetting, {
  strMethod, S, Swaption
}
```

Chapter 10

Hybrid Credit Equity Inflation Multicurrency Model with FX Jump at Name Default

In the hybrid credit equity inflation multicurrency (with FX jumps) extension of the multifactor Hull-White interest rate model (CR_EQ_FX_IF_IR_HW_NF_JFX), a single-currency multifactor Hull-White model is used for the nominal interest rate for each currency. In addition, the spread between the nominal and real interest rates of each currency is also modelled as a single-currency multifactor Hull-White model. For each spot foreign exchange rate, spot equity price, and inflation index, the log-normal model is used. (Each exchange rate, each spot equity price, and each inflation index is modelled with one driving factor.) The default event is simulated using the deterministic hazard rates for each counterparty name in the model. The exchange rates can be devalued at the default event. The following two approaches are supported:

1. The exchange rate has a jump of a certain value at the default of any of the model names affecting this exchange rate. In this case, each path of the exchange rate may have multiple jumps.
2. The exchange rate has a jump of a certain value only at the first default event among the defaults of the model names affecting this exchange rate. In this case, each path of the exchange rate has a single jump.

This model also supports derived inflation indexes. A derived inflation index has the same driving factors as a core inflation index and inflation index rate curve, but has different inflation index and inflation rate curve starting values.

For information about the methodology of the CR_EQ_FX_IF_IR_HW_NF_JFX model, see the following chapter in *Markit Analytics Model Framework Mathematical Reference*: “Wrong Way Risk Model with Deterministic Hazard Rates and FX Jump at Name Default”.

10.1 Module (CR_EQ_FX_IF_IR_HW_NF_JFX)

The Model Framework module that implements the hybrid credit equity inflation multicurrency (with FX jumps) extension of the multifactor Hull-White interest rate model (CR_EQ_FX_IF_IR_HW_NF_JFX) is as follows:

```
quic_model_cr_eq_fx_if_ir_hw_nf_jfx:3.0
```

Combine this module name with the module component names identified in this chapter to form a complete module reference. For example, if the component is `QModel_CR_EQ_FX_IF_IR_HW_NF_JFX`, the complete module reference is as follows:

```
QModel_CR_EQ_FX_IF_IR_HW_NF_JFX@quic_model_cr_eq_fx_if_ir_hw_n
f_jfx:3.0
```

10.2 Market Data Generator Parameters (CR_EQ_FX_IF_IR_HW_NF_JFX)

A market data generator parameters set for the Model Framework market data generator includes certain parameters whose value depends on the particular model. These include some parameters that are used directly by the generator itself and others that are used only by the Model Framework model that it invokes (in particular by the model’s simulator component). For descriptions of the direct generator parameters, see the *Markit Analytics Simulation Framework User Guide*. The parameters that are used by Model Framework simulators are described in “Model Framework Simulator Settings” on page 28.

Some of the simulator settings are used by all models and others are used only by certain models. For the latter subset of settings, the information below shows which ones are used by this model.

Generator Parameter: strSimulatorMFWKReference

The parameter strSimulatorMFWKReference specifies the simulator plug-in for the model. The following values of this parameter are available for the CR_EQ_FX_IF_IR_HW_NF_JFX model:

- Simulation algorithm under the risk-neutral measure:

  QMCSimulator_CR_EQ_FX_IF_IR_HW_NF_JFX_RNM@quic_model_cr_eq_fx_if_ir_hw_nf_jfx:3.0

Applicability of Simulator Settings

The following table identifies which simulator plug-ins (if any) support the specified simulator settings.

Table 10.1 Support for Simulator Settings (CR_EQ_FX_IF_IR_HW_NF_JFX)

Parameter	Simulators That Support the Parameter
bStepOnDFDates	QMCSimulator_CR_EQ_FX_IF_IR_HW_NF_JFX_RNM
bPrecalculateCovariances	QMCSimulator_CR_EQ_FX_IF_IR_HW_NF_JFX_RNM
bUseEigenSym and bUsePCA	QMCSimulator_CR_EQ_FX_IF_IR_HW_NF_JFX_RNM
bCholesky	Not applicable
strDecomposition	QMCSimulator_CR_EQ_FX_IF_IR_HW_NF_JFX_RNM
bUseStartEndNumeraireCalc	QMCSimulator_CR_EQ_FX_IF_IR_HW_NF_JFX_RNM
bUseForeignQuantoAdjustment	Not applicable
bUseDeterministicFXDrifts	Not applicable
bUseDeterministicInflationDrifts	Not applicable
bApproximateXIntegral	Not applicable

10.3 Model Preferences (CR_EQ_FX_IF_IR_HW_NF_JFX)

You specify the settings for the model in a model preferences map and in the subsidiary maps that it references. For a general description of a model preferences map, see “Model Preferences Map” on page 32.

10.3.1 Components (CR_EQ_FX_IF_IR_HW_NF_JFX)

The following table identifies the available plug-ins (components of the CR_EQ_FX_IF_IR_HW_NF_JFX module) that implement the model. You specify these as values of members of the model preferences map in the form of full module references.

Table 10.2 Model Plug-In Components (CR_EQ_FX_IF_IR_HW_NF_JFX)

Model Preference	Available Components of the Module
`Model`	`QModel_CR_EQ_FX_IF_IR_HW_NF_JFX`
`CalibrationMethod`	`QModelCalibration_CR_EQ_FX_IF_IR_HW_1F_JFX`
`DataExtractionMethod`	`QDataExtraction_CR_EQ_FX_IF_IR_HW_1F_JFX`

In addition, you must specify the maps that are identified by the other members of the model preferences map. The remainder of this chapter defines these subsidiary maps.

Example

To use the CR_EQ_FX_IF_IR_HW_NF_JFX model, configure a model preferences map so that the `Model`, `CalibrationMethod`, and `DataExtractionMethod` members have the values highlighted in the following sample map.

```
CR_EQ_FX_IF_IR_HW_NF_JFX_ModelPrefs, {
  Model, S, QModel_CR_EQ_FX_IF_IR_HW_NF_JFX@quic_model_cr_eq_fx_if_ir_hw_nf_jfx:3.0
  CalibrationMethod, S,
   QModelCalibration_CR_EQ_FX_IF_IR_HW_1F_JFX@quic_model_cr_eq_fx_if_ir_hw_nf_jfx:3.0
  CalibrationSettings, L, CR_EQ_FX_IF_IR_HW_NF_JFX_CalibrationSettings
  CurveNames, L, CR_EQ_FX_IF_IR_HW_NF_CurveNames
  DataExtractionMethod, S,
   QDataExtraction_CR_EQ_FX_IF_IR_HW_1F_JFX@quic_model_cr_eq_fx_if_ir_hw_nf_jfx:3.0
  DataExtractionSettings, L, CR_EQ_FX_IF_IR_HW_NF_JFX_DataExtractionSettings
  mpTradeInfo, L, PORTFOLIO_INFO}
```

In addition, you must provide the maps that are referenced by the other members of the model preferences map. The following sections define these maps.

10.3.2 Calibration Settings (CR_EQ_FX_IF_IR_HW_NF_JFX)

The `CalibrationSettings` member of the model preferences map refers to another map that specifies parameters related to calibration of the model.

For the calibration of the IR model, a single-currency single-factor Hull-White model is used for the nominal interest rate for each currency. The spread between the nominal and real interest rates of each currency is also modelled as a single-currency single-factor Hull-While model. The inflation index volatilities can be calibrated against inflation index options.

The FX jumps and FX volatility calibration are performed under the assumption that the FX rate may have multiple jumps. The FX jumps are calibrated using the survival probabilities in both foreign and domestic currencies, to match foreign defaultable bond prices. The FX volatilities are calibrated to market at-the-money FX options. Note that if the FX rates have a single jump at the first name default, then the simulated values of the foreign defaultable bonds and FX options, obtained by the calibrated model, will not match the market values.

The table below defines the members of a calibration settings map for the CR_EQ_FX_IF_IR_HW_NF_JFX model. The descriptions of these parameters use the following notation:

- H is the number of currencies. Hence, H–1 is the number of exchange rates.
- E is the number of equities.
- I is the number of inflation indexes.
- K is the number of factors in the interest rate and inflation model.

Table 10.3 Calibration Settings Map for CR_EQ_FX_IF_IR_HW_NF_JFX

Map Key	Type Code	Description	Constraints	Default Value
`astrCCY`	AS	Names of the H currencies. The first name is the domestic currency.	Standard 3-character currency identifiers	
`astrEquity`	AS	Names of the E equities.		
`astrEquityCCY`	AS	Names of the E currencies, corresponding to the equities in `astrEquity`.	Standard 3-character currency identifier. All names must be present in `astrCCY`.	
`astrName`	AS	Credit names.		
`arRecoveryRate`	AR	(Optional) Recovery rates to use for each credit name. Overrides the recovery rate attribute of the input par credit spread curves (if provided).	Number of elements must be equal to the number of names in `astrName`.	If a survival probability curve is input for a name, the value defaults to 0.4.
`bSingleFXJump`	B	Whether the FX rates can have only one jump at the first name default.	One of: • TRUE • FALSE	FALSE
`rFXJumpTolerance`	R	Tolerance level for the FX jump size. If the size of the FX jump for a name is smaller than the tolerance level at all dates, the FX rate is treated as if it is not affected by the name default.		1e-20
`bApproxVACalculation`	B	Whether to use the approximate calculation of the variance-reduced XVA in case of a single FX jump. If the approximate XVA calculation is not used, the additional intermediate variables are computed by the monte carlo simulator for the variance-reduced XVA calculation. This can adversely affect performance and memory usage.	One of: • TRUE • FALSE	TRUE

Table 10.3 Calibration Settings Map for CR_EQ_FX_IF_IR_HW_NF_JFX (Continued)

Map Key	Type Code	Description	Constraints	Default Value
astrII	AS	Names of the *I* inflation indexes.		
astrIICCY	AS	Names of the *I* currencies, corresponding to the inflation indexes in astrII.	Standard 3-character currency identifier. All names must be present in astrCCY.	
astrIIDerived	AS	(Optional) Names of the derived inflation indexes.		
astrIIDerivedFrom	AS	(Optional) Names of the core inflation indexes on which the derived indexes are based, one for each derived index. Required if astrIIDerived is specified.	All names must be present in astrII.	
ampCalibrationSettingsCR	AL	Names of maps, one for each credit name, that specify credit calibration settings. In the current release, CR calibration has no settings.	Referenced maps must exist in the model preferences file. To use the defaults for all settings, provide an empty map.	An array of empty maps, one for each credit name.
ampCalibrationSettingsIR	AL	Names of maps, one for each model currency, that specify the IR calibration settings. For the definition of these maps, see "IR Calibration Settings (CR_EQ_FX_IF_IR_HW_NF_JFX)" on page 199.	Referenced maps must exist in the model preferences file. To use the defaults for all settings, provide an empty map.	
ampCalibrationSettingsFX	AL	Names of maps, one for each foreign currency, that specify FX calibration settings. For the definition of these maps, see "FX Calibration Settings (CR_EQ_FX_IF_IR_HW_NF_JFX)" on page 202.	Referenced maps must exist in the model preferences file. To use the defaults for all settings, provide an empty map.	
ampCalibrationSettingsEQ	AL	Names of maps, one for each equity, that specify equity calibration settings. For the definition of these maps, see "Equity Calibration Settings (CR_EQ_FX_IF_IR_HW_NF_JFX)" on page 202.	Referenced maps must exist in the model preferences file. To use the defaults for all settings, provide an empty map.	An array of empty maps, one for each equity.

Table 10.3 Calibration Settings Map for CR_EQ_FX_IF_IR_HW_NF_JFX (Continued)

Map Key	Type Code	Description	Constraints	Default Value
`ampCalibrationSettingsII`	AL	Names of maps, one for each inflation index, that specify inflation index calibration settings. For the definition of these maps, see "Inflation Index Calibration Settings (CR_EQ_FX_IF_IR_HW_NF_JFX)" on page 203.	Referenced maps must exist in the model preferences file. To use the defaults for all settings, provide an empty map.	An array of maps, each with `bCalibrateToIIOptions` set to TRUE.
`astrBasisCurve`	AS	Nicknames of the interest rate curves used for additive LIBOR basis adjustment.	Include a nickname for each of the curves, in order, specified by the `aBasisCurve` member of the market data map.	

Example

```
CR_EQ_FX_IF_IR_HW_NF_JFX_CallibrationSettings, {
  astrCCY, AS, EUR, USD
  astrEquity, AS, SPX
  astrEquityCCY, AS, USD
  astrName, AS, CS1, CS2
  astrII, AS, I01
  astrIICCY, AS, EUR
  astrIIDerived, AS, I01d1
  astrIIDerivedFrom, AS, I01
  bCorrectCorrMtx, B, FALSE
}
```

10.3.2.1 IR Calibration Settings (CR_EQ_FX_IF_IR_HW_NF_JFX)

The `ampCalibrationSettingsIR` member of a calibration settings map refers to other maps that each specify settings for the calibration of the interest rate model for one currency. The following table defines the members of an IR calibration settings map for the CR_EQ_FX_IF_IR_HW_NF_JFX model.

Table 10.4 IR Calibration Settings Map for CR_EQ_FX_IF_IR_HW_NF_JFX

Map Key	Type Code	Description	Constraints	Default Value
`strCCYDom`	S	Name of the domestic currency.	Standard 3-character currency identifier	
`bUseCapletFormula`	B	Whether to use the caplet formula. If set to TRUE, but the input calibrating instruments are swaptions, this setting reverts to FALSE.	One of: • TRUE • FALSE	FALSE

Table 10.4 IR Calibration Settings Map for CR_EQ_FX_IF_IR_HW_NF_JFX

Map Key	Type Code	Description	Constraints	Default Value
`rNotional`	R	Notional amount to use when calculating prices during calibration.		1.0
`mpRootFindSettings`	L	Name of a map of settings for the root-finding procedure.	Referenced map must exist in the model preferences file.	Empty map
`bAllowNegativeMR`	B	Whether to allow the calibration process to generate a negative mean reversion parameter.	One of: • TRUE • FALSE	FALSE
`strBasisCurveCalib`	S	(Optional) Nickname of the interest rate curve to use for additive LIBOR basis adjustment during calibration. If omitted, the LIBOR basis adjustment is not performed.	Must be one of the names in `astrBasisCurve` in the main calibration settings map.	
`bUseBasisCurveForCalibDiscounting`	B	Whether to use the basis curve, if specified by `strBasisCurveCalib`, for both discounting and forecasting in the calibration (TRUE) or just for forecasting (FALSE).	One of: • TRUE • FALSE	FALSE
`strBasisCurveCalibDisc`	S	(Optional) Nickname of the interest rate curve to use for discounting during calibration. Ignored if `bUseBasisCurveForCalibDiscounting` is set to TRUE.	Must be one of the names in `astrBasisCurve` in the main calibration settings map.	Interest rate curve for the currency of this map, specified by the market data map member `aIRCurve`.
`bNormalVolatilities`	B	Whether to assume normal (TRUE) or log-normal (FALSE) volatilities.	One of: • TRUE • FALSE	FALSE

Example

```
IR_EUR_CalibrationSettings, {
  strBasisCurveCalib, S, EURLibor3M
}
```

10.3.2.1.1 Root-Finding Settings (CR_EQ_FX_IF_IR_HW_NF_JFX)

The `mpRootFindSettings` member of an IR calibration settings map refers to another map that specifies settings for the root-finding process. Most of these settings specify various numerical tolerances. Normally, the default values are suitable.

The following table defines the members of a root-finding settings map for the CR_EQ_FX_IF_IR_HW_NF_JFX model.

Table 10.5 Root-Finding Settings Map for CR_EQ_FX_IF_IR_HW_NF_JFX

Map Key	Type Code	Description	Constraints	Default Value
rVolSensTol	R	Volatility sensitivity tolerance		0.001
rSigmaConst	R	Sigma used in initial guess for root find (units are per annum). If all calibrating instruments are removed, this value is used as the Hull-White volatility parameter.		0.01
rErrorTol	R	Error tolerance for root find to match market prices.		1.0e–14
rRelTolNR	R	Relative tolerance in Newton-Raphson method for root find to match market prices.		1.0e–13
nMaxIterNR	N	Maximum number of iterations in Newton-Raphson method for root find to match market prices.		100
nMaxIterBracket	N	Maximum number of iterations used in bracketing for root find to match market prices.		20
rBracketLow	R	Low value for bracketing for root find to match market prices.		1.0e–10
rBracketHigh	R	High value for bracketing for root find to match market prices.		1.0e–1
nMaxDiv	N	Maximum number of divisions in bisection for root find to match market prices.		100
rRootGuessJam	R	Initial guess for root in Jamshidian decomposition.		0.0
rErrorTolJam	R	Error tolerance in Jamshidian decomposition.		1.0e–13
rRelTolNRJam	R	Relative tolerance in Newton-Raphson method for root find in Jamshidian decomposition.		1.0e–15
nMaxIterNRJam	N	Maximum number of iterations in Newton-Raphson method for root find in Jamshidian decomposition.		100
rMinXJam	R	Minimum X value in bracketing for Jamshidian decomposition.		–0.1
rMaxXJam	R	Maximum X value in bracketing for Jamshidian decomposition.		0.1
nMaxDivJam	N	Maximum number of iterations in bisection for root find in Jamshidian decomposition.		100

10.3.2.2 FX Calibration Settings (CR_EQ_FX_IF_IR_HW_NF_JFX)

The `ampCalibrationSettingsFX` member of a calibration settings map refers to other maps that each specify settings for the calibration of the exchange rate model for one pair of currencies. The following table defines the members of an FX calibration settings map for the CR_EQ_FX_IF_IR_HW_NF_JFX model.

Table 10.6 FX Calibration Settings Map for CR_EQ_FX_IF_IR_HW_NF_JFX

Map Key	Type Code	Description	Constraints	Default Value
`bUseNegativeSpotVols`	B	Whether to add negative FX spot volatilities to the calibrated values during the calibration procedure.	One of: • TRUE • FALSE	FALSE
`bCalibrateFXVolToJumps`	B	Whether to account for FX jumps in the calibration of the FX volatility to the market FX options. If set to FALSE, the FX jumps are ignored in the FX volatility calibration.	One of: • TRUE • FALSE	TRUE
`nFXIntegrationIntervals`	N	(Optional) Number of intervals in the discretization of the integrals in the calculation of the FX option price for the FX volatility calibration. Omit if you specify `rFXIntegrationStep`.		100
`rFXIntegrationStep`	N	(Optional) Size of the integration step (in days) in the calculation of the FX option price for the FX volatility calibration. Ignored if `nFXIntegrationIntervals` is provided.		

Example

```
UseNegativeSpotFXVols, {
  bUseNegativeSpotVols, B, TRUE
  rFXIntegrationStep, R, 10
}
```

10.3.2.3 Equity Calibration Settings (CR_EQ_FX_IF_IR_HW_NF_JFX)

The `ampCalibrationSettingsEQ` member of a calibration settings map refers to other maps that each specify settings for the calibration of the equity model for

one equity. The following table defines the members of a calibration settings map for the CR_EQ_FX_IF_IR_HW_NF_JFX model.

Table 10.7 Equity Calibration Settings Map for CR_EQ_FX_IF_IR_HW_NF_JFX

Map Key	Type Code	Description	Constraints	Default Value
`bUseNegativeSpotVols`	B	(Optional) Whether to add negative equity spot volatilities to the calibrated values during the calibration procedure.	One of: • TRUE • FALSE	FALSE

Example

```
UseNegativeSpotEQVols, {
  bUseNegativeSpotVols, B, TRUE
}
```

10.3.2.4 Inflation Index Calibration Settings (CR_EQ_FX_IF_IR_HW_NF_JFX)

The `ampCalibrationSettingsII` member of a calibration settings map refers to other maps that each specify settings for the calibration of the inflation index model for one inflation index. The following table defines the members of a calibration settings map for the CR_EQ_FX_IF_IR_HW_NF_JFX model.

Table 10.8 Inflation Index Calibration Settings Map for CR_EQ_FX_IF_IR_HW_NF_JFX

Map Key	Type Code	Description	Constraints	Default Value
`bCalibrateToIIOptions`	B	Whether to calibrate inflation index volatilities from inflation index options. If set to FALSE in any of the inflation index calibration settings maps, you must provide `aSpotIIVolCurve` in the Market Data Map. If set to TRUE in any of the inflation index calibration settings maps, you must provide `aSpotIIImpliedVolCurve` in the Market Data Map.	One of: • TRUE • FALSE	
`bUseNegativeSpotVols`	B	(Optional) Whether to add negative inflation index spot volatilities to the calibrated values during the calibration procedure. This input applies only when `bCalibrateToIIOptions` is set to TRUE.	One of: • TRUE • FALSE	FALSE

Example

```
SampleIICalibrationSettings, {
  bCalibrateToIIOptions, B, TRUE
  bUseNegativeSpotVols, B, TRUE
}
```

10.3.3 Market Data Inputs (CR_EQ_FX_IF_IR_HW_NF_JFX)

The CurveNames member of the model preferences map refers to a curves name map that identifies the market data curves that are required for pricing, simulation, and if applicable, internal model calibration. The following table defines the members of a market data map for the CR_EQ_FX_IF_IR_HW_NF_JFX model.

Table 10.9 Market Data Map for CR_EQ_FX_IF_IR_HW_NF_JFX

Map Key	Type Code	Description	Constraints	Default Value
aIRCurve	AS or AL	Either: • Names of curves for discounting (of type DiscountFactor, Yield, or FwdLibor), one for each currency. • Names of lists that specify a set of curves to use in bootstrapping the discount factor, one for each currency. The first curve or list of curves is for the domestic currency, and the remainder are for the foreign currencies. For details about the lists of curves for bootstrapping, see "Specifying the Data to Use in Bootstrapping" on page 34.	Referenced curves must exist in the market data HDF5 file, or referenced lists must exist in an auxiliary transaction data file. The number of elements must equal the number of currencies. Ordinates of a Yield curve must be >0.	
aINFCurve	AS	Names of curves (of type DiscountFactor, Yield, or InflationRate) that specify the inflation-bond-related interest rate for each currency, in the same order as the inflation indexes.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of inflation indexes. Ordinates of a Yield curve must be >0.	

Table 10.9 Market Data Map for CR_EQ_FX_IF_IR_HW_NF_JFX (Continued)

Map Key	Type Code	Description	Constraints	Default Value
`aSpotIICurve`	AS	Names of curves (of type `InflationIndex`) that specify the inflation index for each currency, in the same order as the inflation indexes. Must be provided when `bCalibrateToIIOptions` is set to TRUE in the inflation index calibration settings map.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of inflation indexes.	
`aINFDerivedCurve`	AS	(Optional) Names of curves (of type `Yield`) that specify the inflation-bond-related interest rate for the currency of each derived inflation index, in the same order in which the indexes are listed in the `astrIIDerived` parameter in the calibration settings map. Required if the `astrIIDerived` parameter is specified in the calibration settings map.	Referenced curves must exist in the market data HDF5 file. The number of elements in the array must equal the number of inflation indexes. Ordinates of a `Yield` curve must be >0.	
`aSpotIIDerivedCurve`	AS	(Optional) Names of curves (of type `InflationIndex`) that specify the initial value of each derived inflation index, in the same order in which the indexes are listed in the `astrIIDerived` parameter in the calibration settings map. Required if the `astrIIDerived` parameter is specified in the calibration settings map.	Referenced curves must exist in the market data HDF5 file. The number of elements in the array must equal the number of derived indexes.	
`aSpotFXCurve`	AS	Names of domestic/foreign spot FX curves (of type `Exchange`), one for each currency, in the same order as the IR curves.	The first name, corresponding to the domestic currency, must be `void`. Referenced curves must exist in the market data HDF5 file.	
`aSpotEQCurve`	AS	Names of spot equity curves (of type `Equity or EquityIndex`), one for each equity, in the same order as the equities.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of equities.	
`aEQDividendCurve`	AS	Names of equity dividend curves (of type `DiscreteAbsoluteDividend` or `ContinuousYieldDividend`), one for each equity, in the same order as the equities.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of equities.	

Table 10.9 Market Data Map for CR_EQ_FX_IF_IR_HW_NF_JFX (Continued)

Map Key	Type Code	Description	Constraints	Default Value
`aCreditCurve`	AS	Names of the CDS curves in the domestic currency (of type `ParCreditSpread` or `SurvivalProbability`), one for each credit name, in the same order as the credit names.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of credit names.	
`aaCreditCurveForeignCCY`	AL	(Optional) Names of lists (of type AS), one for each credit name, that specify the CDS curves in foreign currencies (of type `ParCreditSpread` or `SurvivalProbability`) for the FX jump calibration, in the same order as the credit names. Each list specifies the foreign CDS curves for those foreign currencies that have FX jumps at the name default. The indexes of the model foreign currencies corresponding to the curves are specified by the input `aaidxForeignCCY` in the data extraction settings. The order of the curves in the list must be the same as the order of the indexes for the name. If for a currency name, both a foreign CDS curve and an FX jump term structure curve (specified by `aaFXJumpAtNameDefaultCurve`) are provided, the foreign CDS curve is ignored. If for a currency name, neither of these curves is provided, the FX rate is treated as if it is not affected by the name default.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of credit names.	

Table 10.9 Market Data Map for CR_EQ_FX_IF_IR_HW_NF_JFX (Continued)

Map Key	Type Code	Description	Constraints	Default Value
`aaFXJumpAtNameDefaultCurve`	AL	(Optional) Names of lists (of type AS), one for each credit name, specifying the jump term structure curves (of type `Vector`) to bypass the FX jump calibration, in the same order as the credit names. Each list specifies the jump term structure curves for those foreign currencies that have FX jumps at the name default. The indexes of the model foreign currencies corresponding to the curves are specified by the input `aaidxForeignCCY` in the data extraction settings. The order of the curves in the list must be the same as the order of the indexes for the name. If for a currency name, both a foreign CDS curve (specified by `aaCreditCurveForeignCCY`) and an FX jump term structure curve are provided, the foreign CDS curve is ignored. If for a currency name, neither of these curves is provided, the FX rate is treated as if it is not affected by the name default.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of credit names.	
`aINFMeanReversionCurve`	AS	Names of mean reversion curves (of type `MeanReversion`), one for the spread between nominal and real interest rates for each currency, in the same order as the inflation indexes.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of currencies.	
`aINFVolCurve`	AS	Names of volatility curves (of type `ImpliedVol`), one for the spread between nominal and real interest rates for each currency, in the same order as the inflation indexes.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of currencies.	
`aSpotIIVolCurve`	AS	Names of inflation index volatility curves (of type `ImpliedVol`), one for each inflation index, in the same order as the inflation indexes. Must be provided when `bCalibrateToIIOptions` is set to FALSE in the inflation index calibration settings map.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of inflation indexes.	

Table 10.9 Market Data Map for CR_EQ_FX_IF_IR_HW_NF_JFX (Continued)

Map Key	Type Code	Description	Constraints	Default Value
`aSpotIIImpliedVolCurve`	AS	Names of inflation index option implied volatility curves (of type `ImpliedVol`), one for each inflation index, in the same order as the inflation indexes. Must be provided when `bCalibrateToIIOptions` is set to TRUE in the inflation index calibration settings map.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of inflation indexes.	
`aBasisCurve`	AS	Names of curves (of type `DiscountFactor`, `Yield`, or `FwdLibor`) that specify the forecasting interest rates to use for LIBOR basis adjustments for all relevant currencies.	Referenced curves must exist in the market data HDF5 file. Ordinates of a `Yield` curve must be >0.	
`aMeanReversionCurve`	AS	Names of mean reversion curves (of type `MeanReversion`), one for each currency, in the same order as the IR curves.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of currencies.	
`aCapletVolCurve`	AS	Names of caplet volatility curves (of type `CapletVol`), one for each currency, in the same order as the IR curves. Each currency must have either a caplet volatility curve or a swaption volatility curve. A value can be `void` if the model for that currency is calibrated to swaption volatilities.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of currencies.	
`aSwaptionVolCurve`	AS	Names of swaption volatility curves (of type `SwaptionVolMtx`), one for each currency, in the same order as the IR curves. Each currency must have either a caplet volatility curve or a swaption volatility curve. A value can be `void` if the model for that currency is calibrated to caplet volatilities.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of currencies.	
`aFXImpliedVolCurve`	AS	Names of FX option volatility curves (of type `ImpliedVol`), one for each spot FX rate, in the same order as the FX curves. The first name, matching the domestic currency itself, can be left blank.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of currencies.	
`aEQImpliedVolCurve`	AS	Names of equity option volatility curves (of type `EquityImpliedVol` or `ImpliedVol`), one for each spot equity, in the same order as the equity curves.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of equities.	

Table 10.9 Market Data Map for CR_EQ_FX_IF_IR_HW_NF_JFX (Continued)

Map Key	Type Code	Description	Constraints	Default Value
`aCorrelationCurve`	AS	Names of correlation curves (of type `CorrelBlock`) that give the correlations between model risk factors. For more detail, see the description that follows this table.	Referenced curves must exist in the market data HDF5 file.	

Correlation Curves

Construct the correlation curves specified by `aCorrelationCurve` according to the following scheme:

- A model with n currencies, e equities, and m inflation indexes, has $2n–1+e+2m$ risk factors: n short rate risk factors and $n–1$ FX risk factors, e equity risk factors, m spread risk factors associated with inflation indexes, and m inflation index risk factors.
- Let R_i be the risk factors of the model.
- The n risk factors from i=0 to i=n–1 are the short rate risk factors in the same order as the IR curves.
- The n–1 risk factors from i=n to i=2n-2 are the FX risk factors in the same order as the spot FX curves (omitting the first which is trivial).
- The e risk factors from i=2n–1 to i=2n+e–2 are the equity risk factors in the same order as the spot equity curves.
- The m risk factors from i=2n+e–1 to i=2n+e+m–2 are the spread risk factors in the same order as the inflation indexes.
- The m risk factors from i=2n+e+m–1 to i=2n+e+2m–2 are the inflation index risk factors in the same order as the inflation indexes.
- The first 2n+e+2m–2 correlations are the correlations between R_0 and $R_1,\ldots,R_{2n+e+2m-2}$.
- The next 2n+e+2m–3 correlations are the correlations between R_1 and $R_2,\ldots,R_{2n+e+2m-2}$.
- The next 2n+e+2m–4 correlations are the correlations between R_2 and $R_3,\ldots,R_{2n+e+2m-2}$, and so on.

Example

