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Article

Pricing Continuously Monitored Barrier Options under the SABR Model: A Closed-Form Approximation

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Abstract: The stochastic alpha beta rho (SABR) model introduced by Hagan et al. (2002) is widely used in both fixed income and the foreign exchange (FX) markets. Continuously monitored barrier option contracts are among the most popular derivative contracts in the FX markets. In this paper, we develop closed-form formulas to approximate various types of barrier option prices (down-and-out/in, up-and-out/in) under the SABR model. We first derive an approximate formula for the survival density. The barrier option price is the one-dimensional integral of its payoff function and the survival density, which can be easily implemented and quickly evaluated. The approximation error of the survival density is also analyzed. To the best of our knowledge, it is the first time that analytical (approximate) formulas for the survival density and the barrier option prices for the SABR model are derived. Numerical experiments demonstrate the validity and efficiency of these formulas.

Keywords: SABR model; Continuously monitored barrier option; Survival density; Closed-form approximation; Stochastic volatility

1. Introduction

A barrier option is a financial derivative contract that is activated (knocked in) or extinguished (knocked out) when the underlying asset price (e.g., the foreign exchange rate or an interest rate) crosses a pre-specified level. Barrier options are one of the most popular and liquidly traded derivatives, especially in the foreign exchange (FX) markets, and yet closed-form analytical pricing formulas are not available, except for simple cases where the breach of the barrier condition is continuously monitored. As effective risk management tools, they have flexibility and low premiums compared to European options. Moreover, continuously monitored knock-in or knock-out calls and puts are among the most liquid products traded in the FX markets (see, e.g., Lipton, 2001; Hakala and Wystup, 2002; Lipton and McGhee, 2002; Wystup, 2006).

Barrier Option Pricing Under Sabr Model Using Monte Carlo

Bin Chen

Barrier Option Pricing Under Sabr Model Using Monte Carlo:

Barrier Option Pricing Under SABR Model Using Monte Carlo Methods Junling Hu,2013 Abstract The project investigates the prices of barrier options from the constant underlying volatility in the Black Scholes model to stochastic volatility model in SABR framework The constant volatility assumption in derivative pricing is not able to capture the dynamics of volatility In order to resolve the shortcomings of the Black Scholes model it becomes necessary to find a model that reproduces the smile effect of the volatility To model the volatility more accurately we look into the recently developed SABR model which is widely used by practitioners in the financial industry Pricing a barrier option whose payoff to be path dependent intrigued us to find a proper numerical method to approximate its price We discuss the basic sampling methods of Monte Carlo and several popular variance reduction techniques Then we apply Monte Carlo methods to simulate the price of the down and out put barrier options under the Black Scholes model and the SABR model as well as compare the features of these two models *Large Deviations and Asymptotic Methods in Finance* Peter K. Friz,Jim Gatheral,Archil Gulisashvili,Antoine Jacquier,Josef Teichmann,2015-06-16 Topics covered in this volume large deviations differential geometry asymptotic expansions central limit theorems give a full picture of the current advances in the application of asymptotic methods in mathematical finance and thereby provide rigorous solutions to important mathematical and financial issues such as implied volatility asymptotics local volatility extrapolation systemic risk and volatility estimation This volume gathers together ground breaking results in this field by some of its leading experts Over the past decade asymptotic methods have played an increasingly important role in the study of the behaviour of financial models These methods provide a useful alternative to numerical methods in settings where the latter may lose accuracy in extremes such as small and large strikes and small maturities and lead to a clearer understanding of the behaviour of models and of the influence of parameters on this behaviour Graduate students researchers and practitioners will find this book very useful and the diversity of topics will appeal to people from mathematical finance probability theory and differential geometry *Progress in Industrial Mathematics at ECMI 2016* Peregrina Quintela,Patricia Barral,Dolores Gómez,Francisco J. Pena,Jerónimo Rodríguez,Pilar Salgado,Miguel E. Vázquez-Méndez,2018-03-26 This book addresses mathematics in a wide variety of applications ranging from problems in electronics energy and the environment to mechanics and mechatronics Using the classification system defined in the EU Framework Programme for Research and Innovation H2020 several of the topics covered belong to the challenge climate action environment resource efficiency and raw materials and some to health demographic change and wellbeing while others belong to Europe in a changing world inclusive innovative and reflective societies The 19th European Conference on Mathematics for Industry ECMI2016 was held in Santiago de Compostela Spain in June 2016 The proceedings of this conference include the plenary lectures ECMI awards and special lectures mini symposia including the description of each mini symposium and contributed talks The ECMI conferences are organized by