```
CR_EQ_FX_IF_IR_HW_1F_JFX_CurveNames_, {
  aIRCurve, AS, EUR.Yield.EUR, USD.Yield.USD
  aINFCurve, AS, EUR_INF.Yield.EUR
  aSpotIICurve, AS, I_EUR.InflationIndex.EUR
  aSpotFXCurve, AS, void, USD.Exchange.EUR
  aSpotEQCurve, AS, SPX.EquityIndex.USD
  aCreditCurve, AS, CS1.ParCreditSpread.EUR, CS2.ParCreditSpread.EUR
  aaCreditCurveForeignCCY, AL, aCreditCurveForeignCCY_CS1, void
  aaFXJumpAtNameDefaultCurve, AL, void, aFXJumpAtNameDefaultCurve_CS2
  aINFMeanReversionCurve, AS, IRR.MeanReversion.EUR
  aINFVolCurve, AS, IRR.ImpliedVol.EUR
  aSpotIIVolCurve, AS, IIVol.ImpliedVol.EUR
  aSpotIIImpliedVolCurve, AS, IIImplied.ImpliedVol.EUR
  aMeanReversionCurve, AS, EURMR.MeanReversion.EUR, USDMR.MeanReversion.USD
  aSwaptionVolCurve, AS, SemiannualSwapVol.SwaptionVolMtx.EUR
  ..., SemiannualSwapVol.SwaptionVolMtx.USD
  aFXImpliedVolCurve, AS, void, USD.ImpliedVol.EUR
  aEQImpliedVolCurve, AS, void, SPX.ImpliedVol.USD
  aCorrelationCurve, AS
  ..., ShortRateUSD.CorrelBlock.ShortRateEUR
  ..., ShortRateUSD.CorrelBlock.SpotFXEUR
  ..., ShortRateUSD.CorrelBlock.SPX
  ..., ShortRateUSD.CorrelBlock.IRREUR
  ..., ShortRateUSD.CorrelBlock.IIEUR
  ..., ShortRateEUR.CorrelBlock.SpotFXEUR
  ..., ShortRateEUR.CorrelBlock.SPX
  ..., ShortRateEUR.CorrelBlock.IRREUR
  ..., ShortRateEUR.CorrelBlock.IIEUR
  ..., SpotFXEUR.CorrelBlock.SPX
  ..., SpotFXEUR.CorrelBlock.IRREUR
  ..., SpotFXEUR.CorrelBlock.IIEUR
  ..., SPX.CorrelBlock.IRREUR
  ..., SPX.CorrelBlock.IIEUR
  ..., IRREUR.CorrelBlock.IIEUR
}
```

10.3.4 Data Extraction Settings (CR_EQ_FX_IF_IR_HW_NF_JFX)

The `DataExtractionSettings` member of the model preferences map refers to another map that specifies parameters for the data extraction process. The following table defines the members of a data extraction settings map for the CR_EQ_FX_IF_IR_HW_NF_JFX model.

Table 10.10 Data Extraction Settings Map for CR_EQ_FX_IF_IR_HW_NF_JFX

Map Key	Type Code	Description	Constraints	Default Value
`ampIRCurveSettings`	AL	Names of maps, one for each model currency, that specify settings for extracting interest rates. For the definition of these maps, see "Interest Rate Extraction Settings Map" on page 35.	Referenced maps must exist in the model preferences file. To use the defaults for all settings, provide an empty map.	An array of empty maps, one for each currency.
`ampBasisCurveSettings`	AL	Names of maps of settings for the basis data extraction, one for each interest rate curve specified by `aBasisCurve` in the market data map. The settings in these maps are listed in "Interest Rate Extraction Settings Map" on page 35.	Referenced maps must exist in the model preferences file.	The settings specified by `ampIRCurveSettings` are used.
`ampIFCurveSettings`	AL	Names of maps, one for each inflation index, that specify the settings for extracting the inflation-bond-related interest rate. In the current release, inflation index data extraction has no settings.	Referenced maps must exist in the model preferences file.	An array of empty maps, one for each inflation index.
`bExtrapolateDF`	B	Controls whether to extrapolate discount factors and inflation discount factors.	One of: • TRUE • FALSE	FALSE
`nMonthsExtrapDFEnd`	N	Number of months after the calibration date in which to extrapolate the discount factors.		0
`aaidxForeignCCY`	AL	(Optional) Names of lists (of type AN), one for each credit name, that specify the indexes of the foreign currencies into the model currencies for the foreign CDS curves (specified in the curve map input `aaCreditCurveForeignCCY`) or FX jump term structure curves (specified in the curve map input `aaFXJumpAtNameDefaultCurve`), in the same order as the credit names. In each list, the order of the indexes must be the same as the order of the foreign CDS curves or FX jump term structure curves.	Integers between 1 and the number of foreign currencies of the model	

Table 10.10 Data Extraction Settings Map for CR_EQ_FX_IF_IR_HW_NF_JFX (Continued)

Map Key	Type Code	Description	Constraints	Default Value
bUseMFWKStripper	B	Whether to use the model's internal survival probability bootstrapper (TRUE), or the external generic survival probability bootstrapper (FALSE).	One of: • TRUE • FALSE	TRUE
ampSettingsCDS	AL	Names of maps, one for each credit name, that specify credit data extraction settings for purposes of calibration. For the definition of these maps, see "CR Calibration Data Extraction Settings (CR_EQ_FX_IF_IR_HW_NF_JFX)" on page 213.	Referenced maps must exist in the model preferences file. To use the defaults for all settings, provide an empty map.	An array of empty maps, one for each credit name.
ampDataExtractionSettingsIR	AL	Names of maps, one for each model currency, that specify IR data extraction settings for purposes of calibration. For the definition of these maps, see "IR Calibration Data Extraction Settings (CR_EQ_FX_IF_IR_HW_NF_JFX)" on page 224.	Referenced maps must exist in the model preferences file. To use the defaults for all settings, provide an empty map.	
ampDataExtractionSettingsFX	AL	Names of maps, one for each foreign currency, that specify FX data extraction settings for purposes of calibration. In the current release, FX calibration data extraction has no settings.	Referenced maps must exist in the model preferences file.	An array of empty maps, one for each foreign currency.
ampDataExtractionSettingsEQ	AL	Names of maps, one for each equity, that specify equity data extraction settings for purposes of calibration. In the current release, equity calibration data extraction has no settings.	Referenced maps must exist in the model preferences file.	An array of empty maps, one for each equity.
ampDataExtractionSettingsII	AL	Names of maps, one for each inflation index, that specify inflation index data extraction settings for purposes of calibration. In the current release, inflation index calibration data extraction has no settings.	Referenced maps must exist in the model preferences file.	An array of empty maps, one for each inflation index.

Example

```
CR_EQ_FX_IF_IR_HW_NF_JFX_DataExtractionSettings, {
  ampSettingsCDS, AL, mpSettingsCDS_CS1, mpSettingsCDS_CS2
  ampDataExtractionSettingsIR, AL, Swaption_DataExtractionSetting
  ..., Swaption_DataExtractionSetting, Swaption_DataExtractionSetting
  ..., Swaption_DataExtractionSetting
  bExtrapolateDF, B, TRUE
  nMonthsExtrapDFEnd, N, 10
  aaidxForeignCCY, AL, aidxForeignCCY_CS1, aidxForeignCCY_CS2
}
```

10.3.4.1 CR Calibration Data Extraction Settings (CR_EQ_FX_IF_IR_HW_NF_JFX)

The `ampSettingsCDS` member of the data extraction settings map refers to other maps that each specify settings for CR calibration data extraction for one credit name.

You can choose whether to use the model's internal survival probability bootstrapper (`bUseMFWKStripper` = TRUE), or the external generic survival probability bootstrapper (`bUseMFWKStripper` = FALSE).

The model's internal survival probability bootstrapper uses the assumption that defaults occur at the mid-points of each coupon period.

For information about the methodology of the external bootstrapper, see the following Markit Analytics document: *CDS Pricing and Bootstrapping Methodology Notes*.

The sections below define the data extraction settings maps for the internal and external survival probability bootstrappers.

10.3.4.1.1 With the Internal Survival Probability Bootstrapper

The following table defines the members of a CR calibration data extraction settings map for the CR_EQ_FX_IF_IR_HW_NF_JFX model when you use the model's internal survival probability bootstrapper.

Table 10.11 CR Calibration Data Extraction Settings Map for CR_EQ_FX_IF_IR_HW_NF_JFX (Internal Survival Probability Bootstrapper)

Map Key	Type Code	Description	Constraints	Default Value
`strHolidays`	S	(Optional) Name of the relevant set of holidays for adjusting the CDS schedule dates. If omitted, no adjustment is performed.	Name must be the key in the holidays HDF5 file.	
`strBusDayConv`	S	Business day convention for adjusting CDS schedule dates.	See Table B.1 on page 326.	AFTER
`bUseIMMDates`	B	Whether to use IMM dates. If the calibration date is not an IMM date, the CDS maturity is taken to be from the next IMM date.	One of: • TRUE • FALSE	TRUE

Table 10.11 CR Calibration Data Extraction Settings Map for CR_EQ_FX_IF_IR_HW_NF_JFX (Internal Survival Probability Bootstrapper) (Continued)

Map Key	Type Code	Description	Constraints	Default Value
bRoundMidPointToNearestDay	B	Whether to round the coupon period mid points, calculated for accrued interest, to the nearest day.	One of: • TRUE • FALSE	TRUE
bUseYearFracForAccInt	B	Whether to use the year fraction in the calculation of the accrued interest using midpoint approximation.	One of: • TRUE • FALSE	TRUE
rDaysPerAnnumAccInt	R	Number of days per annum in the calculation of the accrued interest using midpoint approximation, if bUseYearFracForAccInt is FALSE.		365.25[dy]
rFwdHazardRateFloor	R	Floor value for the forward hazard rate in bootstrapping.		1e-5
bAccInt	B	Whether to use the accrued interest in bootstrapping.	One of: • TRUE • FALSE	TRUE
bTest	B	Whether to perform the round trip test on par credit spread in bootstrapping.	One of: • TRUE • FALSE	FALSE
bBootstrapClean	B	Whether to take into account the accrued rebate for IMM dates in bootstrapping.	One of: • TRUE • FALSE	TRUE for spread quote data. FALSE for upfront fee quote data.
strSPInterpType	S	Survival probability interpolation method: • Log-linear interpolation on survival probabilities (SPLogLin) • Linear interpolation on survival probability yields (SPYieldLin)	One of: • SPLogLin • SPYieldLin	SPLogLin
bUseBisection	B	Whether to use the bisection method for root finding (TRUE) or the Newton-Raphson method (FALSE).	One of: • TRUE • FALSE	FALSE
rNRTol	R	Tolerance value for the Newton-Raphson method of root finding.		1e-8
nNRMaxIter	N	Maximum number of iterations for Newton-Raphson root finding.		50

Table 10.11 CR Calibration Data Extraction Settings Map for CR_EQ_FX_IF_IR_HW_NF_JFX (Internal Survival Probability Bootstrapper) (Continued)

Map Key	Type Code	Description	Constraints	Default Value
`rSlopeTol`	R	Tolerance for checking if the slope of the objective function is approaching zero in the Newton-Raphson method.		1e-5
`mpOptionsRootGridX`	L	(Optional) Name of a map that specifies settings for root finding by the bisection method.		
`rBisectionLB`	R	Lower bound used in the bisection method of root finding.		0
`rBisectionUB`	R	Upper bound used in the bisection method of root finding.		1
`bLastPeriodAccrualEndUnadjusted`	B	Whether to use the unadjusted accrual end date for the last coupon period.	One of: • TRUE • FALSE	TRUE
`bIMMStepInNext`	B	Whether to use the next date after the calibration date as the IMM step-in date.	One of: • TRUE • FALSE	TRUE
`bFirstPartialIMMCoupon`	B	Whether to use the first partial coupon with IMM dates.	One of: • TRUE • FALSE	FALSE
`bUpfrontFee`	B	Whether the underlying curve data represents upfront fee quotes (TRUE) or par credit spreads (FALSE).	One of: • TRUE • FALSE	FALSE
`oUpfrontFeeFixedCoupon`	R or AR	Fixed coupon rate to use in the calculation when the input credit data is upfront fee quotes. Specify a scalar input (R) if fixed coupons are the same for all maturities, or an array (AR) if fixed coupons are different for different maturities.		0.01
`anUpfrontFeeScheduleMonths`	AN	(Optional) Maturity, as number of months, for each fixed coupon rate for upfront fee quote data. Required when `oUpfrontFeeFixedCoupon` is an array.	Same number of elements as `oUpfrontFeeFixedCoupon`.	
`bReturnDailySPCurve`	B	Whether to return daily survival probability.	One of: • TRUE • FALSE	FALSE
`nSettlementLag`	N	Number of days after which the contract must be settled.		0

Example

```
mpSettingsCDS_CS1, {
  bUseIMMDates, B, false
}
```

10.3.4.1.1.1 Root-Finding Settings (CR_EQ_FX_IF_IR_HW_NF_JFX)

The `mpOptionsRootGridX` member of the CR calibration data extraction settings map above refers to another input map that specifies root-finding settings for the bisection method. These are the options that are parameters of the `RootGridX()` function (for more information see the *QuIC Functions Reference* document which is a set of HTML files included in an Analytics package). The following table defines the members of this map.

Table 10.12 CR Root-Finding Settings Map for CR_EQ_FX_IF_IR_HW_NF_JFX

Map Key	Type Code	Description	Constraints	Default Value
`nDivs`	N	Number of subdivision operations to perform.		30

Example

```
CRDataExtraction_RootFindingSettings, {
  nDivs, N, 50
}
```

10.3.4.1.2 With the External Survival Probability Bootstrapper

The following table defines the members of a CR calibration data extraction settings map for the CR_EQ_FX_IF_IR_HW_NF_JFX model when you use the external generic survival probability bootstrapper.

Table 10.13 CR Calibration Data Extraction Settings Map for CR_EQ_FX_IF_IR_HW_NF_JFX (External Survival Probability Bootstrapper)

Map Key	Type Code	Description	Constraints	Default Value
`strSPFrequency`	S	(Optional) Frequency of the survival probability dates. If set to `COUPONDATES`, the survival probability is generated at the union of the coupon dates of all the CDS instruments used in the bootstrapping. If omitted, the survival probability is generated on the node points of the input credit curve.	One of: • `COUPONDATES` • `DAILY` • `WEEKLY` • `MONTHLY` • `QUARTERLY` • `SEMIANNUAL` • `ANNUAL`	

Table 10.13 CR Calibration Data Extraction Settings Map for CR_EQ_FX_IF_IR_HW_NF_JFX (External Survival Probability Bootstrapper) (Continued)

Map Key	Type Code	Description	Constraints	Default Value
`strHolidayListPremiumLeg`	S	(Optional) Name of the relevant set of holidays for adjusting the CDS schedule dates for the premium leg. If omitted, no adjustment is performed.	Name must be the key in the holidays HDF5 file.	
`strHolidayListProtectionLeg`	S	(Optional) Name of the relevant set of holidays for adjusting the CDS schedule dates for the protection leg. If omitted, no adjustment is performed.	Name must be the key in the holidays HDF5 file.	
`mpCDSBootstrapperSettings`	L	Name of a map that specifies the CDS bootstrapper settings. For a definition of this map, see Table 10.14 on page 218.		
`mpCDSPricerSettings`	L	(Optional) Name of a map that specifies the CDS pricer settings. For a definition of this map, see Table 10.15 on page 219 and Table 10.16 on page 222. Omit this input if the reference credit curve is of type `SurvivalProbability`.		
`mpCDSPricerScheduleSettings`	L	(Optional) Name of a map that specifies the settings for the schedule generation of the CDS pricer. For a definition of this map, see Table 10.17 on page 224. Omit this input if the reference credit curve is of type `SurvivalProbability`.		

Example

```
DataExtractionSettings_ExternalSPBootstrapper_ObligorA {
  strHolidayListPremiumLeg, S, USD
  strHolidayListProtectionLeg, S, WE
  mpCDSBootstrapperSettings, L, CDSBootstrapper_SPEnd
  mpCDSPricerSettings, L, CDSPricer_RollDefaultDates
  mpCDSPricerScheduleSettings, L, CDSPricerSchedule_IMMDates
}
```

10.3.4.1.2.1 External CDS Bootstrapper Settings

The mpCDSBootstrapperSettings member of the CR calibration data extraction settings map above refers to another input map that specifies survival probability bootstrapper settings. The following table defines the members of this map.

Table 10.14 External CDS Bootstrapper Settings Map

Map Key	Type Code	Description	Constraints	Default Value
strCDSBootstrapper	S	Bootstrapper type.	CDSBootstrapperSinglNameSPEnd	
bFloor	B	Whether to floor the value of the optimization parameter in bootstrapping.	One of: • TRUE • FALSE	TRUE
bRoundTripTest	B	Whether to perform the round trip test on the CDS price in bootstrapping.	One of: • TRUE • FALSE	FALSE
bUseYearFracSP	B	Whether to use the year fraction in the calculation of the survival probability, yield, or spot hazard rate.	One of: • TRUE • FALSE	FALSE
nNRMaxIter	N	Maximum number of iterations for Newton-Raphson root finding.		50
rFloor	R	Floor value for the optimization parameter in bootstrapping.		1e-15
rNRTol	R	Tolerance value for the Newton-Raphson method of root finding.		1e-15
rSPDaysPerAnnum	R	(Optional) Number of days per annum in the calculation of the survival probability, yield, or spot hazard rate, if bUseYearFracSP is FALSE. If omitted, the relevant attribute of the credit curve is used.		365 (if not available from the credit curve)
strIncorrectSurvProbPoints	S	Method to handle incorrect survival probability points generated in the bootstrapping.	One of: • ignore • exclude • flatExtrap	exclude
strOptimizationObject	S	Object on which to perform the optimization.	One of: • spotHazardRate • SPYield • SP	spotHazardRate
strSPDaycount	S	(Optional) Day count convention in the calculation of the survival probability, yield, or spot hazard rate, if bUseYearFracSP is TRUE. If omitted, the relevant attribute of the credit curve is used.	See Table B.2 on page 327.	ACT365FIXED (if not available from the credit curve)

Table 10.14 External CDS Bootstrapper Settings Map (Continued)

Map Key	Type Code	Description	Constraints	Default Value
strSPInterpObject	S	Object to interpolate and extrapolate on (log-lin for SP; lin for SPYield).	One of: • SPYield • SP	SPYield
strSPCompounding	S	Compounding frequency of the survival probability curve.	One of: • DAILY • WEEKLY • MONTHLY • QUARTERLY • SEMIANNUAL • ANNUAL • SIMPLE • CONTINUOUS	CONTINUOUS
strSPYieldExtrap	S	Extrapolation method to use when the interpolation is performed on survival probability yield—that is, strSPInterpObject is set to SPYield.	See Table B.3 on page 328.	lin

Example

```
CDSBootstrapper_SPEnd {
  strCDSBootstrapper, S, CDSBootstrapperSingleNameSPEnd
  strSPInterpObject, S, SPYield
  strSPCompounding, S, ANNUAL
  strOptimizationObject, S, spotHazardRate
}
```

10.3.4.1.2.2 External CDS Pricer Settings: Mid-Point Default Pricer

The mpCDSPricerSettings member of the CR calibration data extraction settings map above refers to another input map that specifies CDS pricer settings. The map can be one of two types. The table below defines the members of the setting map for the pricer CDSPricerSISingleNameMidPointDefault in which the default date is assumed to be the mid-point of a coupon period.

Table 10.15 External CDS Pricer Settings Map (CDSPricerSISingleNameMidPointDefault)

Map Key	Type Code	Description	Constraints	Default Value
strCDSPricer	S	CDS pricer type.	CDSPricerSISingleNameMidPointDefault	

Table 10.15 External CDS Pricer Settings Map (`CDSPricerSISingleNameMidPointDefault`)

Map Key	Type Code	Description	Constraints	Default Value
`arCDSFixedCoupon`	AR	(Optional) Fixed coupon rate to use in bootstrapping when the input credit data is upfront fee quotes (`bUpfrontFee` is `TRUE` in the `mpCDSPricerScheduleSettings` map), for the CDS names. The first element, which corresponds to the first name, is used.		`0.01`
`arNotional`	AR	Constant notional for the CDS names. The first element, which corresponds to the first name, is used.		`1.0`
`arRecoveryRate`	AR	(Optional) Recovery rate to use in survival probability bootstrapping and in scaling exposures in valuation adjustment, for the CDS names. The first element, which corresponds to the first name, is used.		`0.4`
`bAccInt`	B	Whether to use the accrued interest in bootstrapping.	One of: • `TRUE` • `FALSE`	`TRUE`
`bClean`	B	Whether to take into account the accrued rebate for the first coupon in bootstrapping.	One of: • `TRUE` • `FALSE`	`TRUE`
`bFirstPartialCoupon`	B	Whether to use the first partial coupon.	One of: • `TRUE` • `FALSE`	`FALSE`
`bPayPremium`	B	Whether to pay premiums (buy the insurance).	One of: • `TRUE` • `FALSE`	`TRUE`
`bRoundMidPointToNearestDay`	B	Whether to round the coupon period mid points, calculated for accrued interest, to the nearest day.	One of: • `TRUE` • `FALSE`	`TRUE`
`bUseYearFracForAccInt`	B	Whether to use the year fraction in the calculation of the accrued interest.	One of: • `TRUE` • `FALSE`	`TRUE`

Table 10.15 External CDS Pricer Settings Map (CDSPricerSISingleNameMidPointDefault)

Map Key	Type Code	Description	Constraints	Default Value
rDaysPerAnnumAccInt	R	(Optional) Number of days per annum in the calculation of the accrued interest, if bUseYearFracForAccInt is FALSE. If omitted, the relevant attribute of the par credit spread curve is used.		
strBusDayConvPremiumLeg	S	Business day convention for adjusting the CDS schedule dates for the premium leg.	See Table B.1 on page 326.	NA
strBusDayConvProtectionLeg	S	Business day convention for adjusting the CDS schedule dates for the protection leg.	See Table B.1 on page 326.	strBusDayConvPremiumLeg
strDaycount	S	(Optional) Day count convention in the calculation of the accrued interest, if bUseYearFracForAccInt is TRUE. If omitted, the relevant attribute of the par credit spread curve is used.	See Table B.2 on page 327.	
strLastPeriodEndDateType	S	Type of accrual end date for the last coupon period.	One of: • adjusted • adjustedAddOneDay • unadjusted • unadjustedAddOneDay	unadjustedAddOneDay

Example

```
SampleCDSPricerSettings_MidpointDefault, {
  strCDSPricer, S, CDSPricerSISingleNameMidPointDefault
  strBusDayConvPremiumLeg, S, MODFOLLOWING
  strBusDayConvProtectionLeg, S, MODFOLLOWING
  bRoundMidPointToNearestDay, B, TRUE
  bClean, B, TRUE
  bUseYearFracForAccInt, B, TRUE
  strDaycount, S, ACT365
  strLastPeriodEndDateType, S, unadjustedAddOneDay
}
```

10.3.4.1.2.3 External CDS Pricer Settings: Roll Default Dates Pricer

The mpCDSPricerSettings member of the CR calibration data extraction settings map above refers to another input map that specifies CDS pricer settings. The map can be one of two types. The table below defines the members of the setting map for the pricer CDSPricerSISingleNameRollDefaultDates in which the default date is assumed to be a whole number of months from the later of the protection start date or the valuation date.

Table 10.16 External CDS Pricer Settings Map (`CDSPricerSISingleNameRollDefaultDates`)

Map Key	Type Code	Description	Constraints	Default Value
`strCDSPricer`	S	CDS pricer type.	`CDSPricerSISingleNameRollDefaultDates`	
`arCDSFixedCoupon`	AR	(Optional) Fixed coupon rate to use in bootstrapping when the input credit data is upfront fee quotes (`bUpfrontFee` is `TRUE` in the `mpCDSPricerScheduleSettings` map), for the CDS names. The first element, which corresponds to the first name, is used.		`0.01`
`arNotional`	AR	Constant notional for the CDS names. The first element, which corresponds to the first name, is used.		`1.0`
`arRecoveryRate`	AR	(Optional) Recovery rate to use in survival probability bootstrapping and in scaling exposures in valuation adjustment, for the CDS names. The first element, which corresponds to the first name, is used.		`0.4`
`bAccInt`	B	Whether to use the accrued interest in bootstrapping.	One of: • `TRUE` • `FALSE`	`TRUE`
`bClean`	B	Whether to take into account the accrued rebate for the first coupon in bootstrapping.	One of: • `TRUE` • `FALSE`	`TRUE`
`bPayPremium`	B	Whether to pay premiums (buy the insurance).	One of: • `TRUE` • `FALSE`	`TRUE`
`bUseYearFracForAccInt`	B	Whether to use the year fraction in the calculation of the accrued interest.	One of: • `TRUE` • `FALSE`	`TRUE`
`nMonthDefaultPeriod`	N	Interval (in months) between two default dates.		`3`
`rDaysPerAnnumAccInt`	R	(Optional) Number of days per annum in the calculation of the accrued interest, if `bUseYearFracForAccInt` is `FALSE`. If omitted, the relevant attribute of the par credit spread curve is used.		

Table 10.16 External CDS Pricer Settings Map (`CDSPricerSISingleNameRollDefaultDates`)

Map Key	Type Code	Description	Constraints	Default Value
`strBusDayConvPremiumLeg`	S	Business day convention for adjusting the CDS schedule dates for the premium leg.	See Table B.1 on page 326.	NA
`strBusDayConvProtectionLeg`	S	Business day convention for adjusting the CDS schedule dates for the protection leg.	See Table B.1 on page 326.	NA
`strDaycount`	S	(Optional) Day count convention in the calculation of the accrued interest, if `bUseYearFracForAccInt` is TRUE. If omitted, the relevant attribute of the par credit spread curve is used.	See Table B.2 on page 327.	
`strFirstPeriodStartDateType`	S	Type of accrual start date for the first coupon period.	One of: • `adjusted` • `unadjusted`	`adjusted`
`strLastDefaultPeriodEndDateType`	S	Type of accrual end date for the last default period.	One of: • `adjusted` • `unadjusted`	`unadjusted`
`strLastPeriodEndDateType`	S	Type of accrual end date for the last coupon period.	One of: • `adjusted` • `adjustedAddOneDay` • `unadjusted` • `unadjustedAddOneDay`	`unadjustedAddOneDay`

Example

```
SampleCDSPricerSettings_RollDefaultDates, {
  strCDSPricer, S, CDSPricerSISingleNameRollDefaultDates
  strBusDayConvPremiumLeg, S, MODFOLLOWING
  strBusDayConvProtectionLeg, S, MODFOLLOWING
  nMonthDefaultPeriod, N, 3
  bClean, B, TRUE
  bUseYearFracForAccInt, B, TRUE
  strDaycount, S, ACT365FIXED
  strLastPeriodEndDateType, S, unadjustedAddOneDay
}
```

10.3.4.1.2.4 External CDS Pricer Schedule Generation Settings

The `mpCDSPricerScheduleSettings` member of the CR calibration data extraction settings map above refers to another input map that specifies settings for the

schedule generation of the CDS pricers. The following table defines the members of this map.

Table 10.17 External CDS Pricer Schedule Generation Settings Map

Map Key	Type Code	Description	Constraints	Default Value
`bUseIMMDates`	B	Whether to use IMM dates. If the valuation date is not an IMM date, the CDS maturity is taken to be from the next IMM date.	One of: • TRUE • FALSE	TRUE
`bIMMStepInNext`	B	Whether to use the next date after the valuation date as the IMM step-in date.	One of: • TRUE • FALSE	TRUE
`bUpfrontFee`	B	Whether the underlying credit curve data represents upfront fee quotes (TRUE) or par credit spreads (FALSE).	One of: • TRUE • FALSE	FALSE

Example

```
CDSPricerSchedule_IMMDates {
 bUseIMMDates, B, TRUE
}
```

10.3.4.2 IR Calibration Data Extraction Settings (CR_EQ_FX_IF_IR_HW_NF_JFX)

The `ampDataExtractionSettingsIR` member of the data extraction settings map refers to other maps that each specify settings for IR calibration data extraction for one currency. The following table defines the members of an IR calibration data extraction settings map for the CR_EQ_FX_IF_IR_HW_NF_JFX model.

Table 10.18 IR Calibration Data Extraction Settings Map for CR_EQ_FX_IF_IR_HW_NF_JFX

Map Key	Type Code	Description	Constraints	Default Value
`strMethod`	S	Type of calibration data.	One of: • `Swaption` • `SelectedSwaptions`	

Table 10.18 IR Calibration Data Extraction Settings Map for CR_EQ_FX_IF_IR_HW_NF_JFX

Map Key	Type Code	Description	Constraints	Default Value
`rSwaptionShift`	R	(Optional) If specified, the market swaption price in the calibration of the model is calculated under the assumption that the swap rate has a shifted log-normal distribution with the specified shift size. In this case, the swaption price in the calibration is calculated using Black's formula with the adjusted swap rate and strike obtained by subtracting `rSwaptionShift` from the original swap rate and strike of the calibrating swaptions.		0
`strDaycountFixed`	S	(Optional) Day count convention in the fixed leg of the calibrating swaptions.	See Table B.2 on page 327.	The *`dayCountConv`* attribute of the input swaption volatility curve is used.
`nSwapTenorFixed`	N	(Optional) Coupon frequency (in months) in the fixed leg of the calibrating swaptions.		The *`tenor`* attribute of the input swaption volatility curve is used.
Use the additional inputs in this section only when `strMethod` is `SelectedSwaptions`				
`astrSwaptionExpiry`	AS	(Optional) Time to expiry to specify the swaption volatilities for extraction from the input swaption volatility curve, in the same units as the expiry ordinates in the curve. If not provided, the times to expiry are assumed to be the expiry ordinate values of the input swaption volatility curve.		
`anSwaptionLength`	AN	(Optional) Lengths in months of the swaptions to specify the volatility for extraction from the input swaption volatility curve, one for each expiry date specified by `astrSwaptionExpiry`. If not provided, the co-terminal swaption volatility is extracted for all expiry dates specified in `astrSwaptionExpiry`. Ignored if `astrSwaptionExpiry` is omitted.	Same number of elements as `astrSwaptionExpiry`.	

Table 10.18 IR Calibration Data Extraction Settings Map for CR_EQ_FX_IF_IR_HW_NF_JFX

Map Key	Type Code	Description	Constraints	Default Value
`arSwaptionStrike`	AR	(Optional) Swaption strike to specify the volatility for extraction from the input swaption volatility curve, one for each expiry date specified by `astrSwaptionExpiry`. If not provided, the at-the-money strike is used for all expiry dates specified in `astrSwaptionExpiry`. Ignored if `astrSwaptionExpiry` is omitted. Used only when the swaption volatility curve is of type `SwaptionVolCube`.	Same number of elements as `astrSwaptionExpiry`.	
`strSwaptionStrikeType`	S	(Optional) Type of the strikes specified in `arSwaptionStrike`. Ignored if `arSwaptionStrike` is omitted. Used only when the swaption volatility curve is of type `SwaptionVolCube`.	One of: • `ABSOLUTE` • `F-K` • `K-F` • `F/K` • `K/F` F is the underlying par swap rate for the swaption period. `ABSOLUTE` means that values represent the strike K. The remaining strike types mean that values are specified in relative terms.	`ABSOLUTE`
`idxBasisCurveCalib`	N	(Optional) Index of the interest rate curve to use for additive LIBOR basis adjustment in the calculation of the swap rate during the extraction of the ATM volatility.	Integer between 0 and $n-1$, where n is the number of curves specified by the market data map member `aBasisCurve`.	The LIBOR basis adjustment is not performed.
`idxBasisCurveCalibDisc`	N	(Optional) Index of the interest rate curve to use for discounting in the calculation of the swap rate during the extraction of the ATM volatility. Ignored if `bUseBasisCurveForCalibDiscounting` is set to TRUE.	Integer between 0 and $n-1$, where n is the number of curves specified by the market data map member `aBasisCurve`.	Interest rate curve for the currency of this map, specified by the market data map member `aIRCurve`.
`bUseBasisCurveForCalibDiscounting`	B	Whether to use the basis curve, if specified by `idxBasisCurveCalib`, for both discounting and forecasting in the calculation of the swap rate (`TRUE`) or just for forecasting (`FALSE`).	One of: • `TRUE` • `FALSE`	`FALSE`

Example

```
Swaption_DataExtractionSetting, {
  strMethod, S, Swaption
}
```

Chapter 11

Hybrid Commodity Credit Equity Inflation Multicurrency Model with Black-Karasinski Model for Hazard Rates

In the hybrid commodify credit equity inflation multicurrency extension of the multifactor Hull-White interest rate model (CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F), a single-currency multifactor Hull-White model is used for the nominal interest rate for each currency. In addition, the spread between the nominal and real interest rates of each currency is also modelled as a single-currency multifactor Hull-White model. For each spot foreign exchange rate, spot equity price, spot commodity price, and inflation index, the log-normal model is used. (Each exchange rate, each spot equity price, each spot commodity price, and each inflation index is modelled with one driving factor.) For each commodity, the spread between interest rate and convenience yield is modelled using a multifactor Hull-White model. For credit modelling, the dynamics of the hazard rate for each credit name is modelled by a single-factor log-normal Black-Karasinski model.

This model also supports derived inflation indexes. A derived inflation index has the same driving factors as a core inflation index and inflation index rate curve, but has different inflation index and inflation rate curve starting values.

For information about the methodology of the CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F model, see the following chapter in *Markit Analytics Model Framework Mathematical Reference*: "Hybrid Commodity Credit Equity Inflation Multi-Currency Model with Multi-Factor Hull-White Models for Interest Rates and Single Factor Black-Karasinski Models for Hazard Rates”.

11.1 Module (CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F)

The Model Framework module that implements the hybrid credit commodity equity inflation multicurrency extension of the multifactor Hull-White interest rate model (CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F) is as follows:

```
quic_model_cm_cr_eq_fx_if_ir_hw_nf_bk_1f:3.0
```

Combine this module name with the module component names identified in this chapter to form a complete module reference. For example, if the component is `QModel_CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F`, the complete module reference is as follows:

```
QModel_CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F@quic_model_cm_cr_eq_fx_if_ir_hw_nf_bk_1f:3.0
```

11.2 Market Data Generator Parameters (CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F)

A market data generator parameters set for the Model Framework market data generator includes certain parameters whose value depends on the particular model. These include some parameters that are used directly by the generator itself and others that are used only by the Model Framework model that it invokes (in particular by the model’s simulator component). For descriptions of the direct generator parameters, see the *Markit Analytics Simulation Framework User Guide*. The parameters that are used by Model Framework simulators are described in “Model Framework Simulator Settings” on page 28.

Some of the simulator settings are used by all models and others are used only by certain models. For the latter subset of settings, the information below shows which ones are used by this model.

Generator Parameter: `strSimulatorMFWKReference`

The parameter `strSimulatorMFWKReference` specifies the simulator plug-in for the model. The following values of this parameter are available for the CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F model:

- Simulation algorithm under the risk-neutral measure:

  ```
  QMCSimulator_CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F_RNM@quic_model_cm_cr_eq_fx_if_ir_hw_nf_bk_1f:3.0
  ```

- Euler simulation algorithm under the risk-neutral measure:

```
QMCSimulator_CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F_RNM_Euler@quic_mode
l_cm_cr_eq_fx_if_ir_hw_nf_bk_1f:3.0
```

Applicability of Simulator Settings

The following table identifies which simulator plug-ins (if any) support the specified simulator settings.

Table 11.1 Support for Simulator Settings (CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F)

Parameter	Simulators That Support the Parameter
`bStepOnDFDates`	• `QMCSimulator_CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F_RNM` • `QMCSimulator_CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F_RNM_Euler`
`bPrecalculateCovariances`	• `QMCSimulator_CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F_RNM` • `QMCSimulator_CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F_RNM_Euler`
`bUseEigenSym` and `bUsePCA`	• `QMCSimulator_CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F_RNM` • `QMCSimulator_CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F_RNM_Euler`
`bCholesky`	Not applicable
`strDecomposition`	Not applicable
`bUseStartEndNumeraireCalc`	• `QMCSimulator_CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F_RNM` • `QMCSimulator_CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F_RNM_Euler`
`bUseForeignQuantoAdjustment`	Not applicable
`bUseDeterministicFXDrifts`	Not applicable
`bUseDeterministicInflationDrifts`	Not applicable
`bApproximateXIntegral`	Not applicable

11.3 Model Preferences (CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F)

You specify the settings for the model in a model preferences map and in the subsidiary maps that it references. For a general description of a model preferences map, see “Model Preferences Map” on page 32.

11.3.1 Components (CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F)

The following table identifies the available plug-ins (components of the CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F module) that implement the model. You specify these as values of members of the model preferences map in the form of full module references.

Table 11.2 Model Plug-In Components (CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F)

Model Preference	Available Components of the Module
`Model`	`QModel_CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F`
`CalibrationMethod`	One of: • `QModelCalibration_CM_CR_EQ_FX_IF_IR_HW_1F_BK_1F` For internal calibration. • `QModelCalibration_CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F_ExtCal` For external calibration. Supports time-varying parameters.
`DataExtractionMethod`	One of: • `QDataExtraction_CM_CR_EQ_FX_IF_IR_HW_1F_BK_1F` For internal calibration. • `QDataExtraction_CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F_ExtCal` For external calibration.

In addition, you must specify the maps that are identified by the other members of the model preferences map. The remainder of this chapter defines these subsidiary maps.

Example

The following figure shows a sample model preferences map that specifies components for this model. In the model preferences file, each map member occupies a single line.

```
CM_CR_EQ_FX_IF_IR_HW_NF_ModelPrefs, {
  Model, S, QModel_CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F@quic_model_cm_cr_eq_fx_if_ir_hw_nf_bk_1f:
   3.0
  CalibrationMethod, S, QModelCalibration_CM_CR_EQ_FX_IF_IR_HW_1F_BK_1F@quic_model_cm_cr_
   eq_fx_if_ir_hw_nf_bk_1f:3.0
  CalibrationSettings, L, CM_CR_EQ_FX_IF_IR_HW_NF_CalibrationSettings
  CurveNames, L, CM_CR_EQ_FX_IF_IR_HW_NF_CurveNames
  DataExtractionMethod, S, QDataExtraction_CM_CR_EQ_FX_IF_IR_HW_1F_BK_1F@quic_model_
   cm_cr_eq_fx_if_ir_hw_nf_bk_1f:3.0
  DataExtractionSettings, L, CM_CR_EQ_FX_IF_IR_HW_NF_DataExtractionSettings
  TradeInfo, L, PORTFOLIO_INFO
}
```

11.3.2 Calibration Settings (CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F)

The `CalibrationSettings` member of the model preferences map refers to another map that specifies parameters related to calibration of the model.

The parameters of the IR, FX, equity, commodity, and inflation models can be calibrated either internally or externally. For external calibration, the resulting model parameters are treated as inputs. For internal calibration, a single-currency single-factor Hull-White model is used for the nominal interest rate for each currency. The spread between the nominal and real interest rates of each currency and the convenience spread for each commodity is also modelled as a single-currency single-factor Hull-While model. The inflation index volatilities can be calibrated against inflation index options similar to the spot FX rate volatilities.

The credit model is calibrated internally to the market data to reproduce the initial CDS prices.

The table below defines the members of a calibration settings map for the CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F model. The descriptions of these parameters use the following notation:

- H is the number of currencies. Hence, H–1 is the number of exchange rates.
- E is the number of equities.
- I is the number of inflation indexes.
- C is the number of credit names.
- L is the number of commodities.
- K is the total number of factors in the model.

The symbols in the Equation Symbol column refer to the following chapter in *Markit Analytics Model Framework Mathematical Reference*: “Hybrid Commodity Credit Equity Inflation Multi-Currency Model with Multi-Factor Hull-White Models for Interest Rates and Single Factor Black-Karasinski Models for Hazard Rates”.

Table 11.3 Calibration Settings Map for CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F

Map Key	Type Code	Description	Constraints	Default Value	Equation Symbol
The inputs in this section are common to all the calibration methods.					
`astrCCY`	AS	Names of the H currencies. The first name is the domestic currency.	Standard 3-character currency identifiers		
`astrEquity`	AS	Names of the E equities.			
`astrEquityCCY`	AS	Names of the E currencies, corresponding to the equities in `astrEquity`.	Standard 3-character currency identifier. All names must be present in `astrCCY`.		
`astrName`	AS	Credit names.	Number of elements must be C.		
`arRecoveryRate`	AR	(Optional) Recovery rates to use for each credit name. Overrides the recovery rate attribute of the input par credit spread curves (if provided).	Number of elements must be C.	If a survival probability curve is input for a name, the value defaults to 0.4.	

Table 11.3 Calibration Settings Map for CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F (Continued)

Map Key	Type Code	Description	Constraints	Default Value	Equation Symbol
`rDaysPerAnnumCR`	R	Number of days per annum to convert the credit model parameters specified in `arKappa` and `aoSigma`, to daily units.		365.25 [dy]	
`arKappa`	AR	Mean reversion parameters for the hazard rates simulation.	Number of elements must be C.		κ_m
`aoSigma`	AR or AL	Volatility parameters for the hazard rates simulation. Can be provided in either of the following formats. • Array of C real values. Each element specifies the constant volatility for one credit name. • Array of C names of lists of type AR. Each list specifies the piece-wise constant volatility for one credit name for the tenor points provided in `aanTTMSigma`.	Referenced lists (in the AL case) must exist in the model preferences file.		η_m^{CR}
`aanTTMSigma`	AL	Array of C names of lists of types AN. Each list specifies the tenor points (in units specified by `strSigmaTTMUnits`) for the volatility provided in `aoSigma` for one credit name. Omit this input if you specify constant volatilities.			
`strSigmaTTMUnits`	S	Units of the tenors of the hazard rate volatility parameter specified by `aanTTMSigma`.	One of: • `months` • `days`	`months`	
`astrII`	AS	Names of the I inflation indexes.			
`astrIICCY`	AS	Names of the I currencies, corresponding to the inflation indexes in `astrII`.	Standard 3-character currency identifier. All names must be present in `astrCCY`.		
`astrIIDerived`	AS	(Optional) Names of the derived inflation indexes.			

Table 11.3 Calibration Settings Map for CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F (Continued)

Map Key	Type Code	Description	Constraints	Default Value	Equation Symbol
`astrIIDerivedFrom`	AS	(Optional) Names of the core inflation indexes on which the derived indexes are based, one for each derived index. Required if `astrIIDerived` is specified.	All names must be present in `astrII`.		
`bCorrectCorrMtx`	B	Whether to ensure that the input correlation matrix is positive semidefinite by using principal components analysis.	One of: • TRUE • FALSE	TRUE	
`rEigenThreshold`	R	If `bCorrectCorrMtx` is TRUE, all eigenvectors associated with eigenvalues less than this threshold times the largest eigenvalue are set to zero.		1e-15	
`astrCommodity`	AS	Names of the L commodities.			
`astrCommodityCCY`	AS	Names of the L currencies, corresponding to the commodities in `astrCommodity`.	Standard 3-character currency identifier. All names must be present in `astrCCY`.		
`strModelParametersOutputFile`	S	(Optional) File path of the HDF5 file to which the calculated model parameters are written. This file has the same format as a file for externally calibrated parameters. Typically used only for troubleshooting. If omitted, no file is produced.			
`strModelParametersOutputName`	S	(Optional) Name to give this model parameters set in the file specified by `strModelParametersOutputFile`.		`mpModelParams`	
`bOutputCalibrationData`	B	Whether to include the calibration data in the HDF5 file specified by `strModelParametersOutputFile`. Typically used only for troubleshooting because it may significantly increase the size of the file.	One of: • TRUE • FALSE	FALSE	

Table 11.3 Calibration Settings Map for CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F (Continued)

Map Key	Type Code	Description	Constraints	Default Value	Equation Symbol
ampCalibrationSettingsCR	AL	Names of maps, one for each credit name, that specify credit calibration settings. For the definition of these maps, see "Credit Calibration Settings (CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F)" on page 242	Referenced maps must exist in the model preferences file. To use the defaults for all settings, provide an empty map.	An array of empty maps, one for each credit name.	
Use the inputs in this section only when CalibrationMethod is QModelCalibration_CM_CR_EQ_FX_IF_IR_HW_1F_BK_1F					
ampCalibrationSettingsIR	AL	Names of maps, one for each model currency, that specify the IR calibration settings. For the definition of these maps, see "IR Calibration Settings (CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F)" on page 243.	Referenced maps must exist in the model preferences file. To use the defaults for all settings, provide an empty map.		
ampCalibrationSettingsFX	AL	Names of maps, one for each foreign currency, that specify FX calibration settings. For the definition of these maps, see "FX Calibration Settings (CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F)" on page 246.	Referenced maps must exist in the model preferences file. To use the defaults for all settings, provide an empty map.		
ampCalibrationSettingsEQ	AL	Names of maps, one for each equity, that specify equity calibration settings. For the definition of these maps, see "Equity Calibration Settings (CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F)" on page 246.	Referenced maps must exist in the model preferences file. To use the defaults for all settings, provide an empty map.	An array of empty maps, one for each equity.	
ampCalibrationSettingsII	AL	Names of maps, one for each inflation index, that specify inflation index calibration settings. For the definition of these maps, see "Inflation Index Calibration Settings (CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F)" on page 247.	Referenced maps must exist in the model preferences file. To use the defaults for all settings, provide an empty map.	An array of empty maps, one for each inflation index.	

Table 11.3 Calibration Settings Map for CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F (Continued)

Map Key	Type Code	Description	Constraints	Default Value	Equation Symbol
`ampCalibrationSettingsCM`	AL	Names of maps, one for each commodity, that specify commodity calibration settings. For the definition of these maps, see “Commodity Calibration Settings (CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F)” on page 248.	Referenced maps must exist in the model preferences file. To use the defaults for all settings, provide an empty map.	An array of empty maps, one for each commodity.	
`astrBasisCurve`	AS	Nicknames of the interest rate curves used for additive LIBOR basis adjustment.	Include a nickname for each of the curves, in order, specified by the `aBasisCurve` member of the market data map.		
`bOutputFitResults`	B	Whether to report the results of the calibration (comparison of the prices of calibrating instruments from the calibrated model and calculated analytically from market data).	One of: • TRUE • FALSE	FALSE	
`strOutputFile`	S	(Optional) File path of the CSV file to which calibration results are written (if requested by `bOutputFitResults`).		Results are displayed in the audit pane only.	
Use the inputs in this section only when `CalibrationMethod` is `QModelCalibration_CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F_ExtCal`					
`g1dtEta`	GD	Ascending sequence of M+1 dates that define the intervals of the volatility functions.	The first date must be the calibration date.		
`ag1rA`	AL	Names of lists (of type `GR`) that specify the mean-reversion parameters. Each list specifies the parameter for one currency.	Number of elements must be H. Referenced lists must exist in the auxiliary transaction data file.		$a_{k,i}$
`ag1rAlpha`	AL	Names of lists (of type `GR`) that specify the mean-reversion parameters for inflation spreads. Each list specifies the parameter for one spread between nominal and real interest rates for an inflation index.	Number of elements must be I. Referenced lists must exist in the auxiliary transaction data file.		$\alpha_{k,i}$

Table 11.3 Calibration Settings Map for CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F (Continued)

Map Key	Type Code	Description	Constraints	Default Value	Equation Symbol
`ag1rGamma`	AL	Names of lists (of type GR) that specify the mean-reversion parameters for commodity convenience spreads. Each list specifies the parameter for one spread between interest rate and convenience yield for a commodity.	Number of elements must be L. Referenced lists must exist in the auxiliary transaction data file.		$\gamma_{k,i}$
`ag2rEta`	AL	Names of lists (of type AL) for each currency. Each currency list specifies names of lists (of type GR) for each of its K factors. Each currency-factor list specifies the value of the IR volatility parameter (eta) in each of the M time intervals defined by `g1dtEta`. For a given currency-factor pair, the value in interval m applies from `g1dtEta`$_m$ up to but not including `g1dtEta`$_{m+1}$. The value in the last interval is also used on the last date and beyond the last date (constant extrapolation).	Number of elements must be H. Referenced lists must exist in the auxiliary transaction data file.		$\eta_{k,i}(t)$
`ag2rNu`	AL	Names of lists (of type AL) for each spread between nominal and real interest rates for an inflation index. Each spread list specifies names of lists (of type GR) for each of its K factors. Each spread index-factor list specifies the value of the IR volatility parameter (eta) in each of the M time intervals defined by `g1dtEta`. For a given inflation index-factor pair, the value in interval m applies from `g1dtEta`$_m$ up to but not including `g1dtEta`$_{m+1}$. The value in the last interval is also used on the last date and beyond the last date (constant extrapolation).	Number of elements must be I. Referenced lists must exist in the auxiliary transaction data file.		$\nu_{k,i}(t)$

Table 11.3 Calibration Settings Map for CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F (Continued)

Map Key	Type Code	Description	Constraints	Default Value	Equation Symbol
ag2rSigmaCM	AL	Names of lists (of type AL) for each spread between interest rate and convenience yield for a commodity. Each spread list specifies names of lists (of type GR) for each of its K factors. Each spread index-factor list specifies the value of the convenience spread volatility parameter in each of the M time intervals defined by g1dtEta. For a given convenience spread index-factor pair, the value in interval m applies from g1dtEta$_m$ up to but not including g1dtEta$_{m+1}$. The value in the last interval is also used on the last date and beyond the last date (constant extrapolation).	Number of elements must be L. Referenced lists must exist in the auxiliary transaction data file.		$\sigma_{k.i}(t)$
ag1rEtaFX	AL	Names of lists (of type GR) that specify, for each currency, the value of the FX volatility parameter (eta) in each of the M time intervals defined by g1dtEta. For a given currency, the value in interval m applies from g1dtEta$_m$ up to but not including g1dtEta$_{m+1}$. The value in the last interval is also used on the last date and beyond the last date (constant extrapolation).	Number of elements must be H–1. Referenced lists must exist in the auxiliary transaction data file.		$\eta_k^{FX}(t)$
ag1rEtaEquity	AL	Names of lists (of type GR) that specify, for each equity, the value of the volatility parameter (eta) in each of the M time intervals defined by g1dtEta. For a given equity, the value in interval m applies from g1dtEta$_m$ up to but not including g1dtEta$_{m+1}$. The value in the last interval is also used on the last date and beyond the last date (constant extrapolation).	Number of elements must be E. Referenced lists must exist in the auxiliary transaction data file.		$\eta_j^{EQ}(t)$

Table 11.3 Calibration Settings Map for CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F (Continued)

Map Key	Type Code	Description	Constraints	Default Value	Equation Symbol
`ag1rEtaIF`	AL	Names of lists (of type GR) that specify, for each inflation index, the value of the inflation index volatility parameter (eta) in each of the M time intervals defined by `g1dtEta`. For a given inflation index, the value in interval m applies from `g1dtEta`$_m$ up to but not including `g1dtEta`$_{m+1}$. The value in the last interval is also used on the last date and beyond the last date (constant extrapolation).	Number of elements must be I. Referenced lists must exist in the auxiliary transaction data file.		$\eta_k^I(\mathrm{t})$
`ag1rEtaCM`	AL	Names of lists (of type GR) that specify, for each commodity, the value of the commodity spot volatility parameter in each of the M time intervals defined by `g1dtEta`. For a given commodity, the value in interval m applies from `g1dtEta`$_m$ up to but not including `g1dtEta`$_{m+1}$. The value in the last interval is also used on the last date and beyond the last date (constant extrapolation).	Number of elements must be L. Referenced lists must exist in the auxiliary transaction data file.		$\eta_k^{cm}(t)$
`g3rCorrMtx`	AL	Names of lists (of type AL) for each factor. Each factor list specifies names of lists (of type GR) for each pairing with other factors. Each factor-pair list specifies the value of their pairwise correlation as a piecewise function of time over the intervals defined by `g1dtEta`. For a given pair of factors, the value in interval m applies from `g1dtEta`$_m$ up to but not including `g1dtEta`$_{m+1}$. The value in the last interval is also used on the last date and beyond the last date (constant extrapolation). For details, see the note that follows this table.	$-1 \le \rho \le 1$		$\rho(t)$

Note: Construction of g3CorrMtx

The correlations include those between the IR factors (within one currency and between the different currencies), FX factors, equity factors, hazard rate factors, factors of the spread between nominal and real interest rates, and inflation indexes.

Consider a 2-D slice of the g3CorrMtx grid along the eta axis (this is, for a given time). This 2-D factor correlation matrix is square and of length

$$\sum_{i=1}^{H} K_i + (H-1) + E + C + \sum_{j=1}^{I} K_j^I + I + \sum_{j=1}^{L} K_j^{cm} + L$$

in each dimension. It is symmetric, so we consider the construction in only one dimension. Place the risk factors in the following order:

- K_1 factors of the interest rate for currency 1, then the K_2 factors of the interest rate for currency 2, and so on for the H currencies
- (H–1) factors of the exchange rates
- E factors of the spot equity prices
- C factors of the hazard rates
- K_1^I factors of the spread between the nominal and real short rate for the first inflation index, then the K_2^I factors of the spread for the second inflation index, and so on for the I inflation indexes
- I factors of the inflation index
- K_1^{cm} factors of the spread between the interest rate and convenience yield for the first commodity, then the K_2^{cm} factors of the convenience spread for the second commodity, and so on for the L commodities.
- L factors of the commodity spot prices

Example

This example uses the time-varying parameter calibration.

```
CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F_CallibrationSettings_ExtCal, {
  g1dtEta, GD, 2005/10/11, 2005/11/11
  astrCCY, AS, EUR, USD
  astrEquity, AS, SPX
  astrCCYEquity, AS, USD
  astrName, AS, CS1, CS2
  ag1rA, AL, g1rA_EUR, g1rA_USD
  ag2rEta, AL, ag1rEta_EUR, ag1rEta_USD
  ag1rEtaFX, AL, g1rEtaFX_USD
  ag1rEtaEquity, AL, g1rEtaEQ_USD
  arKappa, AR, 0.01
  aoSigma, AL, arSigma_CS1, arSigma_CS2
  aanTTMSigma, AL, arTTMSigma_CS1, arTTMSigma_CS2
  astrCommodity, AS, CM01
  ag1rGamma, AL, g1rGamma_CM01
  ag2rSigmaCM, AL, ag1rSigmaCM_CM01
  ag1rEtaCM, AL, g1rEtaCM_I01
  astrCommodityCCY, AS, EUR
```

```
  g3rCorrMtx, AL
  ..., ag1rCorrMtx_EUR_factor0, ag1rCorrMtx_EUR_factor1
  ..., ag1rCorrMtx_EUR_factor2
  ..., ag1rCorrMtx_USD_factor0, ag1rCorrMtx_USD_factor1
  ..., ag1rCorrMtx_USD_factor2
  ..., ag1rCorrMtx_FX_Vol_USD
  ..., ag1rCorrMtx_SPX_Vol_USD
  ..., ag1rCorrMtx_CS1
  ..., ag1rCorrMtx_CS2
  ..., ag1rCorrMtx_CM01_factor0, ag1rCorrMtx_CM01_factor1
  ..., ag1rCorrMtx_CM01_factor2
  ..., ag1rCorrMtx_CM_Vol_CM01
  bCorrectCorrMtx, B, FALSE
}
```

11.3.2.1 Credit Calibration Settings (CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F)

The ampCalibrationSettingsCR member of a calibration settings map refers to other maps that each specify settings for the calibration of the credit model for one credit name. The following table defines the members of a credit calibration settings map for the CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F model.

Table 11.4 Credit Calibration Settings Map for CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F

Map Key	Type Code	Description	Constraints	Default Value
rMaxTimeStep	R	Maximum time step in the tree calculation when calibrating a credit model.		10[dy]
nBootStrapIter	N	Number of bootstrap iterations to use when calibrating a credit model to CDS with correlations.		2
bUseCreditCorrelations	B	Whether to take into account credit correlations with IR risk factors when calibrating a credit model to CDS.	One of: • TRUE • FALSE	TRUE
nMaxIterNR	N	Maximum number of iterations in Newton-Raphson root finding when calibrating a credit model.		50
rErrorTol	R	Error tolerance in Newton-Raphson root finding when calibrating a credit model.		1e-15
bPruneTree	B	Whether to prune the tree in the tree calculation when calibrating a credit model.	One of: • TRUE • FALSE	TRUE
rPruneStdDev	R	Number of standard deviations to prune tree in the tree calculation when calibrating a credit model.		5
astrInterpXi	AS	Interpolation method to use for the calibrated parameter ξ ξ, one for each credit name.	See Table B.3 on page 328. Number of elements must be C.	lin

Table 11.4 Credit Calibration Settings Map for CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F

Map Key	Type Code	Description	Constraints	Default Value
astrExtrapXi	AS	Extrapolation method to use for the calibrated parameter ξ ξ, one for each credit name.	See Table B.3 on page 328. Number of elements must be C.	lin

Example

```
CS1_CalibrationSettings, {
  rMaxTimeStep, R, 5[dy]
  rPruneStdDev, R, 3
}
```

11.3.2.2 IR Calibration Settings (CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F)

The ampCalibrationSettingsIR member of a calibration settings map refers to other maps that each specify settings for the calibration of the interest rate model for one currency. The following table defines the members of an IR calibration settings map for the CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F model.

Table 11.5 IR Calibration Settings Map for CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F

Map Key	Type Code	Description	Constraints	Default Value
strCCYDom	S	Name of the domestic currency.	Standard 3-character currency identifier	
bUseCapletFormula	B	Whether to use the caplet formula. If set to TRUE, but the input calibrating instruments are swaptions, this setting reverts to FALSE.	One of: • TRUE • FALSE	FALSE
rNotional	R	Notional amount to use when calculating prices during calibration.		1.0
mpRootFindSettings	L	Name of a map of settings for the root-finding procedure.	Referenced map must exist in the model preferences file.	Empty map
bAllowNegativeMR	B	Whether to allow the calibration process to generate a negative mean reversion parameter.	One of: • TRUE • FALSE	FALSE
strBasisCurveCalib	S	(Optional) Nickname of the interest rate curve to use for additive LIBOR basis adjustment during calibration. If omitted, the LIBOR basis adjustment is not performed.	Must be one of the names in astrBasisCurve in the main calibration settings map.	

Table 11.5 IR Calibration Settings Map for CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F

Map Key	Type Code	Description	Constraints	Default Value
`bUseBasisCurveForCalibDiscounting`	B	Whether to use the basis curve, if specified by `strBasisCurveCalib`, for both discounting and forecasting in the calibration (TRUE) or just for forecasting (FALSE).	One of: • TRUE • FALSE	FALSE
`strBasisCurveCalibDisc`	S	(Optional) Nickname of the interest rate curve to use for discounting during calibration. Ignored if `bUseBasisCurveForCalibDiscounting` is set to TRUE.	Must be one of the names in `astrBasisCurve` in the main calibration settings map.	Interest rate curve for the currency of this map, specified by the market data map member `aIRCurve`.
`bNormalVolatilities`	B	Whether to assume normal (TRUE) or log-normal (FALSE) volatilities.	One of: • TRUE • FALSE	FALSE

Example

```
IR_EUR_CalibrationSettings, {
  strBasisCurveCalib, S, EURLibor3M
}
```

11.3.2.2.1 Root-Finding Settings (CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F)

The `mpRootFindSettings` member of an IR calibration settings map refers to another map that specifies settings for the root-finding process. Most of these settings specify various numerical tolerances. Normally, the default values are suitable.

The following table defines the members of a root-finding settings map for the CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F model.

Table 11.6 Root-Finding Settings Map for CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F

Map Key	Type Code	Description	Constraints	Default Value
`rVolSensTol`	R	Volatility sensitivity tolerance		0.001
`rSigmaConst`	R	Sigma used in initial guess for root find (units are per annum). If all calibrating instruments are removed, this value is used as the Hull-White volatility parameter.		0.01
`rErrorTol`	R	Error tolerance for root find to match market prices.		1.0e–14

Table 11.6 Root-Finding Settings Map for CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F

Map Key	Type Code	Description	Constraints	Default Value
`rRelTolNR`	R	Relative tolerance in Newton-Raphson method for root find to match market prices.		1.0e–13
`nMaxIterNR`	N	Maximum number of iterations in Newton-Raphson method for root find to match market prices.		100
`nMaxIterBracket`	N	Maximum number of iterations used in bracketing for root find to match market prices.		20
`rBracketLow`	R	Low value for bracketing for root find to match market prices.		1.0e–10
`rBracketHigh`	R	High value for bracketing for root find to match market prices.		1.0e–1
`nMaxDiv`	N	Maximum number of divisions in bisection for root find to match market prices.		100
`rRootGuessJam`	R	Initial guess for root in Jamshidian decomposition.		0.0
`rErrorTolJam`	R	Error tolerance in Jamshidian decomposition.		1.0e–13
`rRelTolNRJam`	R	Relative tolerance in Newton-Raphson method for root find in Jamshidian decomposition.		1.0e–15
`nMaxIterNRJam`	N	Maximum number of iterations in Newton-Raphson method for root find in Jamshidian decomposition.		100
`rMinXJam`	R	Minimum X value in bracketing for Jamshidian decomposition.		–0.1
`rMaxXJam`	R	Maximum X value in bracketing for Jamshidian decomposition.		0.1
`nMaxDivJam`	N	Maximum number of iterations in bisection for root find in Jamshidian decomposition.		100

11.3.2.3 FX Calibration Settings (CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F)

The `ampCalibrationSettingsFX` member of a calibration settings map refers to other maps that each specify settings for the calibration of the exchange rate model for one pair of currencies. The following table defines the members of an FX calibration settings map for the CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F model.

Table 11.7 FX Calibration Settings Map for CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F

Map Key	Type Code	Description	Constraints	Default Value
`bUseNegativeSpotVols`	B	Whether to add negative FX spot volatilities to the calibrated values during the calibration procedure.	One of: • TRUE • FALSE	FALSE

Example

```
UseNegativeSpotFXVols, {
  bUseNegativeSpotVols, B, TRUE
}
```

11.3.2.4 Equity Calibration Settings (CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F)

The `ampCalibrationSettingsEQ` member of a calibration settings map refers to other maps that each specify settings for the calibration of the equity model for one equity. The following table defines the members of a calibration settings map for the CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F model.

Table 11.8 Equity Calibration Settings Map for CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F

Map Key	Type Code	Description	Constraints	Default Value
`bUseNegativeSpotVols`	B	(Optional) Whether to add negative equity spot volatilities to the calibrated values during the calibration procedure.	One of: • TRUE • FALSE	FALSE

Example

```
UseNegativeSpotEQVols, {
  bUseNegativeSpotVols, B, TRUE
}
```

11.3.2.5 Inflation Index Calibration Settings (CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F)

The ampCalibrationSettingsII member of a calibration settings map refers to other maps that each specify settings for the calibration of the inflation index model for one inflation index. The following table defines the members of a calibration settings map for the CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F model.

Table 11.9 Inflation Index Calibration Settings Map for CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F

Map Key	Type Code	Description	Constraints	Default Value
bCalibrateToIIOptions	B	Whether to calibrate inflation index volatilities from inflation index options. If set to FALSE in any of the inflation index calibration settings maps, you must provide aSpotIIVolCurve in the Market Data Map. If set to TRUE in any of the inflation index calibration settings maps, you must provide aSpotIIImpliedVolCurve in the Market Data Map.	One of: • TRUE • FALSE	TRUE
bUseNegativeSpotVols	B	(Optional) Whether to add negative inflation index spot volatilities to the calibrated values during the calibration procedure. This input applies only when bCalibrateToIIOptions is set to TRUE.	One of: • TRUE • FALSE	FALSE

Example

```
SampleIICalibrationSettings, {
  bCalibrateToIIOptions, B, TRUE
  bUseNegativeSpotVols, B, TRUE
}
```

11.3.2.6 Commodity Calibration Settings (CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F)

The `ampCalibrationSettingsCM` member of a calibration settings map refers to other maps that each specify settings for the calibration of the commodity spot price model for one commodity. The following table defines the members of a calibration settings map for the CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F model.

Table 11.10 Commodity Calibration Settings Map for CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F

Map Key	Type Code	Description	Constraints	Default Value
`bCalibrateToCMOptions`	B	Whether to calibrate commodity spot price volatilities from commodity options. If set to FALSE in any of the commodity calibration settings maps, you must provide `aCMVolCurve` in the Market Data Map. If set to TRUE in any of the commodity calibration settings maps, you must provide `aCMImpliedVolCurve` in the Market Data Map.	One of: • TRUE • FALSE	TRUE
`bUseNegativeSpotVols`	B	(Optional) Whether to add negative commodity spot price volatilities to the calibrated values during the calibration procedure. This input applies only when `bCalibrateToCMOptions` is set to TRUE.	One of: • TRUE • FALSE	FALSE

Example

```
SampleCMCalibrationSettings, {
  bCalibrateToCMOptions, B, TRUE
  bUseNegativeSpotVols, B, TRUE
}
```

11.3.3 Market Data Inputs (CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F)

The `CurveNames` member of the model preferences map refers to a market data map that identifies the market data curves that are required for pricing, simulation, and if applicable, internal model calibration. The following table defines the members of a market data map for the CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F model.

Table 11.11 Market Data Map for CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F

Map Key	Type Code	Description	Constraints	Default Value
`aIRCurve`	AS or AL	Either: • Names of curves for discounting (of type `DiscountFactor`, `Yield`, or `FwdLibor`), one for each currency. • Names of lists that specify a set of curves to use in bootstrapping the discount factor, one for each currency. The first curve or list of curves is for the domestic currency, and the remainder are for the foreign currencies. For details about the lists of curves for bootstrapping, see “Specifying the Data to Use in Bootstrapping” on page 34.	Referenced curves must exist in the market data HDF5 file, or referenced lists must exist in an auxiliary transaction data file. The number of elements must equal the number of currencies. Ordinates of a `Yield` curve must be >0.	
`aINFCurve`	AS	Names of curves (of type `DiscountFactor`, `Yield`, or `InflationRate`) that specify the inflation-bond-related interest rate for each currency, in the same order as the inflation indexes.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of inflation indexes. Ordinates of a `Yield` curve must be >0.	
`aSpotIICurve`	AS	Names of curves (of type `InflationIndex`) that specify the inflation index for each currency, in the same order as the inflation indexes. Must be provided when `bCalibrateToIIOptions` is set to TRUE in the inflation index calibration settings map.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of inflation indexes.	

Table 11.11 Market Data Map for CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F (Continued)

Map Key	Type Code	Description	Constraints	Default Value
`aINFDerivedCurve`	AS	(Optional) Names of curves (of type `Yield`) that specify the inflation-bond-related interest rate for the currency of each derived inflation index, in the same order in which the indexes are listed in the `astrIIDerived` parameter in the calibration settings map. Required if the `astrIIDerived` parameter is specified in the calibration settings map.	Referenced curves must exist in the market data HDF5 file. The number of elements in the array must equal the number of inflation indexes. Ordinates of a `Yield` curve must be >0.	
`aSpotIIDerivedCurve`	AS	(Optional) Names of curves (of type `InflationIndex`) that specify the initial value of each derived inflation index, in the same order in which the indexes are listed in the `astrIIDerived` parameter in the calibration settings map. Required if the `astrIIDerived` parameter is specified in the calibration settings map.	Referenced curves must exist in the market data HDF5 file. The number of elements in the array must equal the number of derived indexes.	
`aSpotFXCurve`	AS	Names of domestic/foreign spot FX curves (of type `Exchange`), one for each currency, in the same order as the IR curves.	The first name, corresponding to the domestic currency, must be `void`. Referenced curves must exist in the market data HDF5 file.	
`aSpotEQCurve`	AS	Names of spot equity curves (of type `Equity` or `EquityIndex`), one for each equity, in the same order as the equities.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of equities.	
`aEQDividendCurve`	AS	Names of equity dividend curves (of type `DiscreteAbsoluteDividend` or `ContinuousYieldDividend`), one for each equity, in the same order as the equities.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of equities.	
`aCreditCurve`	AS	Names of the CDS curves (of type `ParCreditSpread`), one for each credit name, in the same order as the credit names.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of credit names.	

Table 11.11 Market Data Map for CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F (Continued)

Map Key	Type Code	Description	Constraints	Default Value
`aForwardCMCurve`	AS	Names of the commodity futures curves (of type `Commodity`), one for each commodity, in the same order as commodities.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of commodities.	
Use the inputs in this section only when `DataExtractionMethod` is `QDataExtraction_CM_CR_EQ_FX_IF_IR_HW_1F_BK_1F`				
`aINFMeanReversionCurve`	AS	Names of mean reversion curves (of type `MeanReversion`), one for the spread between nominal and real interest rates for each currency, in the same order as the inflation indexes.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of currencies.	
`aINFVolCurve`	AS	Names of volatility curves (of type `ImpliedVol`), one for the spread between nominal and real interest rates for each currency, in the same order as the inflation indexes.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of currencies.	
`aSpotIIVolCurve`	AS	Names of inflation index volatility curves (of type `ImpliedVol`), one for each inflation index, in the same order as the inflation indexes. Must be provided when `bCalibrateToIIOptions` is set to FALSE in the inflation index calibration settings map.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of inflation indexes.	
`aSpotIIImpliedVolCurve`	AS	Names of inflation index option implied volatility curves (of type `ImpliedVol`), one for each inflation index, in the same order as the inflation indexes. Must be provided when `bCalibrateToIIOptions` is set to TRUE in the inflation index calibration settings map.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of inflation indexes.	
`aCMMeanReversionCurve`	AS	Names of mean reversion curves (of type `MeanReversion`), one for the spread between interest rate and convenience yield, for each commodity, in the same order as the commodities.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of commodities.	
`aCMSpreadVolCurve`	AS	Names of volatility curves (of type `CommodityImpliedVol`), one for the spread between interest rate and convenience yield for each commodity, in the same order as the commodities.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of commodities.	

Table 11.11 Market Data Map for CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F (Continued)

Map Key	Type Code	Description	Constraints	Default Value
`aCMVolCurve`	AS	Names of commodity spot volatility curves (of type `CommodityImpliedVol`), one for each commodity, in the same order as the commodities. Must be provided when `bCalibrateToCMOptions` is set to FALSE in the inflation index calibration settings map.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of commodities.	
`aCMImpliedVolCurve`	AS	Names of commodity futures option implied volatility curves (of type `CommodityImpliedVol` or `CommodityImpliedVolMtx`), one for each commodity, in the same order as the commodities. Must be provided when `bCalibrateToCMOptions` is set to TRUE in the commodity calibration settings map.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of commodities.	
`aBasisCurve`	AS	Names of curves (of type `DiscountFactor`, `Yield`, or `FwdLibor`) that specify the forecasting interest rates to use for LIBOR basis adjustments for all relevant currencies.	Referenced curves must exist in the market data HDF5 file. Ordinates of a `Yield` curve must be >0.	
`aMeanReversionCurve`	AS	Names of mean reversion curves (of type `MeanReversion`), one for each currency, in the same order as the IR curves.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of currencies.	
`aCapletVolCurve`	AS	Names of caplet volatility curves (of type `CapletVol`), one for each currency, in the same order as the IR curves. Each currency must have either a caplet volatility curve or a swaption volatility curve. A value can be `void` if the model for that currency is calibrated to swaption volatilities.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of currencies.	
`aSwaptionVolCurve`	AS	Names of swaption volatility curves (of type `SwaptionVolMtx`), one for each currency, in the same order as the IR curves. Each currency must have either a caplet volatility curve or a swaption volatility curve. A value can be `void` if the model for that currency is calibrated to caplet volatilities.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of currencies.	

Table 11.11 Market Data Map for CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F (Continued)

Map Key	Type Code	Description	Constraints	Default Value
`aFXImpliedVolCurve`	AS	Names of FX option volatility curves (of type `ImpliedVol`), one for each spot FX rate, in the same order as the FX curves. The first name, matching the domestic currency itself, can be left blank.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of currencies.	
`aEQImpliedVolCurve`	AS	Names of equity option volatility curves (of type `EquityImpliedVol` or `ImpliedVol`), one for each spot equity, in the same order as the equity curves.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of equities.	
`aCorrelationCurve`	AS	Names of correlation curves (of type `CorrelBlock`) that give the correlations between model risk factors. For more detail, see the description that follows this table.	Referenced curves must exist in the market data HDF5 file.	

Correlation Curves

Construct the correlation curves specified by `aCorrelationCurve` according to the following scheme:

- A model with n currencies, e equities, c credit names, and m inflation indexes, has $2n–1+e+c+2m$ risk factors: n interest rate risk factors and $n–1$ FX risk factors, e equity risk factors, c credit risk factors, m spread risk factors associated with inflation indexes, and m inflation index risk factors.
- Let R_i be the risk factors of the model.
- The n risk factors from $i=0$ to $i=n–1$ are the interest rate risk factors in the same order as the IR curves.
- The $n–1$ risk factors from $i=n$ to $i=2n-2$ are the FX risk factors in the same order as the spot FX curves (omitting the first which is trivial).
- The e risk factors from $i=2n–1$ to $i=2n+e–2$ are the equity risk factors in the same order as the spot equity curves.
- The c risk factors from $i=2n+e–1$ to $i=2n+e+c–2$ are the credit risk factors in the same order as the credit spread curves.
- The m risk factors from $i=2n+e+c–1$ to $i=2n+e+c+m–2$ are the spread risk factors in the same order as the inflation indexes.
- The m risk factors from $i=2n+e+c+m–1$ to $i=2n+e+c+2m–2$ are the inflation index risk factors in the same order as the inflation indexes.
- The l risk factors from $i=2n+e+c+2m–1$ to $i=2n+e+c+2m+l–2$ are the commodity convenience spread risk factors in the same order as the inflation indexes.
- The l risk factors from $i=2n+e+c+2m+l–1$ to $i=2n+e+c+2m+2l–2$ are the commodity spot risk factors in the same order as the inflation indexes.
- The first $2n+e+c+2m+2l–2$ correlations are the correlations between R_0 and $R_1,\ldots, R_{2n+e+c+2m+2l–2}$.
- The next $2n+e+c+2m+2l–3$ correlations are the correlations between R_1 and $R_2,\ldots, R_{2n+e+c+2m+2l–2}$.

- The next $2n+e+c+2m+2l-4$ correlations are the correlations between R_2 and $R_3, \ldots, R_{2n+e+c+2m+2l-2}$, and so on.

Example

```
CR_EQ_FX_IF_IR_HW_1F_BK_1F_CurveNames_, {
  aIRCurve, AS, EUR.Yield.EUR, USD.Yield.USD
  aForwardCMCurve, AS, CM01.Commodity.EUR
  aSpotFXCurve, AS, void, USD.Exchange.EUR
  aSpotEQCurve, AS, SPX.EquityIndex.USD
  aCreditCurve, AS, CS1.ParCreditSpread.USD, CS2.ParCreditSpread.EUR
  aCMMeanReversionCurve, AS, CM01Spread.MeanReversion.EUR
  aCMSpreadVolCurve, AS, CM01Spread.CommodityImpliedVol.EUR
  aCMVolCurve, AS, CM01.CommodityImpliedVol.EUR
  aCMImpliedVolCurve, AS, CM01Implied.CommodityImpliedVol.EUR
  aMeanReversionCurve, AS, EURMR.MeanReversion.EUR, USDMR.MeanReversion.USD
  aSwaptionVolCurve, AS, SemiannualSwapVol.SwaptionVolMtx.EUR
  ..., SemiannualSwapVol.SwaptionVolMtx.USD
  aFXImpliedVolCurve, AS, void, USD.ImpliedVol.EUR
  aEQImpliedVolCurve, AS, void, SPX.ImpliedVol.USD
  aCorrelationCurve, AS
  ..., ShortRateUSD.CorrelBlock.ShortRateEUR
  ..., ShortRateUSD.CorrelBlock.SpotFXEUR
  ..., ShortRateUSD.CorrelBlock.SPX
  ..., ShortRateUSD.CorrelBlock.CS1
  ..., ShortRateUSD.CorrelBlock.CS2
  ..., ShortRateUSD.CorrelBlock.CM01Spread
  ..., ShortRateUSD.CorrelBlock.CM01
  ..., ShortRateEUR.CorrelBlock.SpotFXEUR
  ..., ShortRateEUR.CorrelBlock.SPX
  ..., ShortRateEUR.CorrelBlock.CS1
  ..., ShortRateEUR.CorrelBlock.CS2
  ..., ShortRateEUR.CorrelBlock.CM01Spread
  ..., ShortRateEUR.CorrelBlock.CM01
  ..., SpotFXEUR.CorrelBlock.SPX
  ..., SpotFXEUR.CorrelBlock.CS1
  ..., SpotFXEUR.CorrelBlock.CS2
  ..., SpotFXEUR.CorrelBlock.CM01Spread
  ..., SpotFXEUR.CorrelBlock.CM01
  ..., SPX.CorrelBlock.CS1
  ..., SPX.CorrelBlock.CS2
  ..., SPX.CorrelBlock.CM01Spread
  ..., SPX.CorrelBlock.CM01
  ..., CS1.CorrelBlock.CS2
  ..., CS1.CorrelBlock.CM01Spread
  ..., CS1.CorrelBlock.CM01
  ..., CS2.CorrelBlock.CM01Spread
  ..., CS2.CorrelBlock.CM01
  ...,CM01Spread.CorrelBlock.CM01
}
```

11.3.4 Data Extraction Settings (CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F)

The `DataExtractionSettings` member of the model preferences map refers to another map that specifies parameters for the data extraction process. The following table defines the members of a data extraction settings map for the CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F model.

Table 11.12 Data Extraction Settings Map for CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F

Map Key	Type Code	Description	Constraints	Default Value
`ampIRCurveSettings`	AL	Names of maps, one for each model currency, that specify settings for extracting interest rates. For the definition of these maps, see "Interest Rate Extraction Settings Map" on page 35.	Referenced maps must exist in the model preferences file. To use the defaults for all settings, provide an empty map.	An array of empty maps, one for each currency.
`ampBasisCurveSettings`	AL	Names of maps of settings for the basis data extraction, one for each interest rate curve specified by `aBasisCurve` in the market data map. The settings in these maps are listed in "Interest Rate Extraction Settings Map" on page 35.	Referenced maps must exist in the model preferences file.	The settings specified by `ampIRCurveSettings` are used.
`ampIFCurveSettings`	AL	Names of maps, one for each inflation index, that specify the settings for extracting the inflation-bond-related interest rate. In the current release, inflation index data extraction has no settings.	Referenced maps must exist in the model preferences file.	An array of empty maps, one for each inflation index.
`bExtrapolateDF`	B	Controls whether to extrapolate discount factors and inflation discount factors.	One of: • TRUE • FALSE	FALSE
`nMonthsExtrapDFEnd`	N	Number of months after the calibration date in which to extrapolate the discount factors.		0
`aidxCDSCCY`	AN	Index of the CDS currency for each credit name.	Integers between 0 and the number of foreign currencies of the model.	0

Table 11.12 Data Extraction Settings Map for CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F

Map Key	Type Code	Description	Constraints	Default Value
`bUseMFWKStripper`	B	Whether to use the model's internal survival probability bootstrapper (TRUE), or the external generic survival probability bootstrapper (FALSE).	One of: • TRUE • FALSE	TRUE
`ampSettingsCDS`	AL	Names of maps, one for each credit name, that specify credit data extraction settings for purposes of calibration. For the definition of these maps, see "CR Calibration Data Extraction Settings (CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F)" on page 257.	Referenced maps must exist in the model preferences file. To use the defaults for all settings, provide an empty map.	An array of empty maps, one for each credit name.
Use the inputs in this section only when `DataExtractionMethod` is `QDataExtraction_CM_CR_EQ_FX_IF_IR_HW_1F_BK_1F`				
`ampDataExtractionSettingsIR`	AL	Names of maps, one for each model currency, that specify IR data extraction settings for purposes of calibration. For the definition of these maps, see "IR Calibration Data Extraction Settings (CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F)" on page 268.	Referenced maps must exist in the model preferences file. To use the defaults for all settings, provide an empty map.	
`ampDataExtractionSettingsFX`	AL	Names of maps, one for each foreign currency, that specify FX data extraction settings for purposes of calibration. In the current release, FX calibration data extraction has no settings.	Referenced maps must exist in the model preferences file.	An array of empty maps, one for each foreign currency.
`ampDataExtractionSettingsEQ`	AL	Names of maps, one for each equity, that specify equity data extraction settings for purposes of calibration. In the current release, equity calibration data extraction has no settings.	Referenced maps must exist in the model preferences file.	An array of empty maps, one for each equity.
`ampDataExtractionSettingsII`	AL	Names of maps, one for each inflation index, that specify inflation index data extraction settings for purposes of calibration. In the current release, inflation index calibration data extraction has no settings.	Referenced maps must exist in the model preferences file.	An array of empty maps, one for each inflation index.

Table 11.12 Data Extraction Settings Map for CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F

Map Key	Type Code	Description	Constraints	Default Value
`ampDataExtractionSettingsCM`	AL	Names of maps, one for each commodity, that specify commodity data extraction settings for purposes of calibration. In the current release, commodity calibration data extraction has no settings.	Referenced maps must exist in the model preferences file.	An array of empty maps, one for each commodity.

Example

```
CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F_DataExtractionSettings, {
  ampDataExtractionSettingsIR, AL, Swaption_DataExtractionSetting
  ampSettingsCDS, AL, CS1_mpSettingsCDS, CS2_mpSettingsCDS
  aidxCDSCCY, AN, 1, 1
  bExtrapolateDF, B, TRUE
  nMonthsExtrapDFEnd, N, 10
}
```

11.3.4.1 CR Calibration Data Extraction Settings (CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F)

The `ampDataExtractionSettingsCR` member of the data extraction settings map refers to other maps that each specify settings for CR calibration data extraction for one credit name.

You can choose whether to use the model's internal survival probability bootstrapper (`bUseMFWKStripper = TRUE`), or the external generic survival probability bootstrapper (`bUseMFWKStripper = FALSE`).

The model's internal survival probability bootstrapper uses the assumption that defaults occur at the mid-points of each coupon period.

For information about the methodology of the external bootstrapper, see the following Markit Analytics document: *CDS Pricing and Bootstrapping Methodology Notes*.

The sections below define the data extraction settings maps for the internal and external survival probability bootstrappers.

11.3.4.1.1 With the Internal Survival Probability Bootstrapper

The following table defines the members of a CR calibration data extraction settings map for the CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F model when you use the model's internal survival probability bootstrapper.

Table 11.13 CR Calibration Data Extraction Settings Map for CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F (Internal Survival Probability Bootstrapper)

Map Key	Type Code	Description	Constraints	Default Value
bUseIMMDates	B	Whether to use IMM dates. If TRUE and the calibration date is not an IMM date, the CDS maturity is taken to be from the next IMM date.	One of: • TRUE • FALSE	TRUE
bRoundMidPointToNearestDay	B	Whether to round the coupon period mid points, calculated for accrued interest, to the nearest day.	One of: • TRUE • FALSE	TRUE
bUseYearFracForAccInt	B	Whether to use the year fraction in the calculation of the accrued interest using midpoint approximation.	One of: • TRUE • FALSE	TRUE
rDaysPerAnnumAccInt	R	Number of days per annum in the calculation of the accrued interest using midpoint approximation, if bUseYearFracForAccInt is FALSE.		365.25[dy]
rFwdHazardRateFloor	R	Floor value for the forward hazard rate in bootstrapping.		1e-5
bAccInt	B	Whether to use the accrued interest in bootstrapping.	One of: • TRUE • FALSE	TRUE
bTest	B	Whether to perform the round trip test on par credit spread in bootstrapping.	One of: • TRUE • FALSE	FALSE
bBootstrapClean	B	Whether to take into account the accrued rebate for IMM dates in bootstrapping.	One of: • TRUE • FALSE	TRUE for spread quote data. FALSE for upfront fee quote data.
strSPInterpType	S	Survival probability interpolation method: • Log-linear interpolation on survival probabilities (SPLogLin) • Linear interpolation on survival probability yields (SPYieldLin)	One of: • SPLogLin • SPYieldLin	SPLogLin
bUseBisection	B	Whether to use the bisection method for root finding (TRUE) or the Newton-Raphson method (FALSE).	One of: • TRUE • FALSE	FALSE
rNRTol	R	Tolerance value for the Newton-Raphson method of root finding.		1e-8

Table 11.13 CR Calibration Data Extraction Settings Map for CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F (Internal Survival Probability Bootstrapper)

Map Key	Type Code	Description	Constraints	Default Value
nNRMaxIter	N	Maximum number of iterations for Newton-Raphson root finding.		50
mpOptionsRootGridX	L	(Optional) Name of a map that specifies settings for root finding by the bisection method.		
rBisectionLB	R	Lower bound used in the bisection method of root finding.		0
rBisectionUB	R	Upper bound used in the bisection method of root finding.		1
bLastPeriodAccrualEndUnadjusted	B	Whether to use the unadjusted accrual end date for the last coupon period if bUseIMMDates is TRUE.	One of: • TRUE • FALSE	TRUE
bIMMStepInNext	B	Whether to use the next date after the calibration date as the IMM step-in date.	One of: • TRUE • FALSE	TRUE
bFirstPartialIMMCoupon	B	Whether to use the first partial coupon with IMM dates.	One of: • TRUE • FALSE	FALSE
bUpfrontFee	B	Whether the underlying curve data represents upfront fee quotes (TRUE) or par credit spreads (FALSE).	One of: • TRUE • FALSE	FALSE
oUpfrontFeeFixedCoupon	R or AR	Fixed coupon rate to use in the calculation when the input credit data is upfront fee quotes. Specify a scalar input (R) if fixed coupons are the same for all maturities, or an array (AR) if fixed coupons are different for different maturities.		0.01
anUpfrontFeeScheduleMonths	AN	(Optional) Maturity, as number of months, for each fixed coupon rate for upfront fee quote data. Required when oUpfrontFeeFixedCoupon is an array.	Same number of elements as oUpfrontFeeFixedCoupon.	
nSettlementLag	N	Number of days after which the contract must be settled.		0

Example

```
mpSettingsCDS_ObligorA, {
  bRoundMidpointToNearestDay, B, TRUE
  bUseYearFracForAccInt, B, TRUE
  bAccInt, B, TRUE
  rFwdHazardRateFloor, R, 1e-5
  bUseBisection, B, FALSE
  bTest, B, FALSE
  bBootstrapClean, B, TRUE
  strSPInterpType, S, SPYieldLin
  bUpfrontFee, B, TRUE
  oUpfrontFeeFixedCoupon, R, 0.015
  nSettlementLag, N, 2
}
```

11.3.4.1.1.1 Root-Finding Settings (CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F)

The `mpOptionsRootGridX` member of the CR calibration data extraction settings map above refers to another input map that specifies root-finding settings for the bisection method. These are the options that are parameters of the `RootGridX()` function (for more information see the *QuIC Functions Reference* document which is a set of HTML files included in an Analytics package). The following table defines the members of this map.

Table 11.14 CR Root-Finding Settings Map for CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F

Map Key	Type Code	Description	Constraints	Default Value
`nDivs`	`N`	Number of subdivision operations to perform.		30

Example

```
CRDataExtraction_RootFindingSettings, {
  nDivs, N, 50
}
```

11.3.4.1.2 With the External Survival Probability Bootstrapper

The following table defines the members of a CR calibration data extraction settings map for the CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F model when you use the external generic survival probability bootstrapper.

Table 11.15 CR Calibration Data Extraction Settings Map for CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F (External Survival Probability Bootstrapper)

Map Key	Type Code	Description	Constraints	Default Value
`strSPFrequency`	S	(Optional) Frequency of the survival probability dates. If set to `COUPONDATES`, the survival probability is generated at the union of the coupon dates of all the CDS instruments used in the bootstrapping. If omitted, the survival probability is generated on the node points of the input credit curve.	One of: • `COUPONDATES` • `DAILY` • `WEEKLY` • `MONTHLY` • `QUARTERLY` • `SEMIANNUAL` • `ANNUAL`	
`strHolidayListPremiumLeg`	S	(Optional) Name of the relevant set of holidays for adjusting the CDS schedule dates for the premium leg. If omitted, no adjustment is performed.	Name must be the key in the holidays HDF5 file.	
`strHolidayListProtectionLeg`	S	(Optional) Name of the relevant set of holidays for adjusting the CDS schedule dates for the protection leg. If omitted, no adjustment is performed.	Name must be the key in the holidays HDF5 file.	
`mpCDSBootstrapperSettings`	L	Name of a map that specifies the CDS bootstrapper settings. For a definition of this map, see Table 11.16 on page 262.		
`mpCDSPricerSettings`	L	(Optional) Name of a map that specifies the CDS pricer settings. For a definition of this map, see Table 11.17 on page 264 and Table 11.18 on page 266. Omit this input if the reference credit curve is of type `SurvivalProbability`.		
`mpCDSPricerScheduleSettings`	L	(Optional) Name of a map that specifies the settings for the schedule generation of the CDS pricer. For a definition of this map, see Table 11.19 on page 268. Omit this input if the reference credit curve is of type `SurvivalProbability`.		

Example

```
DataExtractionSettings_ExternalSPBootstrapper_ObligorA {
  strHolidayListPremiumLeg, S, USD
  strHolidayListProtectionLeg, S, WE
  mpCDSBootstrapperSettings, L, CDSBootstrapper_SPEnd
  mpCDSPricerSettings, L, CDSPricer_RollDefaultDates
  mpCDSPricerScheduleSettings, L, CDSPricerSchedule_IMMDates
}
```

11.3.4.1.2.1 External CDS Bootstrapper Settings

The `mpCDSBootstrapperSettings` member of the CR calibration data extraction settings map above refers to another input map that specifies survival probability bootstrapper settings. The following table defines the members of this map.

Table 11.16 External CDS Bootstrapper Settings Map

Map Key	Type Code	Description	Constraints	Default Value
`strCDSBootstrapper`	S	Bootstrapper type.	`CDSBootstrapperSinglеNameSPEnd`	
`bFloor`	B	Whether to floor the value of the optimization parameter in bootstrapping.	One of: • TRUE • FALSE	TRUE
`bRoundTripTest`	B	Whether to perform the round trip test on the CDS price in bootstrapping.	One of: • TRUE • FALSE	FALSE
`bUseYearFracSP`	B	Whether to use the year fraction in the calculation of the survival probability, yield, or spot hazard rate.	One of: • TRUE • FALSE	FALSE
`nNRMaxIter`	N	Maximum number of iterations for Newton-Raphson root finding.		50
`rFloor`	R	Floor value for the optimization parameter in bootstrapping.		1e-15
`rNRTol`	R	Tolerance value for the Newton-Raphson method of root finding.		1e-15
`rSPDaysPerAnnum`	R	(Optional) Number of days per annum in the calculation of the survival probability, yield, or spot hazard rate, if `bUseYearFracSP` is FALSE. If omitted, the relevant attribute of the credit curve is used.		365 (if not available from the credit curve)
`strIncorrectSurvProbPoints`	S	Method to handle incorrect survival probability points generated in the bootstrapping.	One of: • `ignore` • `exclude` • `flatExtrap`	`exclude`

Table 11.16 External CDS Bootstrapper Settings Map (Continued)

Map Key	Type Code	Description	Constraints	Default Value
strOptimizationObject	S	Object on which to perform the optimization.	One of: • spotHazardRate • SPYield • SP	spotHazardRate
strSPDaycount	S	(Optional) Day count convention in the calculation of the survival probability, yield, or spot hazard rate, if bUseYearFracSP is TRUE. If omitted, the relevant attribute of the credit curve is used.	See Table B.2 on page 327.	ACT365FIXED (if not available from the credit curve)
strSPInterpObject	S	Object to interpolate and extrapolate on (log-lin for SP; lin for SPYield).	One of: • SPYield • SP	SPYield
strSPCompounding	S	Compounding frequency of the survival probability curve.	One of: • DAILY • WEEKLY • MONTHLY • QUARTERLY • SEMIANNUAL • ANNUAL • SIMPLE • CONTINUOUS	CONTINUOUS
strSPYieldExtrap	S	Extrapolation method to use when the interpolation is performed on survival probability yield—that is, strSPInterpObject is set to SPYield.	See Table B.3 on page 328.	lin

Example

```
CDSBootstrapper_SPEnd {
  strCDSBootstrapper, S, CDSBootstrapperSingleNameSPEnd
  strSPInterpObject, S, SPYield
  strSPCompounding, S, ANNUAL
  strOptimizationObject, S, spotHazardRate
}
```

11.3.4.1.2.2 External CDS Pricer Settings: Mid-Point Default Pricer

The mpCDSPricerSettings member of the CR calibration data extraction settings map above refers to another input map that specifies CDS pricer settings. The map can be one of two types. The table below defines the members of the setting map for the pricer CDSPricerSISingleNameMidPointDefault in which the default date is assumed to be the mid-point of a coupon period.

Table 11.17 External CDS Pricer Settings Map (`CDSPricerSISingleNameMidPointDefault`)

Map Key	Type Code	Description	Constraints	Default Value
`strCDSPricer`	S	CDS pricer type.	`CDSPricerSISingleNameMidPointDefault`	
`arCDSFixedCoupon`	AR	(Optional) Fixed coupon rate to use in bootstrapping when the input credit data is upfront fee quotes (`bUpfrontFee` is TRUE in the `mpCDSPricerScheduleSettings` map), for the CDS names. The first element, which corresponds to the first name, is used.		`0.01`
`arNotional`	AR	Constant notional for the CDS names. The first element, which corresponds to the first name, is used.		`1.0`
`arRecoveryRate`	AR	(Optional) Recovery rate to use in survival probability bootstrapping and in scaling exposures in valuation adjustment, for the CDS names. The first element, which corresponds to the first name, is used.		`0.4`
`bAccInt`	B	Whether to use the accrued interest in bootstrapping.	One of: • TRUE • FALSE	TRUE
`bClean`	B	Whether to take into account the accrued rebate for the first coupon in bootstrapping.	One of: • TRUE • FALSE	TRUE
`bFirstPartialCoupon`	B	Whether to use the first partial coupon.	One of: • TRUE • FALSE	FALSE
`bPayPremium`	B	Whether to pay premiums (buy the insurance).	One of: • TRUE • FALSE	TRUE
`bRoundMidPointToNearestDay`	B	Whether to round the coupon period mid points, calculated for accrued interest, to the nearest day.	One of: • TRUE • FALSE	TRUE
`bUseYearFracForAccInt`	B	Whether to use the year fraction in the calculation of the accrued interest.	One of: • TRUE • FALSE	TRUE

Table 11.17 External CDS Pricer Settings Map (`CDSPricerSISingleNameMidPointDefault`)

Map Key	Type Code	Description	Constraints	Default Value
`rDaysPerAnnumAccInt`	R	(Optional) Number of days per annum in the calculation of the accrued interest, if `bUseYearFracForAccInt` is `FALSE`. If omitted, the relevant attribute of the par credit spread curve is used.		
`strBusDayConvPremiumLeg`	S	Business day convention for adjusting the CDS schedule dates for the premium leg.	See Table B.1 on page 326.	`NA`
`strBusDayConvProtectionLeg`	S	Business day convention for adjusting the CDS schedule dates for the protection leg.	See Table B.1 on page 326.	`strBusDayConvPremiumLeg`
`strDaycount`	S	(Optional) Day count convention in the calculation of the accrued interest, if `bUseYearFracForAccInt` is `TRUE`. If omitted, the relevant attribute of the par credit spread curve is used.	See Table B.2 on page 327.	
`strLastPeriodEndDateType`	S	Type of accrual end date for the last coupon period.	One of: • `adjusted` • `adjustedAddOneDay` • `unadjusted` • `unadjustedAddOneDay`	`unadjustedAddOneDay`

Example

```
SampleCDSPricerSettings_MidpointDefault, {
  strCDSPricer, S, CDSPricerSISingleNameMidPointDefault
  strBusDayConvPremiumLeg, S, MODFOLLOWING
  strBusDayConvProtectionLeg, S, MODFOLLOWING
  bRoundMidPointToNearestDay, B, TRUE
  bClean, B, TRUE
  bUseYearFracForAccInt, B, TRUE
  strDaycount, S, ACT365
  strLastPeriodEndDateType, S, unadjustedAddOneDay
}
```

11.3.4.1.2.3 External CDS Pricer Settings: Roll Default Dates Pricer

The `mpCDSPricerSettings` member of the CR calibration data extraction settings map above refers to another input map that specifies CDS pricer settings. The map can be one of two types. The table below defines the members of the setting map for the pricer `CDSPricerSISingleNameRollDefaultDates` in which the default date is assumed to be a whole number of months from the later of the protection start date or the valuation date.

Table 11.18 External CDS Pricer Settings Map (`CDSPricerSISingleNameRollDefaultDates`)

Map Key	Type Code	Description	Constraints	Default Value
`strCDSPricer`	S	CDS pricer type.	`CDSPricerSISingleNameRollDefaultDates`	
`arCDSFixedCoupon`	AR	(Optional) Fixed coupon rate to use in bootstrapping when the input credit data is upfront fee quotes (`bUpfrontFee` is `TRUE` in the `mpCDSPricerScheduleSettings` map), for the CDS names. The first element, which corresponds to the first name, is used.		`0.01`
`arNotional`	AR	Constant notional for the CDS names. The first element, which corresponds to the first name, is used.		`1.0`
`arRecoveryRate`	AR	(Optional) Recovery rate to use in survival probability bootstrapping and in scaling exposures in valuation adjustment, for the CDS names. The first element, which corresponds to the first name, is used.		`0.4`
`bAccInt`	B	Whether to use the accrued interest in bootstrapping.	One of: • `TRUE` • `FALSE`	`TRUE`
`bClean`	B	Whether to take into account the accrued rebate for the first coupon in bootstrapping.	One of: • `TRUE` • `FALSE`	`TRUE`
`bPayPremium`	B	Whether to pay premiums (buy the insurance).	One of: • `TRUE` • `FALSE`	`TRUE`
`bUseYearFracForAccInt`	B	Whether to use the year fraction in the calculation of the accrued interest.	One of: • `TRUE` • `FALSE`	`TRUE`
`nMonthDefaultPeriod`	N	Interval (in months) between two default dates.		`3`
`rDaysPerAnnumAccInt`	R	(Optional) Number of days per annum in the calculation of the accrued interest, if `bUseYearFracForAccInt` is `FALSE`. If omitted, the relevant attribute of the par credit spread curve is used.		

Table 11.18 External CDS Pricer Settings Map (`CDSPricerSISingleNameRollDefaultDates`)

Map Key	Type Code	Description	Constraints	Default Value
strBusDayConvPremiumLeg	S	Business day convention for adjusting the CDS schedule dates for the premium leg.	See Table B.1 on page 326.	NA
strBusDayConvProtectionLeg	S	Business day convention for adjusting the CDS schedule dates for the protection leg.	See Table B.1 on page 326.	NA
strDaycount	S	(Optional) Day count convention in the calculation of the accrued interest, if bUseYearFracForAccInt is TRUE. If omitted, the relevant attribute of the par credit spread curve is used.	See Table B.2 on page 327.	
strFirstPeriodStartDateType	S	Type of accrual start date for the first coupon period.	One of: • adjusted • unadjusted	adjusted
strLastDefaultPeriodEndDateType	S	Type of accrual end date for the last default period.	One of: • adjusted • unadjusted	unadjusted
strLastPeriodEndDateType	S	Type of accrual end date for the last coupon period.	One of: • adjusted • adjustedAddOneDay • unadjusted • unadjustedAddOneDay	unadjustedAddOneDay

Example

```
SampleCDSPricerSettings_RollDefaultDates, {
  strCDSPricer, S, CDSPricerSISingleNameRollDefaultDates
  strBusDayConvPremiumLeg, S, MODFOLLOWING
  strBusDayConvProtectionLeg, S, MODFOLLOWING
  nMonthDefaultPeriod, N, 3
  bClean, B, TRUE
  bUseYearFracForAccInt, B, TRUE
  strDaycount, S, ACT365FIXED
  strLastPeriodEndDateType, S, unadjustedAddOneDay
}
```

11.3.4.1.2.4 External CDS Pricer Schedule Generation Settings

The `mpCDSPricerScheduleSettings` member of the CR calibration data extraction settings map above refers to another input map that specifies settings for the

schedule generation of the CDS pricers. The following table defines the members of this map.

Table 11.19 External CDS Pricer Schedule Generation Settings Map

Map Key	Type Code	Description	Constraints	Default Value
`bUseIMMDates`	B	Whether to use IMM dates. If the valuation date is not an IMM date, the CDS maturity is taken to be from the next IMM date.	One of: • TRUE • FALSE	TRUE
`bIMMStepInNext`	B	Whether to use the next date after the valuation date as the IMM step-in date.	One of: • TRUE • FALSE	TRUE
`bUpfrontFee`	B	Whether the underlying credit curve data represents upfront fee quotes (TRUE) or par credit spreads (FALSE).	One of: • TRUE • FALSE	FALSE

Example

```
CDSPricerSchedule_IMMDates {
 bUseIMMDates, B, TRUE
}
```

11.3.4.2 IR Calibration Data Extraction Settings (CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F)

The `ampDataExtractionSettingsIR` member of the data extraction settings map refers to other maps that each specify settings for IR calibration data extraction for one currency. The following table defines the members of an IR calibration data extraction settings map for the CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F model.

Table 11.20 IR Calibration Data Extraction Settings Map for CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F

Map Key	Type Code	Description	Constraints	Default Value
`strMethod`	S	Type of calibration data.	One of: • `Swaption` • `SelectedSwaptions`	

Table 11.20 IR Calibration Data Extraction Settings Map for CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F (Continued)

Map Key	Type Code	Description	Constraints	Default Value
`rSwaptionShift`	R	(Optional) If specified, the market swaption price in the calibration of the model is calculated under the assumption that the swap rate has a shifted log-normal distribution with the specified shift size. In this case, the swaption price in the calibration is calculated using Black's formula with the adjusted swap rate and strike obtained by subtracting `rSwaptionShift` from the original swap rate and strike of the calibrating swaptions.		0
`strDaycountFixed`	S	(Optional) Day count convention in the fixed leg of the calibrating swaptions.	See Table B.2 on page 327.	The *`dayCountConv`* attribute of the input swaption volatility curve is used.
`nSwapTenorFixed`	N	(Optional) Coupon frequency (in months) in the fixed leg of the calibrating swaptions.		The *`tenor`* attribute of the input swaption volatility curve is used.
`bCalibrateIRMarketPriceOfRiskToIRCurve`	B	Whether to use the input discount factor curve instead of the input IR forward average curve in the IR market price of risk calibration.	One of: • TRUE • FALSE	FALSE
Use the additional inputs in this section only when `strMethod` is `SelectedSwaptions`				
`astrSwaptionExpiry`	AS	(Optional) Time to expiry to specify the swaption volatilities for extraction from the input swaption volatility curve, in the same units as the expiry ordinates in the curve. If not provided, the times to expiry are assumed to be the expiry ordinate values of the input swaption volatility curve.		

Table 11.20 IR Calibration Data Extraction Settings Map for CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F (Continued)

Map Key	Type Code	Description	Constraints	Default Value
`anSwaptionLength`	`AN`	(Optional) Lengths in months of the swaptions to specify the volatility for extraction from the input swaption volatility curve, one for each expiry date specified by `astrSwaptionExpiry`. If not provided, the co-terminal swaption volatility is extracted for all expiry dates specified in `astrSwaptionExpiry`. Ignored if `astrSwaptionExpiry` is omitted.	Same number of elements as `astrSwaptionExpiry`.	
`arSwaptionStrike`	`AR`	(Optional) Swaption strike to specify the volatility for extraction from the input swaption volatility curve, one for each expiry date specified by `astrSwaptionExpiry`. If not provided, the at-the-money strike is used for all expiry dates specified in `astrSwaptionExpiry`. Ignored if `astrSwaptionExpiry` is omitted. Used only when the swaption volatility curve is of type `SwaptionVolCube`.	Same number of elements as `astrSwaptionExpiry`.	
`strSwaptionStrikeType`	`S`	(Optional) Type of the strikes specified in `arSwaptionStrike`. Ignored if `arSwaptionStrike` is omitted. Used only when the swaption volatility curve is of type `SwaptionVolCube`.	One of: • `ABSOLUTE` • `F-K` • `K-F` • `F/K` • `K/F` F is the underlying par swap rate for the swaption period. `ABSOLUTE` means that values represent the strike K. The remaining strike types mean that values are specified in relative terms.	`ABSOLUTE`
`idxBasisCurveCalib`	`N`	(Optional) Index of the interest rate curve to use for additive LIBOR basis adjustment in the calculation of the swap rate during the extraction of the ATM volatility.	Integer between 0 and n–1, where n is the number of curves specified by the market data map member `aBasisCurve`.	The LIBOR basis adjustment is not performed.

Table 11.20 IR Calibration Data Extraction Settings Map for CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F (Continued)

Map Key	Type Code	Description	Constraints	Default Value
idxBasisCurveCalibDisc	N	(Optional) Index of the interest rate curve to use for discounting in the calculation of the swap rate during the extraction of the ATM volatility. Ignored if bUseBasisCurveForCalibDiscounting is set to TRUE.	Integer between 0 and n–1, where n is the number of curves specified by the market data map member aBasisCurve.	Interest rate curve for the currency of this map, specified by the market data map member aIRCurve.
bUseBasisCurveForCalibDiscounting	B	Whether to use the basis curve, if specified by idxBasisCurveCalib, for both discounting and forecasting in the calculation of the swap rate (TRUE) or just for forecasting (FALSE).	One of: • TRUE • FALSE	FALSE

Example

```
Swaption_DataExtractionSetting, {
  strMethod, S, Swaption
}
```

Chapter 12

Hybrid Commodity Credit Equity Inflation Multicurrency Model

In the hybrid commodify credit equity inflation multicurrency extension of the multifactor Hull-White interest rate model (CM_CR_EQ_FX_IF_IR_HW_NF), a single-currency multifactor Hull-White model is used for the nominal interest rate for each currency. In addition, the spread between the nominal and real interest rates of each currency is also modelled as a single-currency multifactor Hull-White model. For each spot foreign exchange rate, spot equity price, spot commodity price, and inflation index, the log-normal model is used. (Each exchange rate, each spot equity price, each spot commodity price, and each inflation index is modelled with one driving factor.) For each commodity, the spread between interest rate and convenience yield is modelled using a multifactor Hull-White model. For credit modelling, the dynamics of the hazard rate for each credit name is modelled by a single-factor Hull-White model.

This model also supports derived inflation indexes. A derived inflation index has the same driving factors as a core inflation index and inflation index rate curve, but has different inflation index and inflation rate curve starting values.

For information about the methodology of the CM_CR_EQ_FX_IF_IR_HW_NF model, see the following chapter in *Markit Analytics Model Framework Mathematical Reference*: “Hybrid Commodity Credit Equity Inflation Multi-Currency Model with Multi-

Factor Hull-White Models for Interest Rates and Single Factor Hull-White Models for Hazard Rates”.

12.1 Module (CM_CR_EQ_FX_IF_IR_HW_NF)

The Model Framework module that implements the hybrid credit commodity equity inflation multicurrency extension of the multifactor Hull-White interest rate model (CM_CR_EQ_FX_IF_IR_HW_NF) is as follows:

```
quic_model_cm_cr_eq_fx_if_ir_hw_nf:3.0
```

Combine this module name with the module component names identified in this chapter to form a complete module reference. For example, if the component is `QModel_CM_CR_EQ_FX_IF_IR_HW_NF`, the complete module reference is as follows:

```
QModel_CM_CR_EQ_FX_IF_IR_HW_NF@quic_model_cm_cr_eq_fx_if_ir_hw
_nf:3.0
```

12.2 Market Data Generator Parameters (CM_CR_EQ_FX_IF_IR_HW_NF)

A market data generator parameters set for the Model Framework market data generator includes certain parameters whose value depends on the particular model. These include some parameters that are used directly by the generator itself and others that are used only by the Model Framework model that it invokes (in particular by the model’s simulator component). For descriptions of the direct generator parameters, see the *Markit Analytics Simulation Framework User Guide*. The parameters that are used by Model Framework simulators are described in “Model Framework Simulator Settings” on page 28.

Some of the simulator settings are used by all models and others are used only by certain models. For the latter subset of settings, the information below shows which ones are used by this model.

Generator Parameter: `strSimulatorMFWKReference`

The parameter `strSimulatorMFWKReference` specifies the simulator plug-in for the model. The following values of this parameter are available for the CM_CR_EQ_FX_IF_IR_HW_NF model:

- Simulation algorithm under the risk-neutral measure:

  ```
  QMCSimulator_CM_CR_EQ_FX_IF_IR_HW_NF_RNM@quic_model_cm_cr_eq_f
  x_if_ir_hw_nf:3.0
  ```

- Euler simulation algorithm under the risk-neutral measure:

  ```
  QMCSimulator_CM_CR_EQ_FX_IF_IR_HW_NF_RNM_Euler@quic_model_cm_c
  r_eq_fx_if_ir_hw_nf:3.0
  ```

- Simulation algorithm under the real-world measure:

  ```
  QMCSimulator_CM_CR_EQ_FX_IF_IR_HW_NF_RWM@quic_model_cm_cr_eq_f
  x_if_ir_hw_nf:3.0
  ```

- Euler simulation algorithm under the real-world measure:
  QMCSimulator_CM_CR_EQ_FX_IF_IR_HW_NF_RWM_Euler@quic_model_cm_cr_eq_fx_if_ir_hw_nf:3.0

Applicability of Simulator Settings

The following table identifies which simulator plug-ins (if any) support the specified simulator settings.

Table 12.1 Support for Simulator Settings (CM_CR_EQ_FX_IF_IR_HW_NF)

Parameter	Simulators That Support the Parameter
bStepOnDFDates	• QMCSimulator_CM_CR_EQ_FX_IF_IR_HW_NF_RNM • QMCSimulator_CM_CR_EQ_FX_IF_IR_HW_NF_RNM_Euler • QMCSimulator_CM_CR_EQ_FX_IF_IR_HW_NF_RWM • QMCSimulator_CM_CR_EQ_FX_IF_IR_HW_NF_RWM_Euler
bPrecalculateCovariances	• QMCSimulator_CM_CR_EQ_FX_IF_IR_HW_NF_RNM • QMCSimulator_CM_CR_EQ_FX_IF_IR_HW_NF_RNM_Euler • QMCSimulator_CM_CR_EQ_FX_IF_IR_HW_NF_RWM • QMCSimulator_CM_CR_EQ_FX_IF_IR_HW_NF_RWM_Euler
bUseEigenSym and bUsePCA	• QMCSimulator_CM_CR_EQ_FX_IF_IR_HW_NF_RNM • QMCSimulator_CM_CR_EQ_FX_IF_IR_HW_NF_RNM_Euler • QMCSimulator_CM_CR_EQ_FX_IF_IR_HW_NF_RWM • QMCSimulator_CM_CR_EQ_FX_IF_IR_HW_NF_RWM_Euler
bCholesky	Not applicable
strDecomposition	Not applicable
bUseStartEndNumeraireCalc	• QMCSimulator_CM_CR_EQ_FX_IF_IR_HW_NF_RNM • QMCSimulator_CM_CR_EQ_FX_IF_IR_HW_NF_RNM_Euler
bUseForeignQuantoAdjustment	Not applicable
bUseDeterministicFXDrifts	Not applicable
bUseDeterministicInflationDrifts	Not applicable
bApproximateXIntegral	Not applicable

12.3 Model Preferences (CM_CR_EQ_FX_IF_IR_HW_NF)

You specify the settings for the model in a model preferences map and in the subsidiary maps that it references. For a general description of a model preferences map, see “Model Preferences Map” on page 32.

To calibrate the model risk factor volatilities, use one of the following approaches:

1. **Combined implied-historical calibration** (supported only for single-factor IR, inflation, and commodity spread models). IR, FX, equity, inflation index, and commodity spot volatilities are calibrated to the implied market volatility data. The hazard rate, inflation spread, and commodity convenience spread volatilities as well as the correlation between all model risk factors are calculated from the input covariance data, which is pre-calculated from the historical time series. In addition, you can replace implied volatility calibration with the historical calibration input data for any of the model risk factors.

2. **Historical calibration**. Volatilities and correlations for all model risk factors are calculated from the input covariance data between the forward rates and other model factors, pre-calculated from the historical time series.
3. **External calibration**. You provide the parameters of the simulation SDE.

Approaches 1 and 2 allow you to:

- Provide the historical covariance data in one of the following formats: covariance matrix or correlation matrix and volatility curves.
- Overwrite any of the calibrated volatilities with direct input of the values to use in the simulation SDE.

12.3.1 Components (CM_CR_EQ_FX_IF_IR_HW_NF)

The following table identifies the available plug-ins (components of the CM_CR_EQ_FX_IF_IR_HW_NF module) that implement the model. You specify these as values of members of the model preferences map in the form of full module references.

Table 12.2 Model Plug-In Components (CM_CR_EQ_FX_IF_IR_HW_NF)

Model Preference	Available Components of the Module
`Model`	`QModel_CM_CR_EQ_FX_IF_IR_HW_NF`
`CalibrationMethod`	One of: • `QModelCalibration_CM_CR_EQ_FX_IF_IR_HW_1F_Comb` For combined implied-historical calibration. • `QModelCalibration_CM_CR_EQ_FX_IF_IR_HW_NF_FwdCov` For calibration to historical covariance between forward rates and other model factors. • `QModelCalibration_CM_CR_EQ_FX_IF_IR_HW_NF_ExtCal` For external calibration. Supports time-varying parameters.
`DataExtractionMethod`	One of: • `QDataExtraction_CM_CR_EQ_FX_IF_IR_HW_CombCorr` For providing input covariance in the format of correlation and volatility curves. • `QDataExtraction_CM_CR_EQ_FX_IF_IR_HW_CombCov` For providing input covariance in the format of the covariance curve. • `QDataExtraction_CM_CR_EQ_FX_IF_IR_HW_NF_ExtCal` For external calibration.

In addition, you must specify the maps that are identified by the other members of the model preferences map. The remainder of this chapter defines these subsidiary maps.

Example

The following figure shows a sample model preferences map that specifies components for this model. In the model preferences file, each map member occupies a single line.

```
CM_CR_EQ_FX_IF_IR_HW_NF_ModelPrefs, {
  Model, S, QModel_CM_CR_EQ_FX_IF_IR_HW_NF@quic_model_cm_cr_eq_fx_if_ir_hw_nf:
   3.0
  CalibrationMethod, S, QModelCalibration_CM_CR_EQ_FX_IF_IR_HW_1F_Comb@quic_model_cm_cr_
   eq_fx_if_ir_hw_nf:3.0
  CalibrationSettings, L, CM_CR_EQ_FX_IF_IR_HW_1F_CalibrationSettings
  CurveNames, L, CM_CR_EQ_FX_IF_IR_HW_1F_CurveNames
  DataExtractionMethod, S, QDataExtraction_CM_CR_EQ_FX_IF_IR_HW_CombCorr@quic_model_
   cm_cr_eq_fx_if_ir_hw_nf:3.0
  DataExtractionSettings, L, CM_CR_EQ_FX_IF_IR_HW_1F_DataExtractionSettings
  TradeInfo, L, PORTFOLIO_INFO
}
```

12.3.2 Calibration Settings (CM_CR_EQ_FX_IF_IR_HW_NF)

The `CalibrationSettings` member of the model preferences map refers to another map that specifies parameters related to calibration of the model. The table below defines the members of a calibration settings map for the CM_CR_EQ_FX_IF_IR_HW_NF model. The descriptions of these parameters use the following notation:

- H is the number of currencies. Hence, H–1 is the number of exchange rates.
- E is the number of equities.
- I is the number of inflation indexes.
- C is the number of credit names.
- L is the number of commodities.
- K is the total number of factors in the model.

The symbols in the Equation Symbol column refer to the following chapter in *Markit Analytics Model Framework Mathematical Reference*: “Hybrid Commodity Credit Equity Inflation Multi-Currency Model with Multi-Factor Hull-White Models for Interest Rates and Single Factor Hull-White Models for Hazard Rates”.

Table 12.3 Calibration Settings Map for CM_CR_EQ_FX_IF_IR_HW_NF

Map Key	Type Code	Description	Constraints	Default Value	Equation Symbol
The inputs in this section are common to all the calibration methods.					
`astrCCY`	AS	Names of the H currencies. The first name is the domestic currency.	Standard 3-character currency identifiers		
`astrEquity`	AS	Names of the E equities.			

Table 12.3 Calibration Settings Map for CM_CR_EQ_FX_IF_IR_HW_NF (Continued)

Map Key	Type Code	Description	Constraints	Default Value	Equation Symbol
astrEquityCCY	AS	Names of the E currencies, corresponding to the equities in astrEquity.	Standard 3-character currency identifier. All names must be present in astrCCY.		
astrName	AS	Credit names.	Number of elements must be C.		
arRecoveryRate	AR	(Optional) Recovery rates to use for each credit name. Overrides the recovery rate attribute of the input par credit spread curves (if provided).	Number of elements must be C.	If a survival probability curve is input for a name, the value defaults to 0.4.	
rDaysPerAnnumCR	R	Number of days per annum to convert the credit model parameters specified in arKappa and aoSigma, to daily units.		365.25 [dy]	
astrII	AS	Names of the I inflation indexes.			
astrIICCY	AS	Names of the I currencies, corresponding to the inflation indexes in astrII.	Standard 3-character currency identifier. All names must be present in astrCCY.		
astrIIDerived	AS	(Optional) Names of the derived inflation indexes.			
astrIIDerivedFrom	AS	(Optional) Names of the core inflation indexes on which the derived indexes are based, one for each derived index. Required if astrIIDerived is specified.	All names must be present in astrII.		
bCorrectCorrMtx	B	Whether to ensure that the input correlation matrix is positive semidefinite by using principal components analysis.	One of: • TRUE • FALSE	TRUE	
rEigenThreshold	R	If bCorrectCorrMtx is TRUE, all eigenvectors associated with eigenvalues less than this threshold times the largest eigenvalue are set to zero.		1e-15	

Table 12.3 Calibration Settings Map for CM_CR_EQ_FX_IF_IR_HW_NF (Continued)

Map Key	Type Code	Description	Constraints	Default Value	Equation Symbol
astrCommodity	AS	Names of the L commodities.			
astrCommodityCCY	AS	Names of the L currencies, corresponding to the commodities in astrCommodity.	Standard 3-character currency identifier. All names must be present in astrCCY.		
strModelParametersOutputFile	S	(Optional) File path of the HDF5 file to which the calculated model parameters are written. This file has the same format as a file for externally calibrated parameters. Typically used only for troubleshooting. If omitted, no file is produced.			
strModelParametersOutputName	S	(Optional) Name to give this model parameters set in the file specified by strModelParametersOutputFile.		mpModelParams	
bOutputCalibrationData	B	Whether to include the calibration data in the HDF5 file specified by strModelParametersOutputFile. Typically used only for troubleshooting because it may significantly increase the size of the file.	One of: • TRUE • FALSE	FALSE	
ampCalibrationSettingsCR	AL	Names of maps, one for each credit name, that specify credit calibration settings. For the definition of these maps, see "Credit Calibration Settings (CM_CR_EQ_FX_IF_IR_HW_NF)" on page 286	Referenced maps must exist in the model preferences file. To use the defaults for all settings, provide an empty map.	An array of empty maps, one for each credit name.	

Table 12.3 Calibration Settings Map for CM_CR_EQ_FX_IF_IR_HW_NF (Continued)

Map Key	Type Code	Description	Constraints	Default Value	Equation Symbol
Use the inputs in this section only when `CalibrationMethod` is `QModelCalibration_CM_CR_EQ_FX_IF_IR_HW_1F_Comb`					
`ampCalibrationSettingsIR`	AL	Names of maps, one for each model currency, that specify the IR implied calibration settings. For the definition of these maps, see "IR Calibration Settings (CM_CR_EQ_FX_IF_IR_HW_NF)" on page 287.	Referenced maps must exist in the model preferences file. To use the defaults for all settings, provide an empty map.		
`ampCalibrationSettingsFX`	AL	Names of maps, one for each foreign currency, that specify FX implied calibration settings. For the definition of these maps, see "FX Calibration Settings (CM_CR_EQ_FX_IF_IR_HW_NF)" on page 290.	Referenced maps must exist in the model preferences file. To use the defaults for all settings, provide an empty map.		
`ampCalibrationSettingsEQ`	AL	Names of maps, one for each equity, that specify equity implied calibration settings. For the definition of these maps, see "Equity Calibration Settings (CM_CR_EQ_FX_IF_IR_HW_NF)" on page 290.	Referenced maps must exist in the model preferences file. To use the defaults for all settings, provide an empty map.	An array of empty maps, one for each equity.	
`ampCalibrationSettingsII`	AL	Names of maps, one for each inflation index, that specify inflation index implied calibration settings. For the definition of these maps, see "Inflation Index Calibration Settings (CM_CR_EQ_FX_IF_IR_HW_NF)" on page 291.	Referenced maps must exist in the model preferences file. To use the defaults for all settings, provide an empty map.	An array of empty maps, one for each inflation index.	
`ampCalibrationSettingsCM`	AL	Names of maps, one for each commodity, that specify commodity implied calibration settings. For the definition of these maps, see "Commodity Calibration Settings (CM_CR_EQ_FX_IF_IR_HW_NF)" on page 292.	Referenced maps must exist in the model preferences file. To use the defaults for all settings, provide an empty map.	An array of empty maps, one for each commodity.	

Table 12.3 Calibration Settings Map for CM_CR_EQ_FX_IF_IR_HW_NF (Continued)

Map Key	Type Code	Description	Constraints	Default Value	Equation Symbol
`astrBasisCurve`	AS	Nicknames of the interest rate curves used for additive LIBOR basis adjustment.	Include a nickname for each of the curves, in order, specified by the `aBasisCurve` member of the market data map.		
`bOutputFitResults`	B	Whether to report the results of the calibration (comparison of the prices of calibrating instruments from the calibrated model and calculated analytically from market data).	One of: • TRUE • FALSE	FALSE	
`strOutputFile`	S	(Optional) File path of the CSV file to which calibration results are written (if requested by `bOutputFitResults`).		Results are displayed in the audit pane only.	
Use the inputs in this section only when `CalibrationMethod` is `QModelCalibration_CM_CR_EQ_FX_IF_IR_HW_NF_ExtCal`					
`g1dtEta`	GD	Ascending sequence of M+1 dates that define the intervals of the volatility functions.	The first date must be the calibration date.		
`ag1rA`	AL	Names of lists (of type GR) that specify the mean-reversion parameters. Each list specifies the parameter for one currency.	Number of elements must be H. Referenced lists must exist in the auxiliary transaction data file.		$a_{k,i}$
`ag1rAlpha`	AL	Names of lists (of type GR) that specify the mean-reversion parameters for inflation spreads. Each list specifies the parameter for one spread between nominal and real interest rates for an inflation index.	Number of elements must be I. Referenced lists must exist in the auxiliary transaction data file.		$\alpha_{k,i}$
`ag1rGamma`	AL	Names of lists (of type GR) that specify the mean-reversion parameters for commodity convenience spreads. Each list specifies the parameter for one spread between interest rate and convenience yield for a commodity.	Number of elements must be L. Referenced lists must exist in the auxiliary transaction data file.		$\gamma_{k,i}$

Table 12.3 Calibration Settings Map for CM_CR_EQ_FX_IF_IR_HW_NF (Continued)

Map Key	Type Code	Description	Constraints	Default Value	Equation Symbol
ag2rEta	AL	Names of lists (of type AL) for each currency. Each currency list specifies names of lists (of type GR) for each of its K factors. Each currency-factor list specifies the value of the IR volatility parameter (eta) in each of the M time intervals defined by g1dtEta. For a given currency-factor pair, the value in interval m applies from g1dtEta$_m$ up to but not including g1dtEta$_{m+1}$. The value in the last interval is also used on the last date and beyond the last date (constant extrapolation).	Number of elements must be H. Referenced lists must exist in the auxiliary transaction data file.		$\eta_{k,i}(t)$
ag2rNu	AL	Names of lists (of type AL) for each spread between nominal and real interest rates for an inflation index. Each spread list specifies names of lists (of type GR) for each of its K factors. Each spread index-factor list specifies the value of the IR volatility parameter (eta) in each of the M time intervals defined by g1dtEta. For a given inflation index-factor pair, the value in interval m applies from g1dtEta$_m$ up to but not including g1dtEta$_{m+1}$. The value in the last interval is also used on the last date and beyond the last date (constant extrapolation).	Number of elements must be I. Referenced lists must exist in the auxiliary transaction data file.		$\nu_{k,i}(t)$

Table 12.3 Calibration Settings Map for CM_CR_EQ_FX_IF_IR_HW_NF (Continued)

Map Key	Type Code	Description	Constraints	Default Value	Equation Symbol
ag2rSigmaCM	AL	Names of lists (of type AL) for each spread between interest rate and convenience yield for a commodity. Each spread list specifies names of lists (of type GR) for each of its K factors. Each spread index-factor list specifies the value of the convenience spread volatility parameter in each of the M time intervals defined by g1dtEta. For a given convenience spread index-factor pair, the value in interval m applies from g1dtEta$_m$ up to but not including g1dtEta$_{m+1}$. The value in the last interval is also used on the last date and beyond the last date (constant extrapolation).	Number of elements must be L. Referenced lists must exist in the auxiliary transaction data file.		$\sigma_{k.i}(t)$
ag1rEtaFX	AL	Names of lists (of type GR) that specify, for each currency, the value of the FX volatility parameter (eta) in each of the M time intervals defined by g1dtEta. For a given currency, the value in interval m applies from g1dtEta$_m$ up to but not including g1dtEta$_{m+1}$. The value in the last interval is also used on the last date and beyond the last date (constant extrapolation).	Number of elements must be H–1. Referenced lists must exist in the auxiliary transaction data file.		$\eta_k^{FX}(t)$
ag1rEtaEquity	AL	Names of lists (of type GR) that specify, for each equity, the value of the volatility parameter (eta) in each of the M time intervals defined by g1dtEta. For a given equity, the value in interval m applies from g1dtEta$_m$ up to but not including g1dtEta$_{m+1}$. The value in the last interval is also used on the last date and beyond the last date (constant extrapolation).	Number of elements must be E. Referenced lists must exist in the auxiliary transaction data file.		$\eta_j^{EQ}(t)$

Table 12.3 Calibration Settings Map for CM_CR_EQ_FX_IF_IR_HW_NF (Continued)

Map Key	Type Code	Description	Constraints	Default Value	Equation Symbol
`ag1rEtaIF`	AL	Names of lists (of type GR) that specify, for each inflation index, the value of the inflation index volatility parameter (eta) in each of the M time intervals defined by `g1dtEta`. For a given inflation index, the value in interval m applies from `g1dtEta`$_m$ up to but not including `g1dtEta`$_{m+1}$. The value in the last interval is also used on the last date and beyond the last date (constant extrapolation).	Number of elements must be I. Referenced lists must exist in the auxiliary transaction data file.		$\eta_k^I(\mathrm{t})$
`ag1rEtaCM`	AL	Names of lists (of type GR) that specify, for each commodity, the value of the commodity spot volatility parameter in each of the M time intervals defined by `g1dtEta`. For a given commodity, the value in interval m applies from `g1dtEta`$_m$ up to but not including `g1dtEta`$_{m+1}$. The value in the last interval is also used on the last date and beyond the last date (constant extrapolation).	Number of elements must be L. Referenced lists must exist in the auxiliary transaction data file.		$\eta_k^{cm}(t)$
`arKappa`	AR	Mean reversion parameters for the hazard rates simulation.	Number of elements must be C.		κ_m
`aoSigma`	AR or AL	Volatility parameters for the hazard rates simulation. Can be provided in either of the following formats. • Array of C real values. Each element specifies the constant volatility for one credit name. • Array of C names of lists of type AR. Each list specifies the piece-wise constant volatility for one credit name for the tenor points provided in `aanTTMSigma`.	Referenced lists (in the AL case) must exist in the model preferences file.		η_m^{CR}

Table 12.3 Calibration Settings Map for CM_CR_EQ_FX_IF_IR_HW_NF (Continued)

Map Key	Type Code	Description	Constraints	Default Value	Equation Symbol
aanTTMSigma	AL	Array of C names of lists of types AN. Each list specifies the tenor points (in units specified by strSigmaTTMUnits) for the volatility provided in aoSigma for one credit name. Omit this input if you specify constant volatilities.			
strSigmaTTMUnits	S	Units of the tenors of the hazard rate volatility parameter specified by aanTTMSigma.	One of: • months • days	months	
g3rCorrMtx	AL	Names of lists (of type AL) for each factor. Each factor list specifies names of lists (of type GR) for each pairing with other factors. Each factor-pair list specifies the value of their pairwise correlation as a piecewise function of time over the intervals defined by g1dtEta. For a given pair of factors, the value in interval m applies from g1dtEta$_m$ up to but not including g1dtEta$_{m+1}$. The value in the last interval is also used on the last date and beyond the last date (constant extrapolation). For details, see the note that follows this table.	$-1 \le \rho \le 1$		$\rho(t)$

Note: Construction of g3CorrMtx

The correlations include those between the IR factors (within one currency and between the different currencies), FX factors, equity factors, hazard rate factors, factors of the spread between nominal and real interest rates, and inflation indexes.

Consider a 2-D slice of the g3CorrMtx grid along the eta axis (this is, for a given time). This 2-D factor correlation matrix is square and of length

$$\sum_{i=1}^{H} K_i + (H-1) + E + C + \sum_{j=1}^{I} K_j^I + I + \sum_{j=1}^{L} K_j^{cm} + L$$

in each dimension. It is symmetric, so we consider the construction in only one dimension. Place the risk factors in the following order:

- K_1 factors of the interest rate for currency 1, then the K_2 factors of the interest rate for currency 2, and so on for the H currencies

- (H–1) factors of the exchange rates
- E factors of the spot equity prices
- C factors of the hazard rates
- K_1^I factors of the spread between the nominal and real short rate for the first inflation index, then the K_2^I factors of the spread for the second inflation index, and so on for the I inflation indexes
- I factors of the inflation index
- K_1^{cm} factors of the spread between the interest rate and convenience yield for the first commodity, then the K_2^{cm} factors of the convenience spread for the second commodity, and so on for the L commodities.
- L factors of the commodity spot prices

Example

This example uses the time-varying parameter calibration.

```
CM_CR_EQ_FX_IF_IR_HW_NF_CallibrationSettings_ExtCal, {
  g1dtEta, GD, 2005/10/11, 2005/11/11
  astrCCY, AS, EUR, USD
  astrEquity, AS, SPX
  astrCCYEquity, AS, USD
  astrName, AS, CS1, CS2
  ag1rA, AL, g1rA_EUR, g1rA_USD
  ag2rEta, AL, ag1rEta_EUR, ag1rEta_USD
  ag1rEtaFX, AL, g1rEtaFX_USD
  ag1rEtaEquity, AL, g1rEtaEQ_USD
  arKappa, AR, 0.01
  aoSigma, AL, arSigma_CS1, arSigma_CS2
  aanTTMSigma, AL, arTTMSigma_CS1, arTTMSigma_CS2
  astrCommodity, AS, CM01
  ag1rGamma, AL, g1rGamma_CM01
  ag2rSigmaCM, AL, ag1rSigmaCM_CM01
  ag1rEtaCM, AL, g1rEtaCM_I01
  astrCommodityCCY, AS, EUR
  g3rCorrMtx, AL
  ..., ag1rCorrMtx_EUR_factor0, ag1rCorrMtx_EUR_factor1
  ..., ag1rCorrMtx_EUR_factor2
  ..., ag1rCorrMtx_USD_factor0, ag1rCorrMtx_USD_factor1
  ..., ag1rCorrMtx_USD_factor2
  ..., ag1rCorrMtx_FX_Vol_USD
  ..., ag1rCorrMtx_SPX_Vol_USD
  ..., ag1rCorrMtx_CS1
  ..., ag1rCorrMtx_CS2
  ..., ag1rCorrMtx_CM01_factor0, ag1rCorrMtx_CM01_factor1
  ..., ag1rCorrMtx_CM01_factor2
  ..., ag1rCorrMtx_CM_Vol_CM01
  bCorrectCorrMtx, B, FALSE
}
```

12.3.2.1 Credit Calibration Settings (CM_CR_EQ_FX_IF_IR_HW_NF)

The `ampCalibrationSettingsCR` member of a calibration settings map refers to other maps that each specify settings for the calibration of the credit model for one credit name. The following table defines the members of a credit calibration settings map for the CM_CR_EQ_FX_IF_IR_HW_NF model.

Table 12.4 Credit Calibration Settings Map for CM_CR_EQ_FX_IF_IR_HW_NF

Map Key	Type Code	Description	Constraints	Default Value
`bCRVolAdjustmentToNegHR`	B	Whether to adjust the hazard rate volatility to a user-specified level of the probability of hazard rate to go negative.	One of: • TRUE • FALSE	FALSE
`rProbNegHRLevel`	R	Benchmark level of the probability of hazard rate to go negative used in the hazard rate volatility adjustment. Ignored if `bCRVolAdjustmentToNegHR` is FALSE.		0.01
`dtLastCRVolAdjustmentToNegHR`	D	Last date on which the adjustment of the hazard rate volatility is required. If provided, the date is added to the combined grid of the jump dates of the hazard rate volatility and survival probability. Ignored if `bCRVolAdjustmentToNegHR` is FALSE.		

Example

```
CS1_CalibrationSettings, {
  bCRVolAdjustmentToNegHR, B, TRUE
  rProbNegHRLevel, R, 0.005
}
```

12.3.2.2 IR Calibration Settings (CM_CR_EQ_FX_IF_IR_HW_NF)

The `ampCalibrationSettingsIR` member of a calibration settings map refers to other maps that each specify settings for the calibration of the interest rate model for one currency. The following table defines the members of an IR calibration settings map for the CM_CR_EQ_FX_IF_IR_HW_NF model.

Table 12.5 IR Calibration Settings Map for CM_CR_EQ_FX_IF_IR_HW_NF

Map Key	Type Code	Description	Constraints	Default Value
strCCYDom	S	Name of the domestic currency.	Standard 3-character currency identifier	
bUseCapletFormula	B	Whether to use the caplet formula. If set to TRUE, but the input calibrating instruments are swaptions, this setting reverts to FALSE.	One of: • TRUE • FALSE	FALSE
rNotional	R	Notional amount to use when calculating prices during calibration.		1.0
mpRootFindSettings	L	Name of a map of settings for the root-finding procedure.	Referenced map must exist in the model preferences file.	Empty map
bAllowNegativeMR	B	Whether to allow the calibration process to generate a negative mean reversion parameter.	One of: • TRUE • FALSE	FALSE
strBasisCurveCalib	S	(Optional) Nickname of the interest rate curve to use for additive LIBOR basis adjustment during calibration. If omitted, the LIBOR basis adjustment is not performed.	Must be one of the names in astrBasisCurve in the main calibration settings map.	
bUseBasisCurveForCalibDiscounting	B	Whether to use the basis curve, if specified by strBasisCurveCalib, for both discounting and forecasting in the calibration (TRUE) or just for forecasting (FALSE).	One of: • TRUE • FALSE	FALSE
strBasisCurveCalibDisc	S	(Optional) Nickname of the interest rate curve to use for discounting during calibration. Ignored if bUseBasisCurveForCalibDiscounting is set to TRUE.	Must be one of the names in astrBasisCurve in the main calibration settings map.	Interest rate curve for the currency of this map, specified by the market data map member aIRCurve.
bNormalVolatilities	B	Whether to assume normal (TRUE) or log-normal (FALSE) volatilities.	One of: • TRUE • FALSE	FALSE

Example

```
IR_EUR_CalibrationSettings, {
  strBasisCurveCalib, S, EURLibor3M
}
```

12.3.2.2.1 Root-Finding Settings (CM_CR_EQ_FX_IF_IR_HW_NF)

The `mpRootFindSettings` member of an IR calibration settings map refers to another map that specifies settings for the root-finding process. Most of these settings specify various numerical tolerances. Normally, the default values are suitable.

The following table defines the members of a root-finding settings map for the CM_CR_EQ_FX_IF_IR_HW_NF model.

Table 12.6 Root-Finding Settings Map for CM_CR_EQ_FX_IF_IR_HW_NF

Map Key	Type Code	Description	Constraints	Default Value
`rVolSensTol`	R	Volatility sensitivity tolerance		0.001
`rSigmaConst`	R	Sigma used in initial guess for root find (units are per annum). If all calibrating instruments are removed, this value is used as the Hull-White volatility parameter.		0.01
`rErrorTol`	R	Error tolerance for root find to match market prices.		1.0e–14
`rRelTolNR`	R	Relative tolerance in Newton-Raphson method for root find to match market prices.		1.0e–13
`nMaxIterNR`	N	Maximum number of iterations in Newton-Raphson method for root find to match market prices.		100
`nMaxIterBracket`	N	Maximum number of iterations used in bracketing for root find to match market prices.		20
`rBracketLow`	R	Low value for bracketing for root find to match market prices.		1.0e–10
`rBracketHigh`	R	High value for bracketing for root find to match market prices.		1.0e–1
`nMaxDiv`	N	Maximum number of divisions in bisection for root find to match market prices.		100
`rRootGuessJam`	R	Initial guess for root in Jamshidian decomposition.		0.0
`rErrorTolJam`	R	Error tolerance in Jamshidian decomposition.		1.0e–13
`rRelTolNRJam`	R	Relative tolerance in Newton-Raphson method for root find in Jamshidian decomposition.		1.0e–15
`nMaxIterNRJam`	N	Maximum number of iterations in Newton-Raphson method for root find in Jamshidian decomposition.		100

Table 12.6 Root-Finding Settings Map for CM_CR_EQ_FX_IF_IR_HW_NF

Map Key	Type Code	Description	Constraints	Default Value
`rMinXJam`	R	Minimum X value in bracketing for Jamshidian decomposition.		–0.1
`rMaxXJam`	R	Maximum X value in bracketing for Jamshidian decomposition.		0.1
`nMaxDivJam`	N	Maximum number of iterations in bisection for root find in Jamshidian decomposition.		100

12.3.2.3 FX Calibration Settings (CM_CR_EQ_FX_IF_IR_HW_NF)

The `ampCalibrationSettingsFX` member of a calibration settings map refers to other maps that each specify settings for the calibration of the exchange rate model for one pair of currencies. The following table defines the members of an FX calibration settings map for the CM_CR_EQ_FX_IF_IR_HW_NF model.

Table 12.7 FX Calibration Settings Map for CM_CR_EQ_FX_IF_IR_HW_NF

Map Key	Type Code	Description	Constraints	Default Value
`bUseNegativeSpotVols`	B	Whether to add negative FX spot volatilities to the calibrated values during the calibration procedure.	One of: • TRUE • FALSE	FALSE

Example

```
UseNegativeSpotFXVols, {
  bUseNegativeSpotVols, B, TRUE
}
```

12.3.2.4 Equity Calibration Settings (CM_CR_EQ_FX_IF_IR_HW_NF)

The `ampCalibrationSettingsEQ` member of a calibration settings map refers to other maps that each specify settings for the calibration of the equity model for

one equity. The following table defines the members of a calibration settings map for the CM_CR_EQ_FX_IF_IR_HW_NF model.

Table 12.8 Equity Calibration Settings Map for CM_CR_EQ_FX_IF_IR_HW_NF

Map Key	Type Code	Description	Constraints	Default Value
`bUseNegativeSpotVols`	B	(Optional) Whether to add negative equity spot volatilities to the calibrated values during the calibration procedure.	One of: • TRUE • FALSE	FALSE

Example

```
UseNegativeSpotEQVols, {
  bUseNegativeSpotVols, B, TRUE
}
```

12.3.2.5 Inflation Index Calibration Settings (CM_CR_EQ_FX_IF_IR_HW_NF)

The `ampCalibrationSettingsII` member of a calibration settings map refers to other maps that each specify settings for the calibration of the inflation index model for one inflation index. The following table defines the members of a calibration settings map for the CM_CR_EQ_FX_IF_IR_HW_NF model.

Table 12.9 Inflation Index Calibration Settings Map for CM_CR_EQ_FX_IF_IR_HW_NF

Map Key	Type Code	Description	Constraints	Default Value
`bCalibrateToIIOptions`	B	Whether to calibrate inflation index volatilities from inflation index options. If set to FALSE in any of the inflation index calibration settings maps, you must provide `aSpotIIVolCurve` in the Market Data Map. If set to TRUE in any of the inflation index calibration settings maps, you must provide `aSpotIIImpliedVolCurve` in the Market Data Map.	One of: • TRUE • FALSE	TRUE
`bUseNegativeSpotVols`	B	(Optional) Whether to add negative inflation index spot volatilities to the calibrated values during the calibration procedure. This input applies only when `bCalibrateToIIOptions` is set to TRUE.	One of: • TRUE • FALSE	FALSE

Example

```
SampleIICalibrationSettings, {
  bCalibrateToIIOptions, B, TRUE
  bUseNegativeSpotVols, B, TRUE
}
```

12.3.2.6 Commodity Calibration Settings (CM_CR_EQ_FX_IF_IR_HW_NF)

The ampCalibrationSettingsCM member of a calibration settings map refers to other maps that each specify settings for the calibration of the commodity spot price model for one commodity. The following table defines the members of a calibration settings map for the CM_CR_EQ_FX_IF_IR_HW_NF model.

Table 12.10 Commodity Calibration Settings Map for CM_CR_EQ_FX_IF_IR_HW_NF

Map Key	Type Code	Description	Constraints	Default Value
bCalibrateToCMOptions	B	Whether to calibrate commodity spot price volatilities from commodity options. If set to FALSE in any of the commodity calibration settings maps, you must provide aCMVolCurve in the Market Data Map. If set to TRUE in any of the commodity calibration settings maps, you must provide aCMImpliedVolCurve in the Market Data Map.	One of: • TRUE • FALSE	TRUE
bUseNegativeSpotVols	B	(Optional) Whether to add negative commodity spot price volatilities to the calibrated values during the calibration procedure. This input applies only when bCalibrateToCMOptions is set to TRUE.	One of: • TRUE • FALSE	FALSE

Example

```
SampleCMCalibrationSettings, {
  bCalibrateToCMOptions, B, TRUE
  bUseNegativeSpotVols, B, TRUE
}
```

12.3.3 Market Data Inputs (CM_CR_EQ_FX_IF_IR_HW_NF)

The `CurveNames` member of the model preferences map refers to a market data map that identifies the market data curves that are required for pricing, simulation, and model calibration. The following table defines the members of a market data map for the CM_CR_EQ_FX_IF_IR_HW_NF model.

Table 12.11 Market Data Map for CM_CR_EQ_FX_IF_IR_HW_NF

Map Key	Type Code	Description	Constraints	Default Value
`aIRCurve`	AS or AL	Either: • Names of curves for discounting (of type `DiscountFactor`, `Yield`, or `FwdLibor`), one for each currency. • Names of lists that specify a set of curves to use in bootstrapping the discount factor, one for each currency. The first curve or list of curves is for the domestic currency, and the remainder are for the foreign currencies. For details about the lists of curves for bootstrapping, see "Specifying the Data to Use in Bootstrapping" on page 34.	Referenced curves must exist in the market data HDF5 file, or referenced lists must exist in an auxiliary transaction data file. The number of elements must equal the number of currencies. Ordinates of a `Yield` curve must be >0.	
`aINFCurve`	AS	Names of curves (of type `DiscountFactor`, `Yield`, or `InflationRate`) that specify the inflation-bond-related interest rate for each currency, in the same order as the inflation indexes.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of inflation indexes. Ordinates of a `Yield` curve must be >0.	
`aSpotIICurve`	AS	Names of curves (of type `InflationIndex`) that specify the inflation index for each currency, in the same order as the inflation indexes. Must be provided when `bCalibrateToIIOptions` is set to TRUE in the inflation index calibration settings map.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of inflation indexes.	

Table 12.11 Market Data Map for CM_CR_EQ_FX_IF_IR_HW_NF (Continued)

Map Key	Type Code	Description	Constraints	Default Value
aINFDerivedCurve	AS	(Optional) Names of curves (of type Yield) that specify the inflation-bond-related interest rate for the currency of each derived inflation index, in the same order in which the indexes are listed in the astrIIDerived parameter in the calibration settings map. Required if the astrIIDerived parameter is specified in the calibration settings map.	Referenced curves must exist in the market data HDF5 file. The number of elements in the array must equal the number of inflation indexes. Ordinates of a Yield curve must be >0.	
aSpotIIDerivedCurve	AS	(Optional) Names of curves (of type InflationIndex) that specify the initial value of each derived inflation index, in the same order in which the indexes are listed in the astrIIDerived parameter in the calibration settings map. Required if the astrIIDerived parameter is specified in the calibration settings map.	Referenced curves must exist in the market data HDF5 file. The number of elements in the array must equal the number of derived indexes.	
aSpotFXCurve	AS	Names of domestic/foreign spot FX curves (of type Exchange), one for each currency, in the same order as the IR curves.	The first name, corresponding to the domestic currency, must be void. Referenced curves must exist in the market data HDF5 file.	
aSpotEQCurve	AS	Names of spot equity curves (of type Equity or EquityIndex), one for each equity, in the same order as the equities.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of equities.	
aEQDividendCurve	AS	Names of equity dividend curves (of type DiscreteAbsoluteDividend or ContinuousYieldDividend), one for each equity, in the same order as the equities.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of equities.	
aCreditCurve	AS	Names of the CDS curves (of type ParCreditSpread), one for each credit name, in the same order as the credit names.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of credit names.	

Table 12.11 Market Data Map for CM_CR_EQ_FX_IF_IR_HW_NF (Continued)

Map Key	Type Code	Description	Constraints	Default Value
aForwardCMCurve	AS	Names of the commodity futures curves (of type Commodity), one for each commodity, in the same order as commodities.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of commodities.	
aIRMarketPriceOfRiskCurve	AS	Names of the curves (of type GenericMatrix) that specify the market price of IR risk, used in the calculation of the real world drift, one for each currency. The curve ordinates specify the forward rate tenors, corresponding to the values of the market price of risk. The curve ordinates must contain benchmark IR tenors specified in the data extraction settings map. The values, corresponding to those tenors, are extracted for use in the simulation of the corresponding short rate factors.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of currencies.	
Use the inputs in this section only when DataExtractionMethod is QDataExtraction_CM_CR_EQ_FX_IF_IR_HW_CombCov or QDataExtraction_CM_CR_EQ_FX_IF_IR_HW_CombCorr				
aMeanReversionCurve	AS	Names of mean reversion curves (of type Vector), one for each currency, in the same order as the IR curves. The curve ordinates specify the forward rate tenors, corresponding to the mean reversion values. The curve ordinates must contain benchmark IR tenors specified in the data extraction settings map. The values, corresponding to those tenors, are extracted for use in the simulation of the corresponding short rate factors.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of currencies.	
aCRMeanReversionCurve	AS	Names of mean reversion curves (of type Vector), one for each name, in the same order as the credit curves. The curve ordinates specify the forward hazard rate tenors, corresponding to the mean reversion values. The curve ordinates must contain the benchmark CR tenor specified in the data extraction settings map. The value, corresponding to that tenor, is extracted for use in the simulation of the instantaneous hazard rate.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of names.	

Table 12.11 Market Data Map for CM_CR_EQ_FX_IF_IR_HW_NF (Continued)

Map Key	Type Code	Description	Constraints	Default Value
`aINFMeanReversionCurve`	AS	Names of mean reversion curves (of type `Vector`), one for the spread between nominal and real interest rates for each currency, in the same order as the inflation indexes. The curve ordinates specify the forward rate tenors, corresponding to the mean reversion values. The curve ordinates must contain benchmark inflation spread tenors specified in the data extraction settings map. The values, corresponding to those tenors, are extracted for use in the simulation of the corresponding factors of the inflation spread.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of currencies.	
`aCMMeanReversionCurve`	AS	Names of mean reversion curves (of type `Vector`), one for the spread between interest rate and convenience yield, for each commodity, in the same order as the commodities. The curve ordinates specify the forward rate tenors, corresponding to the mean reversion values. The curve ordinates must contain benchmark commodity tenors specified in the data extraction settings map. The values, corresponding to those tenors, are extracted for use in the simulation of the corresponding factors of the convenience spread.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of commodities.	
`aCapletVolCurve`	AS	Names of caplet volatility curves (of type `CapletVol`), one for each currency, in the same order as the IR curves. For details of the configuration of the volatility curves, see "Risk Factor Covariance Data Inputs" on page 301.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of currencies.	
`aSwaptionVolCurve`	AS	Names of swaption volatility curves (of type `SwaptionVolMtx`), one for each currency, in the same order as the IR curves. For details of the configuration of the volatility curves, see "Risk Factor Covariance Data Inputs" on page 301.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of currencies.	

Table 12.11 Market Data Map for CM_CR_EQ_FX_IF_IR_HW_NF (Continued)

Map Key	Type Code	Description	Constraints	Default Value
`aIRForwardVolCurve`	AS	Names of the IR forward volatility curves (of type `GenericMatrix`), one for each currency, in the same order as the IR curves. For details of the configuration of the volatility curves, see “Risk Factor Covariance Data Inputs” on page 301. For details of the curve format, see “Volatility Curves” on page 302.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of currencies.	
`aIRVolCurve`	AS	Names of the short IR volatility curves (of type `GenericMatrix`), one for each currency, in the same order as the IR curves. For details of the configuration of the volatility curves, see “Risk Factor Covariance Data Inputs” on page 301. For details of the curve format, see “Volatility Curves” on page 302.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of currencies.	
`aFXImpliedVolCurve`	AS	Names of FX option volatility curves (of type `ImpliedVol`), one for each spot FX rate, in the same order as the FX curves. The first name, matching the domestic currency itself, can be left blank. For details of the configuration of the volatility curves, see “Risk Factor Covariance Data Inputs” on page 301.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of currencies.	
`aSpotFXVolCurve`	AS	Names of spot FX volatility curves (of type `Vector`), one for each spot FX rate, in the same order as the FX curves. The first name, matching the domestic currency itself, can be left blank. For details of the configuration of the volatility curves, see “Risk Factor Covariance Data Inputs” on page 301. For details of the curve format, see “Volatility Curves” on page 302.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of currencies.	

Table 12.11 Market Data Map for CM_CR_EQ_FX_IF_IR_HW_NF (Continued)

Map Key	Type Code	Description	Constraints	Default Value
`aEQImpliedVolCurve`	AS	Names of equity option volatility curves (of type `EquityImpliedVol` or `ImpliedVol`), one for each spot equity, in the same order as the equity curves. For details of the configuration of the volatility curves, see “Risk Factor Covariance Data Inputs” on page 301. For details of the curve format, see “Volatility Curves” on page 302.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of equities.	
`aSpotEQVolCurve`	AS	Names of spot equity volatility curves (of type `Vector`), one for each spot equity, in the same order as the equity curves. For details of the configuration of the volatility curves, see “Risk Factor Covariance Data Inputs” on page 301. For details of the curve format, see “Volatility Curves” on page 302.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of equities.	
`aINFForwardVolCurve`	AS	Names of forward inflation spread volatility curves (of type `GenericMatrix`), one for each inflation index, in the same order as the inflation indexes. For details of the configuration of the volatility curves, see “Risk Factor Covariance Data Inputs” on page 301. For details of the curve format, see “Volatility Curves” on page 302.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of inflation indexes.	
`aINFVolCurve`	AS	Names of inflation spread volatility curves (of type `GenericMatrix`), one for each inflation index, in the same order as the inflation indexes. For details of the configuration of the volatility curves, see “Risk Factor Covariance Data Inputs” on page 301. For details of the curve format, see “Volatility Curves” on page 302.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of inflation indexes.	

Table 12.11 Market Data Map for CM_CR_EQ_FX_IF_IR_HW_NF (Continued)

Map Key	Type Code	Description	Constraints	Default Value
`aSpotIIImpliedVolCurve`	AS	Names of inflation index option implied volatility curves (of type `ImpliedVol`), one for each inflation index, in the same order as the inflation indexes. For details of the configuration of the volatility curves, see "Risk Factor Covariance Data Inputs" on page 301. For details of the curve format, see "Volatility Curves" on page 302.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of inflation indexes.	
`aSpotIIVolCurve`	AS	Names of spot inflation index volatility curves (of type `Vector`), one for each inflation index, in the same order as the inflation indexes. For details of the configuration of the volatility curves, see "Risk Factor Covariance Data Inputs" on page 301. For details of the curve format, see "Volatility Curves" on page 302.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of inflation indexes.	
`aCMSpreadForwardVolCurve`	AS	Names of forward commodity convenience spread volatility curves (of type `GenericMatrix`), one for each commodity, in the same order as the commodities. For details of the configuration of the volatility curves, see "Risk Factor Covariance Data Inputs" on page 301. For details of the curve format, see "Volatility Curves" on page 302.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of commodities.	
`aCMSpreadVolCurve`	AS	Names of commodity convenience spread volatility curves (of type `GenericMatrix`), one for each commodity, in the same order as the commodities. For details of the configuration of the volatility curves, see "Risk Factor Covariance Data Inputs" on page 301. For details of the curve format, see "Volatility Curves" on page 302.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of commodities.	

Table 12.11 Market Data Map for CM_CR_EQ_FX_IF_IR_HW_NF (Continued)

Map Key	Type Code	Description	Constraints	Default Value
`aCMImpliedVolCurve`	AS	Names of commodity futures option implied volatility curves (of type `CommodityImpliedVol` or `CommodityImpliedVolMtx`), one for each commodity, in the same order as the commodities. For details of the configuration of the volatility curves, see "Risk Factor Covariance Data Inputs" on page 301. For details of the curve format, see "Volatility Curves" on page 302.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of commodities.	
`aCMVolCurve`	AS	Names of commodity spot volatility curves (of type `Vector`), one for each commodity, in the same order as the commodities. For details of the configuration of the volatility curves, see "Risk Factor Covariance Data Inputs" on page 301. For details of the curve format, see "Volatility Curves" on page 302.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of commodities.	
`aBasisCurve`	AS	Names of curves (of type `DiscountFactor`, `Yield`, or `FwdLibor`) that specify the forecasting interest rates to use for LIBOR basis adjustments for all relevant currencies.	Referenced curves must exist in the market data HDF5 file. Ordinates of a `Yield` curve must be > 0.	
`CorrelationCurve`	S	Name of the correlation curve (of type `GenericCube`) that gives the correlations between model risk factors. For the details of the curve format, see "Correlation and Covariance Curves" on page 303.	Referenced curve must exist in the market data HDF5 file.	
`CovarianceCurve`	S	Name of the covariance curve (of type `GenericCube`) that give the covariance between model risk factors. For details of the configuration of the covariance curves, see "Risk Factor Covariance Data Inputs" on page 301. For details of the curve format, see "Correlation and Covariance Curves" on page 303.	Referenced curve must exist in the market data HDF5 file.	

Table 12.11 Market Data Map for CM_CR_EQ_FX_IF_IR_HW_NF (Continued)

Map Key	Type Code	Description	Constraints	Default Value
`aIRForwardAverageCurve`	AS	Names of the average forward interest rate curves (of type `Vector`), one for each currency, for use in the calibration of IR market price of risk. The curve ordinates specify the forward rate tenors. The curve ordinates must contain forward IR tenors specified in the input `aarTenorIRForwardAverage` in the data extraction settings map. The values, corresponding to those tenors, are extracted from the curve for use in the IR market price of risk calibration. Ignored for a currency if `aIRMarketPriceOfRisk` is provided and the element corresponding to the currency is not void.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of currencies.	
`aIRShortAverageCurve`	AS	Names of the average short interest rate curves (of type `Scalar`), one for each currency, for use in the calibration of R market price of risk. Ignored for a currency if `aIRMarketPriceOfRisk` is provided and the element corresponding to the currency is not void.	Referenced curves must exist in the market data HDF5 file. The number of elements must equal the number of currencies.	

Risk Factor Covariance Data Inputs

Provide the historical covariance between the model factors in one of the following formats:

- A correlation curve and volatility curves for each of the factors.

  Use the `QDataExtraction_CM_CR_EQ_FX_IF_IR_HW_CombCorr` data extraction class.
- A single covariance curve.

  Use the `QDataExtraction_CM_CR_EQ_FX_IF_IR_HW_CombCov` data extraction class.

For the `QDataExtraction_CM_CR_EQ_FX_IF_IR_HW_CombCorr` data extraction class, you must specify the following inputs:

- `CorrelationCurve`
- `aIRForwardVolCurve`
- `aSpotFXVolCurve`
- `aSpotEQVolCurve`
- `aHazardRateForwardVolCurve`
- `aINFSpreadForwardVolCurve`
- `aSpotIIVolCurve`
- `aCMSpreadForwardVolCurve`

- aSpotCMVolCurve

These curves provide the historical volatilities and the correlations between forward interest rates, spot exchange rates, spot equity prices, forward hazard rates, forward inflation spreads, spot inflation indexes, forward commodity convenience spreads, and commodity spot prices. The order of the elements in the correlation matrix is defined in "Correlation and Covariance Curves" on page 303.

For the QDataExtraction_CM_CR_EQ_FX_IF_IR_HW_CombCov data extraction class, you must specify the CovarianceCurve input, which provides the historical covariance between forward interest rates, spot exchange rates, spot equity prices, forward hazard rates, forward inflation spreads, spot inflation indexes, forward commodity convenience spreads, and commodity spot prices. The order of the elements in the CovarianceCurve is described in "Correlation and Covariance Curves" on page 303.

For the QModelCalibration_CM_CR_EQ_FX_IF_IR_HW_1F_Comb calibration class (for both data extraction classes), you can overwrite the historically calibrated volatilities with the implied calibration for IR, spot FX, spot equity, inflation index, and spot commodity factors. To use the implied calibration, specify the following inputs:

- aSwaptionVolCurve or aCapletVolCurve for IR volatility calibration.
- aFXImpliedVolCurve for spot FX volatility calibration.
- aEQImpliedVolCurve for spot equity volatility calibration.
- aSpotIIImpliedVolCurve for spot inflation index volatility calibration.
- aCMImpliedVolCurve for spot inflation index volatility calibration.

If both implied and historical volatilities are provided, implied calibration is performed.

For the QModelCalibration_CM_CR_EQ_FX_IF_IR_HW_1F_Comb and QModelCalibration_CM_CR_EQ_FX_IF_IR_HW_FwdCov calibration classes, you can overwrite the calibrated volatility with the direct input of instantaneous volatility values to use in the simulation. To do so, specify the following inputs:

- aIRVolCurve for short interest rate volatility.
- aHazardRateVolCurve for hazard rate volatility.
- aINFVolCurve for inflation spread volatility.
- aCMSpreadVolCurve for commodity spread volatility.

If both direct volatility and implied or historical volatility are provided, direct volatility inputs are used. Note that for spot FX, equity, inflation index, and commodity, the historical volatility is directly used in the simulation. That is why no additional inputs are required for these factors for direct volatility inputs.

Volatility Curves

The historical volatility or the direct instantaneous volatility must be provided in a GenericMatrix or Vector curve.

Use GenericMatrix for the IR, hazard rate, inflation spread, and commodity convenience spread volatility. The curve ordinates along the first axis specify the forward tenors, corresponding to the volatility values. The curve ordinates must contain benchmark tenors specified in the data extraction settings map for IR, hazard rate, inflation, and commodity factors. The values, corresponding to those tenors, are extracted for use in the simulation. The curve ordinates along the second axis specify the number of days to the volatility jump date as of the curve base date. The example below shows the constant in time historical IR volatility for 4 forward tenors.

```
GenericMatrix,USD_IR_FWD, 2013/12/16, USD, R, R, R, 0, 180, 360, 720,
3600, 0.0010, 0.0015, 0.0029, 0.065
```

Use `Vector` for the exchange rate, spot equity, inflation index, and spot commodity volatilities. The curve ordinates specify the number of days to the volatility jump date as of the curve base date. The example below shows the constant in time historical spot exchange volatility.

```
Vector, FX_EUR_USD, 2013/12/16, USD,0,0.127
```

Correlation and Covariance Curves

Use `GenericCube` for the correlation and covariance inputs. The curve ordinates along the first and second axis specify the integers corresponding to the number of the risk factor, according to the scheme described below. The third ordinate of the correlation or covariance curve specifies the number of days from the curve base date to the covariance or correlation jump dates.

Consider a 2-D slice of the correlation or covariance curve along the third axis (this is, for a given time). This 2-D factor correlation matrix is square and of length

$$\sum_{i=1}^{H} K_i + (H-1) + E + C + \sum_{j=1}^{I} K_j^I + I + \sum_{j=1}^{L} K_j^{cm} + L$$

in each dimension. It is symmetric, so we consider the construction in only one dimension. Place the risk factors in the following order:

- K_1 factors of the interest rate for currency 1, then the K_2 factors of the interest rate for currency 2, and so on for the H currencies.
- (H–1) factors of the exchange rates.
- E factors of the spot equity prices.
- C factors of the hazard rates.
- K_1^I factors of the spread between the nominal and real short rate for the first inflation index, then the K_2^I factors of the spread for the second inflation index, and so on for the I inflation indexes.
- I factors of the inflation index.
- K_1^{cm} factors of the spread between the interest rate and convenience yield for the first commodity, then the K_2^{cm} factors of the convenience spread for the second commodity, and so on for the L commodities.
- L factors of the commodity spot prices.

Example

The following example shows the combined implied-historical calibration of the single factor model. The implied calibration is used for IR, spot FX, equity, and commodity volatilities. Historical calibration is used for hazard rate and commodity spread volatilities. The curve map below should be used with `QDataExtraction_CM_CR_EQ_FX_IF_IR_HW_CombCorr` data extraction method and `QModelCalibration_CM_CR_EQ_FX_IF_IR_HW_1F_Comb` calibration method.

```
CM_CR_EQ_FX_IR_HW_1F_CurveNames_, {
  aIRCurve, AS, EUR.Yield.EUR, USD.Yield.USD
  aForwardCMCurve, AS, CM01.Commodity.EUR
  aSpotFXCurve, AS, void, USD.Exchange.EUR
  aSpotEQCurve, AS, SPX.EquityIndex.USD
  aCreditCurve, AS, CS1.ParCreditSpread.USD, CS2.ParCreditSpread.EUR
  aCMMeanReversionCurve, AS, CM01Spread.MeanReversion.EUR
  aCMForwardSpreadVolCurve, AS, CM01Spread.CommodityImpliedVol.EUR
  aCMImpliedVolCurve, AS, CM01Implied.CommodityImpliedVol.EUR
  aMeanReversionCurve, AS, EURMR.Vector.EUR, USDMR.Vector.USD
  aSwaptionVolCurve, AS, SemiannualSwapVol.SwaptionVolMtx.EUR
  ..., SemiannualSwapVol.SwaptionVolMtx.USD
  aFXImpliedVolCurve, AS, void, USD.ImpliedVol.EUR
  aEQImpliedVolCurve, AS, void, SPX.ImpliedVol.USD
  aCRMeanReversionCurve, AS, CS1.Vector.USD, CS2.Vector.EUR
  aHazardRateForwardVolCurve, AS, CS1.GenericMatrix.USD, CS2.GenericMatrix.EUR
  CorrelationCurve, S, HistoricalCorr.GenericCube.EUR
}
```

The following example shows the extraction of the model parameters from the historical calibration of the single factor or multifactor model. The curve map below is used with the `QDataExtraction_CM_CR_EQ_FX_IF_IR_HW_CombCov` data extraction method and the `QModelCalibration_CM_CR_EQ_FX_IF_IR_HW_NF_FwdCov` calibration method.

```
CM_CR_EQ_FX_IR_HW_NF_CurveNames_, {
  aIRCurve, AS, EUR.Yield.EUR, USD.Yield.USD
  aForwardCMCurve, AS, CM01.Commodity.EUR
  aSpotFXCurve, AS, void, USD.Exchange.EUR
  aSpotEQCurve, AS, SPX.EquityIndex.USD
  aCreditCurve, AS, CS1.ParCreditSpread.USD, CS2.ParCreditSpread.EUR
  aCMMeanReversionCurve, AS, CM01Spread.MeanReversion.EUR
  aMeanReversionCurve, AS, EURMR.Vector.EUR, USDMR.Vector.USD
  aCRMeanReversionCurve, AS, CS1.Vector.USD, CS2.Vector.EUR
  CovarianceCurve, S, HistoricalCov.GenericCube.EUR
}
```

12.3.4 Data Extraction Settings (CM_CR_EQ_FX_IF_IR_HW_NF)

The `DataExtractionSettings` member of the model preferences map refers to another map that specifies parameters for the data extraction process. The following table defines the members of a data extraction settings map for the CM_CR_EQ_FX_IF_IR_HW_NF model.

Table 12.12 Data Extraction Settings Map for CM_CR_EQ_FX_IF_IR_HW_NF

Map Key	Type Code	Description	Constraints	Default Value
ampIRCurveSettings	AL	Names of maps, one for each model currency, that specify settings for extracting interest rates. For the definition of these maps, see "Interest Rate Extraction Settings Map" on page 35.	Referenced maps must exist in the model preferences file. To use the defaults for all settings, provide an empty map.	An array of empty maps, one for each currency.
ampBasisCurveSettings	AL	Names of maps of settings for the basis data extraction, one for each interest rate curve specified by aBasisCurve in the market data map. The settings in these maps are listed in "Interest Rate Extraction Settings Map" on page 35.	Referenced maps must exist in the model preferences file.	The settings specified by ampIRCurveSettings are used.
ampIFCurveSettings	AL	Names of maps, one for each inflation index, that specify the settings for extracting the inflation-bond-related interest rate. In the current release, inflation index data extraction has no settings.	Referenced maps must exist in the model preferences file.	An array of empty maps, one for each inflation index.
bExtrapolateDF	B	Controls whether to extrapolate discount factors and inflation discount factors.	One of: • TRUE • FALSE	FALSE
nMonthsExtrapDFEnd	N	Number of months after the calibration date in which to extrapolate the discount factors.		0
aidxCDSCCY	AN	Index of the CDS currency for each credit name.	Integers between 0 and the number of foreign currencies of the model.	0
bUseMFWKStripper	B	Whether to use the model's internal survival probability bootstrapper (TRUE), or the external generic survival probability bootstrapper (FALSE).	One of: • TRUE • FALSE	TRUE
ampSettingsCDS	AL	Names of maps, one for each credit name, that specify credit data extraction settings for purposes of calibration. For the definition of these maps, see "CR Calibration Data Extraction Settings (CM_CR_EQ_FX_IF_IR_HW_NF)" on page 307.	Referenced maps must exist in the model preferences file. To use the defaults for all settings, provide an empty map.	An array of empty maps, one for each credit name.

Table 12.12 Data Extraction Settings Map for CM_CR_EQ_FX_IF_IR_HW_NF (Continued)

Map Key	Type Code	Description	Constraints	Default Value
Use the inputs in this section only when `DataExtractionMethod` is `QDataExtraction_CM_CR_EQ_FX_IF_IR_HW_CombCorr` or `QDataExtraction_CM_CR_EQ_FX_IF_IR_HW_CombCov`				
`aarBenchmarkTenorIR`	`AL`	Array of names of lists of types AR, one for each currency name. Each list specifies the forward IR benchmark tenor points, in days, for the currency.	Referenced lists must exist in the model preferences file.	
`aarBenchmarkTenorCR`	`AL`	Array of names of lists of types AR, one for each credit name. Each list specifies the forward hazard rate benchmark tenor points, in days, for the credit name.	Referenced lists must exist in the model preferences file.	
`aarBenchmarkTenorINFSpread`	`AL`	Array of names of lists of types AR, one for each inflation index name. Each list specifies the forward inflation spread tenor points, in days, for the inflation index.	Referenced lists must exist in the model preferences file.	
`aarBenchmarkTenorCMSpread`	`AL`	Array of names of lists of types AR, one for each commodity name. Each list specifies the forward commodity convenience spread tenor points, in days, for the commodity.	Referenced lists must exist in the model preferences file.	
`aarTenorIRForwardAverage`	`AL`	Array of names of lists of types AR, one for each currency name. Each list specifies the forward IR tenor points, in days, to extract average forward interest rates for use in the market price of risk calibration.	Referenced lists must exist in the model preferences file.	
`ampDataExtractionSettingsIR`	`AL`	Names of maps, one for each model currency, that specify IR data extraction settings for purposes of implied calibration. For the definition of these maps, see “IR Calibration Data Extraction Settings (CM_CR_EQ_FX_IF_IR_HW_NF)” on page 318.	Referenced maps must exist in the model preferences file. To use the defaults for all settings, provide an empty map.	
`ampDataExtractionSettingsFX`	`AL`	Names of maps, one for each foreign currency, that specify FX data extraction settings for purposes of implied calibration. In the current release, FX calibration data extraction has no settings.	Referenced maps must exist in the model preferences file.	An array of empty maps, one for each foreign currency.

Table 12.12 Data Extraction Settings Map for CM_CR_EQ_FX_IF_IR_HW_NF (Continued)

Map Key	Type Code	Description	Constraints	Default Value
ampDataExtractionSettingsEQ	AL	Names of maps, one for each equity, that specify equity data extraction settings for purposes of implied calibration. In the current release, equity calibration data extraction has no settings.	Referenced maps must exist in the model preferences file.	An array of empty maps, one for each equity.
ampDataExtractionSettingsII	AL	Names of maps, one for each inflation index, that specify inflation index data extraction settings for purposes of implied calibration. In the current release, inflation index calibration data extraction has no settings.	Referenced maps must exist in the model preferences file.	An array of empty maps, one for each inflation index.
ampDataExtractionSettingsCM	AL	Names of maps, one for each commodity, that specify commodity data extraction settings for purposes of implied calibration. In the current release, commodity calibration data extraction has no settings.	Referenced maps must exist in the model preferences file.	An array of empty maps, one for each commodity.

Example

```
CM_CR_EQ_FX_IF_IR_HW_NF_DataExtractionSettings, {
  aarBenchmarkTenorIR, AL, arBenchmarkTenorIR_2y, arBenchmarkTenorIR_2y
  aarBenchmarkTenorCR, AL, arBenchmarkTenorCR_5y, arBenchmarkTenorCR_5y
  ampDataExtractionSettingsIR, AL, Swaption_DataExtractionSetting, void
  ampSettingsCDS, AL, CS1_mpSettingsCDS, CS2_mpSettingsCDS
  aidxCDSCCY, AN, 1, 1
  bExtrapolateDF, B, TRUE
  nMonthsExtrapDFEnd, N, 10
}
```

12.3.4.1 CR Calibration Data Extraction Settings (CM_CR_EQ_FX_IF_IR_HW_NF)

The `ampDataExtractionSettingsCR` member of the data extraction settings map refers to other maps that each specify settings for CR calibration data extraction for one credit name.

You can choose whether to use the model's internal survival probability bootstrapper (`bUseMFWKStripper = TRUE`), or the external generic survival probability bootstrapper (`bUseMFWKStripper = FALSE`).

The model's internal survival probability bootstrapper uses the assumption that defaults occur at the mid-points of each coupon period.

For information about the methodology of the external bootstrapper, see the following Markit Analytics document: *CDS Pricing and Bootstrapping Methodology Notes*.

The sections below define the data extraction settings maps for the internal and external survival probability bootstrappers.

12.3.4.1.1 With the Internal Survival Probability Bootstrapper

The following table defines the members of a CR calibration data extraction settings map for the CM_CR_EQ_FX_IF_IR_HW_NF model when you use the model's internal survival probability bootstrapper.

Table 12.13 CR Calibration Data Extraction Settings Map for CM_CR_EQ_FX_IF_IR_HW_NF (Internal Survival Probability Bootstrapper)

Map Key	Type Code	Description	Constraints	Default Value
bUseIMMDates	B	Whether to use IMM dates. If TRUE and the calibration date is not an IMM date, the CDS maturity is taken to be from the next IMM date.	One of: • TRUE • FALSE	TRUE
bRoundMidPointToNearestDay	B	Whether to round the coupon period mid points, calculated for accrued interest, to the nearest day.	One of: • TRUE • FALSE	TRUE
bUseYearFracForAccInt	B	Whether to use the year fraction in the calculation of the accrued interest using midpoint approximation.	One of: • TRUE • FALSE	TRUE
rDaysPerAnnumAccInt	R	Number of days per annum in the calculation of the accrued interest using midpoint approximation, if bUseYearFracForAccInt is FALSE.		365.25[dy]
rFwdHazardRateFloor	R	Floor value for the forward hazard rate in bootstrapping.		1e-5
bAccInt	B	Whether to use the accrued interest in bootstrapping.	One of: • TRUE • FALSE	TRUE
bTest	B	Whether to perform the round trip test on par credit spread in bootstrapping.	One of: • TRUE • FALSE	FALSE
bBootstrapClean	B	Whether to take into account the accrued rebate for IMM dates in bootstrapping.	One of: • TRUE • FALSE	TRUE for spread quote data. FALSE for upfront fee quote data.

Table 12.13 CR Calibration Data Extraction Settings Map for CM_CR_EQ_FX_IF_IR_HW_NF (Internal Survival Probability Bootstrapper) (Continued)

Map Key	Type Code	Description	Constraints	Default Value
strSPInterpType	S	Survival probability interpolation method: • Log-linear interpolation on survival probabilities (SPLogLin) • Linear interpolation on survival probability yields (SPYieldLin)	One of: • SPLogLin • SPYieldLin	SPLogLin
bUseBisection	B	Whether to use the bisection method for root finding (TRUE) or the Newton-Raphson method (FALSE).	One of: • TRUE • FALSE	FALSE
rNRTol	R	Tolerance value for the Newton-Raphson method of root finding.		1e-8
nNRMaxIter	N	Maximum number of iterations for Newton-Raphson root finding.		50
mpOptionsRootGridX	L	(Optional) Name of a map that specifies settings for root finding by the bisection method.		
rBisectionLB	R	Lower bound used in the bisection method of root finding.		0
rBisectionUB	R	Upper bound used in the bisection method of root finding.		1
bLastPeriodAccrualEndUnadjusted	B	Whether to use the unadjusted accrual end date for the last coupon period if bUseIMMDates is TRUE.	One of: • TRUE • FALSE	TRUE
bIMMStepInNext	B	Whether to use the next date after the calibration date as the IMM step-in date.	One of: • TRUE • FALSE	TRUE
bFirstPartialIMMCoupon	B	Whether to use the first partial coupon with IMM dates.	One of: • TRUE • FALSE	FALSE
bUpfrontFee	B	Whether the underlying curve data represents upfront fee quotes (TRUE) or par credit spreads (FALSE).	One of: • TRUE • FALSE	FALSE
oUpfrontFeeFixedCoupon	R or AR	Fixed coupon rate to use in the calculation when the input credit data is upfront fee quotes. Specify a scalar input (R) if fixed coupons are the same for all maturities, or an array (AR) if fixed coupons are different for different maturities.		0.01

Table 12.13 CR Calibration Data Extraction Settings Map for CM_CR_EQ_FX_IF_IR_HW_NF (Internal Survival Probability Bootstrapper) (Continued)

Map Key	Type Code	Description	Constraints	Default Value
`anUpfrontFeeScheduleMonths`	`AN`	(Optional) Maturity, as number of months, for each fixed coupon rate for upfront fee quote data. Required when `oUpfrontFeeFixedCoupon` is an array.	Same number of elements as `oUpfrontFeeFixedCoupon`.	
`nSettlementLag`	`N`	Number of days after which the contract must be settled.		0

Example

```
mpSettingsCDS_ObligorA, {
  bRoundMidpointToNearestDay, B, TRUE
  bUseYearFracForAccInt, B, TRUE
  bAccInt, B, TRUE
  rFwdHazardRateFloor, R, 1e-5
  bUseBisection, B, FALSE
  bTest, B, FALSE
  bBootstrapClean, B, TRUE
  strSPInterpType, S, SPYieldLin
  bUpfrontFee, B, TRUE
  oUpfrontFeeFixedCoupon, R, 0.015
  nSettlementLag, N, 2
}
```

12.3.4.1.1.1 Root-Finding Settings (CM_CR_EQ_FX_IF_IR_HW_NF)

The `mpOptionsRootGridX` member of the CR calibration data extraction settings map above refers to another input map that specifies root-finding settings for the bisection method. These are the options that are parameters of the `RootGridX()` function (for more information see the *QuIC Functions Reference* document which is a set of HTML files included in an Analytics package). The following table defines the members of this map.

Table 12.14 CR Root-Finding Settings Map for CM_CR_EQ_FX_IF_IR_HW_NF

Map Key	Type Code	Description	Constraints	Default Value
`nDivs`	`N`	Number of subdivision operations to perform.		30

Example

```
CRDataExtraction_RootFindingSettings, {
  nDivs, N, 50
}
```

12.3.4.1.2 With the External Survival Probability Bootstrapper

The following table defines the members of a CR calibration data extraction settings map for the CM_CR_EQ_FX_IF_IR_HW_NF model when you use the external generic survival probability bootstrapper.

Table 12.15 CR Calibration Data Extraction Settings Map for CM_CR_EQ_FX_IF_IR_HW_NF (External Survival Probability Bootstrapper)

Map Key	Type Code	Description	Constraints	Default Value
`strSPFrequency`	S	(Optional) Frequency of the survival probability dates. If set to `COUPONDATES`, the survival probability is generated at the union of the coupon dates of all the CDS instruments used in the bootstrapping. If omitted, the survival probability is generated on the node points of the input credit curve.	One of: • `COUPONDATES` • `DAILY` • `WEEKLY` • `MONTHLY` • `QUARTERLY` • `SEMIANNUAL` • `ANNUAL`	
`strHolidayListPremiumLeg`	S	(Optional) Name of the relevant set of holidays for adjusting the CDS schedule dates for the premium leg. If omitted, no adjustment is performed.	Name must be the key in the holidays HDF5 file.	
`strHolidayListProtectionLeg`	S	(Optional) Name of the relevant set of holidays for adjusting the CDS schedule dates for the protection leg. If omitted, no adjustment is performed.	Name must be the key in the holidays HDF5 file.	
`mpCDSBootstrapperSettings`	L	Name of a map that specifies the CDS bootstrapper settings. For a definition of this map, see Table 12.16 on page 312.		
`mpCDSPricerSettings`	L	(Optional) Name of a map that specifies the CDS pricer settings. For a definition of this map, see Table 12.17 on page 314 and Table 12.18 on page 316. Omit this input if the reference credit curve is of type `SurvivalProbability`.		
`mpCDSPricerScheduleSettings`	L	(Optional) Name of a map that specifies the settings for the schedule generation of the CDS pricer. For a definition of this map, see Table 12.19 on page 318. Omit this input if the reference credit curve is of type `SurvivalProbability`.		

Example

```
DataExtractionSettings_ExternalSPBootstrapper_ObligorA {
  strHolidayListPremiumLeg, S, USD
  strHolidayListProtectionLeg, S, WE
  mpCDSBootstrapperSettings, L, CDSBootstrapper_SPEnd
  mpCDSPricerSettings, L, CDSPricer_RollDefaultDates
  mpCDSPricerScheduleSettings, L, CDSPricerSchedule_IMMDates
}
```

12.3.4.1.2.1 External CDS Bootstrapper Settings

The mpCDSBootstrapperSettings member of the CR calibration data extraction settings map above refers to another input map that specifies survival probability bootstrapper settings. The following table defines the members of this map.

Table 12.16 External CDS Bootstrapper Settings Map

Map Key	Type Code	Description	Constraints	Default Value
strCDSBootstrapper	S	Bootstrapper type.	CDSBootstrapperSinglNameSPEnd	
bFloor	B	Whether to floor the value of the optimization parameter in bootstrapping.	One of: • TRUE • FALSE	TRUE
bRoundTripTest	B	Whether to perform the round trip test on the CDS price in bootstrapping.	One of: • TRUE • FALSE	FALSE
bUseYearFracSP	B	Whether to use the year fraction in the calculation of the survival probability, yield, or spot hazard rate.	One of: • TRUE • FALSE	FALSE
nNRMaxIter	N	Maximum number of iterations for Newton-Raphson root finding.		50
rFloor	R	Floor value for the optimization parameter in bootstrapping.		1e-15
rNRTol	R	Tolerance value for the Newton-Raphson method of root finding.		1e-15
rSPDaysPerAnnum	R	(Optional) Number of days per annum in the calculation of the survival probability, yield, or spot hazard rate, if bUseYearFracSP is FALSE. If omitted, the relevant attribute of the credit curve is used.		365 (if not available from the credit curve)
strIncorrectSurvProbPoints	S	Method to handle incorrect survival probability points generated in the bootstrapping.	One of: • ignore • exclude • flatExtrap	exclude

Table 12.16 External CDS Bootstrapper Settings Map (Continued)

Map Key	Type Code	Description	Constraints	Default Value
`strOptimizationObject`	S	Object on which to perform the optimization.	One of: • `spotHazardRate` • `SPYield` • `SP`	`spotHazardRate`
`strSPDaycount`	S	(Optional) Day count convention in the calculation of the survival probability, yield, or spot hazard rate, if `bUseYearFracSP` is TRUE. If omitted, the relevant attribute of the credit curve is used.	See Table B.2 on page 327.	ACT365FIXED (if not available from the credit curve)
`strSPInterpObject`	S	Object to interpolate and extrapolate on (`log-lin` for SP; `lin` for `SPYield`).	One of: • `SPYield` • `SP`	`SPYield`
`strSPCompounding`	S	Compounding frequency of the survival probability curve.	One of: • `DAILY` • `WEEKLY` • `MONTHLY` • `QUARTERLY` • `SEMIANNUAL` • `ANNUAL` • `SIMPLE` • `CONTINUOUS`	`CONTINUOUS`
`strSPYieldExtrap`	S	Extrapolation method to use when the interpolation is performed on survival probability yield—that is, `strSPInterpObject` is set to `SPYield`.	See Table B.3 on page 328.	`lin`

Example

```
CDSBootstrapper_SPEnd {
  strCDSBootstrapper, S, CDSBootstrapperSingleNameSPEnd
  strSPInterpObject, S, SPYield
  strSPCompounding, S, ANNUAL
  strOptimizationObject, S, spotHazardRate
}
```

12.3.4.1.2.2 External CDS Pricer Settings: Mid-Point Default Pricer

The `mpCDSPricerSettings` member of the CR calibration data extraction settings map above refers to another input map that specifies CDS pricer settings. The map can be one of two types. The table below defines the members of the setting map for the pricer `CDSPricerSISingleNameMidPointDefault` in which the default date is assumed to be the mid-point of a coupon period.

Table 12.17 External CDS Pricer Settings Map (`CDSPricerSISingleNameMidPointDefault`)

Map Key	Type Code	Description	Constraints	Default Value
strCDSPricer	S	CDS pricer type.	CDSPricerSISingleNameMidPointDefault	
arCDSFixedCoupon	AR	(Optional) Fixed coupon rate to use in bootstrapping when the input credit data is upfront fee quotes (bUpfrontFee is TRUE in the mpCDSPricerScheduleSettings map), for the CDS names. The first element, which corresponds to the first name, is used.		0.01
arNotional	AR	Constant notional for the CDS names. The first element, which corresponds to the first name, is used.		1.0
arRecoveryRate	AR	(Optional) Recovery rate to use in survival probability bootstrapping and in scaling exposures in valuation adjustment, for the CDS names. The first element, which corresponds to the first name, is used.		0.4
bAccInt	B	Whether to use the accrued interest in bootstrapping.	One of: • TRUE • FALSE	TRUE
bClean	B	Whether to take into account the accrued rebate for the first coupon in bootstrapping.	One of: • TRUE • FALSE	TRUE
bFirstPartialCoupon	B	Whether to use the first partial coupon.	One of: • TRUE • FALSE	FALSE
bPayPremium	B	Whether to pay premiums (buy the insurance).	One of: • TRUE • FALSE	TRUE
bRoundMidPointToNearestDay	B	Whether to round the coupon period mid points, calculated for accrued interest, to the nearest day.	One of: • TRUE • FALSE	TRUE
bUseYearFracForAccInt	B	Whether to use the year fraction in the calculation of the accrued interest.	One of: • TRUE • FALSE	TRUE

Table 12.17 External CDS Pricer Settings Map (CDSPricerSISingleNameMidPointDefault)

Map Key	Type Code	Description	Constraints	Default Value
rDaysPerAnnumAccInt	R	(Optional) Number of days per annum in the calculation of the accrued interest, if bUseYearFracForAccInt is FALSE. If omitted, the relevant attribute of the par credit spread curve is used.		
strBusDayConvPremiumLeg	S	Business day convention for adjusting the CDS schedule dates for the premium leg.	See Table B.1 on page 326.	NA
strBusDayConvProtectionLeg	S	Business day convention for adjusting the CDS schedule dates for the protection leg.	See Table B.1 on page 326.	strBusDayConvPremiumLeg
strDaycount	S	(Optional) Day count convention in the calculation of the accrued interest, if bUseYearFracForAccInt is TRUE. If omitted, the relevant attribute of the par credit spread curve is used.	See Table B.2 on page 327.	
strLastPeriodEndDateType	S	Type of accrual end date for the last coupon period.	One of: • adjusted • adjustedAddOneDay • unadjusted • unadjustedAddOneDay	unadjustedAddOneDay

Example

```
SampleCDSPricerSettings_MidpointDefault, {
  strCDSPricer, S, CDSPricerSISingleNameMidPointDefault
  strBusDayConvPremiumLeg, S, MODFOLLOWING
  strBusDayConvProtectionLeg, S, MODFOLLOWING
  bRoundMidPointToNearestDay, B, TRUE
  bClean, B, TRUE
  bUseYearFracForAccInt, B, TRUE
  strDaycount, S, ACT365
  strLastPeriodEndDateType, S, unadjustedAddOneDay
}
```

12.3.4.1.2.3 External CDS Pricer Settings: Roll Default Dates Pricer

The mpCDSPricerSettings member of the CR calibration data extraction settings map above refers to another input map that specifies CDS pricer settings. The map can be one of two types. The table below defines the members of the setting map for the pricer CDSPricerSISingleNameRollDefaultDates in which the default date is assumed to be a whole number of months from the later of the protection start date or the valuation date.

Table 12.18 External CDS Pricer Settings Map (`CDSPricerSISingleNameRollDefaultDates`)

Map Key	Type Code	Description	Constraints	Default Value
`strCDSPricer`	S	CDS pricer type.	`CDSPricerSISingleNameRollDefaultDates`	
`arCDSFixedCoupon`	AR	(Optional) Fixed coupon rate to use in bootstrapping when the input credit data is upfront fee quotes (`bUpfrontFee` is `TRUE` in the `mpCDSPricerScheduleSettings` map), for the CDS names. The first element, which corresponds to the first name, is used.		`0.01`
`arNotional`	AR	Constant notional for the CDS names. The first element, which corresponds to the first name, is used.		`1.0`
`arRecoveryRate`	AR	(Optional) Recovery rate to use in survival probability bootstrapping and in scaling exposures in valuation adjustment, for the CDS names. The first element, which corresponds to the first name, is used.		`0.4`
`bAccInt`	B	Whether to use the accrued interest in bootstrapping.	One of: • `TRUE` • `FALSE`	`TRUE`
`bClean`	B	Whether to take into account the accrued rebate for the first coupon in bootstrapping.	One of: • `TRUE` • `FALSE`	`TRUE`
`bPayPremium`	B	Whether to pay premiums (buy the insurance).	One of: • `TRUE` • `FALSE`	`TRUE`
`bUseYearFracForAccInt`	B	Whether to use the year fraction in the calculation of the accrued interest.	One of: • `TRUE` • `FALSE`	`TRUE`
`nMonthDefaultPeriod`	N	Interval (in months) between two default dates.		`3`
`rDaysPerAnnumAccInt`	R	(Optional) Number of days per annum in the calculation of the accrued interest, if `bUseYearFracForAccInt` is `FALSE`. If omitted, the relevant attribute of the par credit spread curve is used.		

Table 12.18 External CDS Pricer Settings Map (`CDSPricerSISingleNameRollDefaultDates`)

Map Key	Type Code	Description	Constraints	Default Value
`strBusDayConvPremiumLeg`	S	Business day convention for adjusting the CDS schedule dates for the premium leg.	See Table B.1 on page 326.	NA
`strBusDayConvProtectionLeg`	S	Business day convention for adjusting the CDS schedule dates for the protection leg.	See Table B.1 on page 326.	NA
`strDaycount`	S	(Optional) Day count convention in the calculation of the accrued interest, if `bUseYearFracForAccInt` is TRUE. If omitted, the relevant attribute of the par credit spread curve is used.	See Table B.2 on page 327.	
`strFirstPeriodStartDateType`	S	Type of accrual start date for the first coupon period.	One of: • `adjusted` • `unadjusted`	`adjusted`
`strLastDefaultPeriodEndDateType`	S	Type of accrual end date for the last default period.	One of: • `adjusted` • `unadjusted`	`unadjusted`
`strLastPeriodEndDateType`	S	Type of accrual end date for the last coupon period.	One of: • `adjusted` • `adjustedAddOneDay` • `unadjusted` • `unadjustedAddOneDay`	`unadjustedAddOneDay`

Example

```
SampleCDSPricerSettings_RollDefaultDates, {
  strCDSPricer, S, CDSPricerSISingleNameRollDefaultDates
  strBusDayConvPremiumLeg, S, MODFOLLOWING
  strBusDayConvProtectionLeg, S, MODFOLLOWING
  nMonthDefaultPeriod, N, 3
  bClean, B, TRUE
  bUseYearFracForAccInt, B, TRUE
  strDaycount, S, ACT365FIXED
  strLastPeriodEndDateType, S, unadjustedAddOneDay
}
```

12.3.4.1.2.4 External CDS Pricer Schedule Generation Settings

The `mpCDSPricerScheduleSettings` member of the CR calibration data extraction settings map above refers to another input map that specifies settings for the

schedule generation of the CDS pricers. The following table defines the members of this map.

Table 12.19 External CDS Pricer Schedule Generation Settings Map

Map Key	Type Code	Description	Constraints	Default Value
bUseIMMDates	B	Whether to use IMM dates. If the valuation date is not an IMM date, the CDS maturity is taken to be from the next IMM date.	One of: • TRUE • FALSE	TRUE
bIMMStepInNext	B	Whether to use the next date after the valuation date as the IMM step-in date.	One of: • TRUE • FALSE	TRUE
bUpfrontFee	B	Whether the underlying credit curve data represents upfront fee quotes (TRUE) or par credit spreads (FALSE).	One of: • TRUE • FALSE	FALSE

Example

```
CDSPricerSchedule_IMMDates {
 bUseIMMDates, B, TRUE
}
```

12.3.4.2 IR Calibration Data Extraction Settings (CM_CR_EQ_FX_IF_IR_HW_NF)

The ampDataExtractionSettingsIR member of the data extraction settings map refers to other maps that each specify settings for IR calibration data extraction for one currency. The following table defines the members of an IR calibration data extraction settings map for the CM_CR_EQ_FX_IF_IR_HW_NF model.

Table 12.20 IR Calibration Data Extraction Settings Map for CM_CR_EQ_FX_IF_IR_HW_NF

Map Key	Type Code	Description	Constraints	Default Value
strMethod	S	Type of calibration data.	One of: • Swaption • SelectedSwaptions	

Table 12.20 IR Calibration Data Extraction Settings Map for CM_CR_EQ_FX_IF_IR_HW_NF

Map Key	Type Code	Description	Constraints	Default Value
`rSwaptionShift`	`R`	(Optional) If specified, the market swaption price in the calibration of the model is calculated under the assumption that the swap rate has a shifted log-normal distribution with the specified shift size. In this case, the swaption price in the calibration is calculated using Black's formula with the adjusted swap rate and strike obtained by subtracting `rSwaptionShift` from the original swap rate and strike of the calibrating swaptions.		0
`strDaycountFixed`	`S`	(Optional) Day count convention in the fixed leg of the calibrating swaptions.	See Table B.2 on page 327.	The *`dayCountConv`* attribute of the input swaption volatility curve is used.
`nSwapTenorFixed`	`N`	(Optional) Coupon frequency (in months) in the fixed leg of the calibrating swaptions.		The *`tenor`* attribute of the input swaption volatility curve is used.
Use the additional inputs in this section only when `strMethod` is `SelectedSwaptions`				
`astrSwaptionExpiry`	`AS`	(Optional) Time to expiry to specify the swaption volatilities for extraction from the input swaption volatility curve, in the same units as the expiry ordinates in the curve. If not provided, the times to expiry are assumed to be the expiry ordinate values of the input swaption volatility curve.		
`anSwaptionLength`	`AN`	(Optional) Lengths in months of the swaptions to specify the volatility for extraction from the input swaption volatility curve, one for each expiry date specified by `astrSwaptionExpiry`. If not provided, the co-terminal swaption volatility is extracted for all expiry dates specified in `astrSwaptionExpiry`. Ignored if `astrSwaptionExpiry` is omitted.	Same number of elements as `astrSwaptionExpiry`.	

Table 12.20 IR Calibration Data Extraction Settings Map for CM_CR_EQ_FX_IF_IR_HW_NF

Map Key	Type Code	Description	Constraints	Default Value
`arSwaptionStrike`	AR	(Optional) Swaption strike to specify the volatility for extraction from the input swaption volatility curve, one for each expiry date specified by `astrSwaptionExpiry`. If not provided, the at-the-money strike is used for all expiry dates specified in `astrSwaptionExpiry`. Ignored if `astrSwaptionExpiry` is omitted. Used only when the swaption volatility curve is of type `SwaptionVolCube`.	Same number of elements as `astrSwaptionExpiry`.	
`strSwaptionStrikeType`	S	(Optional) Type of the strikes specified in `arSwaptionStrike`. Ignored if `arSwaptionStrike` is omitted. Used only when the swaption volatility curve is of type `SwaptionVolCube`.	One of: • `ABSOLUTE` • `F-K` • `K-F` • `F/K` • `K/F` F is the underlying par swap rate for the swaption period. `ABSOLUTE` means that values represent the strike `K`. The remaining strike types mean that values are specified in relative terms.	`ABSOLUTE`
`idxBasisCurveCalib`	N	(Optional) Index of the interest rate curve to use for additive LIBOR basis adjustment in the calculation of the swap rate during the extraction of the ATM volatility.	Integer between 0 and n–1, where n is the number of curves specified by the market data map member `aBasisCurve`.	The LIBOR basis adjustment is not performed.
`idxBasisCurveCalibDisc`	N	(Optional) Index of the interest rate curve to use for discounting in the calculation of the swap rate during the extraction of the ATM volatility. Ignored if `bUseBasisCurveForCalibDiscounting` is set to `TRUE`.	Integer between 0 and n–1, where n is the number of curves specified by the market data map member `aBasisCurve`.	Interest rate curve for the currency of this map, specified by the market data map member `aIRCurve`.
`bUseBasisCurveForCalibDiscounting`	B	Whether to use the basis curve, if specified by `idxBasisCurveCalib`, for both discounting and forecasting in the calculation of the swap rate (`TRUE`) or just for forecasting (`FALSE`).	One of: • `TRUE` • `FALSE`	`FALSE`

Example

```
Swaption_DataExtractionSetting, {
  strMethod, S, Swaption
}
```

Appendix A

Abbreviations

This appendix defines the abbreviations and acronyms that appear in this manual.

CDS	Credit default swap
CM_CR_EQ_FX_IF_IR_HW_NF	Hybrid commodity credit equity inflation multicurrency multifactor Hull-White model (of the Model Framework)
CM_CR_EQ_FX_IF_IR_HW_NF_BK_1F	Hybrid commodity credit equity inflation multicurrency multifactor Hull-White model with Black-Karasinski model for hazard rates (of the Model Framework)
CR	Credit (asset class)
CR_EQ_FX_IF_IR_HW_NF_BK_1F	Hybrid credit equity inflation multicurrency multifactor Hull-White model (of the Model Framework)
CR_EQ_FX_IF_IR_HW_NF_JFX	Hybrid credit equity inflation multicurrency multifactor Hull-White model (of the Model Framework) with FX jump at name default

CSV	Comma-separated values (file format)
EQ	Equity (asset class)
FX	Foreign exchange (asset class or rate)
FX_IR_HW_1F	Multicurrency single-factor Hull-White model (of the Model Framework)
FX_IR_HW_NF	Multicurrency multifactor Hull-White model (of the Model Framework)
FX_IF_IR_HW_NF	Inflation multicurrency multifactor Hull-White model (of the Model Framework)
FX_IF_IR_HW_NF_DI	Inflation multicurrency multifactor Hull-White model (of the Model Framework) with derived inflation indexes
HDF5	Hierarchical Data Format 5
HW	Hull-White (as part of a model's short name)
IF	Inflation (as part of a model's short name)
IMM	International Monetary Market
IR	Interest rate (asset class)
IR_HW_1F	Single-currency single-factor Hull-White model (of the Model Framework)
IR_HW_NF	Single-currency multifactor Hull-White model (of the Model Framework)
LIBOR	London interbank offered rate
PFE	Potential future exposure
MASF	Markit Analytics Simulation Framework
VaR	Value at risk

Appendix B

Input Codes

Some input fields require you to enter a fixed code value from a predetermined set. This appendix identifies the valid codes for the following parameters:

- Business day convention
- Day count convention
- Interpolation and extrapolation methods

B.1 Business Day Convention Codes

The table below lists the valid values for business day convention parameters. Each value specifies a convention for handling events that land on non-business days (weekends and holidays).

Table B.1 Business Day Convention Codes

Value	Meaning
BEFORE	The business day immediately prior to the event date.
AFTER	The business day immediately after the event date.
MODFOLLOWING	The business day immediately after the event date if it is in the same month; otherwise, the business day immediately prior to the event date.
MODPRECEDING	The business day immediately preceding the event date if it is in the same month; otherwise, the business day immediately following the event date.
EURODOLLAR	Similar to MODFOLLOWING, but sets the roll date to be the new day. For example, if a schedule is set to roll quarterly on the 15th of every month, the schedule goes from the 15th of one month to the 15th of the next month. If the 15th of the next month is a non-business day, that date is rolled forward (per the MODFOLLOWING rule) to the 16th. The schedule then continues going to the 16th of the subsequent month, and so on. If the roll date reaches the end of the month, it stays at end-of-month for all remaining periods.
NA	Not applicable.

B.2 Day Count Convention Codes

The table below defines possible values for day count convention inputs. Each value specifies a rule for determining the length of a given period and the length of a year, in days, for calculating the year fraction of the period—that is, for determining the numerator and denominator of the year fraction.

A general formula for the year fraction is as follows:

$$\tau = \frac{T_2 - T_1 - H}{N}$$

The table specifies the terms in this formula for each supported convention.

For purposes of determining the year length under the “actual” conventions, the accrual period includes the start date but excludes the end date. For example, a coupon period that ends on 2016/01/01 is considered to have 365 days in the denominator instead of 366. Similarly, using ACTFEB29, a coupon that ends on 2016/02/29 uses only 365 days in the denominator

In most cases, these rules implement conventions defined in *2006 ISDA Definitions*[1] and as amended in *Supplement number 14 to the 2006 ISDA Definitions*[2]. References to the specific sections for these definitions are given in the descriptions below in the format "See *ISDA Definitions* 4.16 (a)."

Table B.2 Day Count Convention Codes

Value	Formula Terms	Notes
ACTACT	T_1 = Start date T_2 = End date H = 0 N = Number of calendar days in the year. If part of the period falls in a leap year, the year fraction is separated into leap-year and non-leap-year periods.	See *ISDA Definitions* 4.16 (b). Used primarily for U.S. government securities.
ACTACT29	Same as ACTFEB29.	
ACTFEB29	T_1 = Start date T_2 = End date H = 0 N = If period includes February 29: 366; otherwise: 365	
ACT360	T_1 = Start date T_2 = End date H = 0 N = 360	See *ISDA Definitions* 4.16 (e). Used primarily for money-market instruments and the U.S. T-Bill dollar discount.
ACT365	Same as ACTACT.	
ACT365_25	T_1 = Start date T_2 = End date H = 0 N = 365.25	
ACT365FIXED	T_1 = Start date T_2 = End date H = 0 N = 365	See *ISDA Definitions* 4.16 (d). Used to calculate Treasury bond-equivalent yields for U.S. T-bills.
ACT365LEAP	T_1 = Start date T_2 = End date H = 0 N = If T_2 lands in a leap year: 366; otherwise: 365	See *ISDA Definitions* 4.16 (i).
EURO30360	T_1 = min(start date, 30th of the month) T_2 = min(end date, 30th of the month) H = 0 N = 360	See *ISDA Definitions* 4.16 (g). Used for Eurobonds and many foreign bonds.

1. *2006 ISDA Definitions* (New York, International Swaps and Derivatives Association Inc., 2006).
2. *Supplement number 14 to the 2006 ISDA Definitions* (New York, International Swaps and Derivatives Association Inc., 2009).

Table B.2 Day Count Convention Codes (Continued)

Value	Formula Terms	Notes
`ONEONE`	$\tau = 1$	See *ISDA Definitions* 4.16 (a).
`THIRTY360`	T_1 = min(start date, 30th of the month) T_2 = If $T_1 \geq 30$: min(end date, 30th of the month); otherwise: end date $H = 0$ $N = 360$	See *ISDA Definitions* 4.16 (f). Used as the NASD convention for most corporate bonds, agencies, municipals, and mortgage-backed securities.

B.3 Interpolation and Extrapolation Codes

The table below defines the values for interpolation and extrapolation method parameters.

Table B.3 Interpolation and Extrapolation Method Codes

Value	Meaning in Interpolation	Meaning in Extrapolation
`none`	No interpolation. Truncates real indices to integers.	No extrapolation. Generates an exception.
`round`	Rounds to nearest point.	Same as `near`.
`near`	Same as `round`.	Constant extrapolation using the nearest in-bounds value.
`lin`	Linear interpolation.	Linear extrapolation.
`quad`	Quadratic interpolation.	Quadratic extrapolation.
`cubic`	Cubic interpolation.	Cubic extrapolation.
`log-lin`	Linear interpolation on the logarithm of the variable.	Linear extrapolation on the logarithm of the variable.
`log-quad`	Quadratic interpolation on the logarithm of the variable.	Quadratic extrapolation on the logarithm of the variable.
`log-cubic`	Cubic interpolation on the logarithm of the variable.	Cubic extrapolation on the logarithm of the variable.
`zero`	Not applicable.	Always returns zero.
`next`	Rounds up to the nearest larger point.	No extrapolation. Generates an exception.
`prev`	Rounds down to the nearest smaller point.	No extrapolation. Generates an exception.
`right`	Same as `next`.	No extrapolation. Generates an exception.
`left`	Same as `prev`.	No extrapolation. Generates an exception.

Table B.3 Interpolation and Extrapolation Method Codes (Continued)

Value	Meaning in Interpolation	Meaning in Extrapolation
`round-half-up`	Same as `round`.	No extrapolation. Generates an exception.
`round-half-down`	Same as `round` except at the midpoint between two points, where it rounds down like `prev`.	No extrapolation. Generates an exception.