the European Consortium for Mathematics in Industry with the aim of promoting interaction between academy and industry leading to innovation in both fields and providing unique opportunities to discuss the latest ideas problems and methodologies and contributing to the advancement of science and technology They also encourage industrial sectors to propose challenging problems where mathematicians can provide insights and fresh perspectives Lastly the ECMI conferences are one of the main forums in which significant advances in industrial mathematics are presented bringing together prominent figures from business science and academia to promote the use of innovative mathematics in industry

Financial Mathematics, Derivatives and Structured Products Raymond H. Chan,Yves ZY. Guo,Spike T. Lee,Xun Li,2024-06-12 This book introduces readers to the financial markets derivatives structured products and how the products are modelled and implemented by practitioners In addition it equips readers with the necessary knowledge of financial markets needed in order to work as product structurers traders sales or risk managers This second edition substantially extends updates and clarifies the previous edition New materials and enhanced contents include but not limited to the role of central counterparties for derivatives transactions the reference rates to replace LIBOR risk neutral modelling for futures and forward discussions and analysis on risk neutral framework and num raires discrete dividend modelling variance reduction techniques for Monte Carlo method finite difference method analysis tree method FX modelling multi name credit derivatives modelling local volatility model forward variance model and local stochastic volatility model to reflect market practice As the book seeks to unify the derivatives modelling and the financial engineering practice in the market it will be of interest to financial practitioners and academic researchers alike The book can also be used as a textbook for the following courses Financial Mathematics undergraduate level Stochastic Modelling in Finance postgraduate level Financial Markets and Derivatives undergraduate level Structured Products and Solutions undergraduate postgraduate level **FX Options and Smile Risk** Antonio Castagna,2010-02-12 The FX options market represents one of the most liquid and strongly competitive markets in the world and features many technical subtleties that can seriously harm the uninformed and unaware trader This book is a unique guide to running an FX options book from the market maker perspective Striking a balance between mathematical rigour and market practice and written by experienced practitioner Antonio Castagna the book shows readers how to correctly build an entire volatility surface from the market prices of the main structures Starting with the basic conventions related to the main FX deals and the basic traded structures of FX options the book gradually introduces the main tools to cope with the FX volatility risk It then goes on to review the main concepts of option pricing theory and their application within a Black Scholes economy and a stochastic volatility environment The book also introduces models that can be implemented to price and manage FX options before examining the effects of volatility on the profits and losses arising from the hedging activity Coverage includes how the Black Scholes model is used in professional trading activity the most suitable stochastic volatility models sources of profit and loss from the Delta and volatility hedging activity

fundamental concepts of smile hedging major market approaches and variations of the Vanna Volga method volatility related Greeks in the Black Scholes model pricing of plain vanilla options digital options barrier options and the less well known exotic options tools for monitoring the main risks of an FX options book The book is accompanied by a CD Rom featuring models in VBA demonstrating many of the approaches described in the book **Financial Modelling** Joerg Kienitz,Daniel Wetterau,2013-02-18 Financial modelling Theory Implementation and Practice with MATLAB Source J rg Kienitz and Daniel Wetterau Financial Modelling Theory Implementation and Practice with MATLAB Source is a unique combination of quantitative techniques the application to financial problems and programming using Matlab The book enables the reader to model design and implement a wide range of financial models for derivatives pricing and asset allocation providing practitioners with complete financial modelling workflow from model choice deriving prices and Greeks using semi analytic and simulation techniques and calibration even for exotic options The book is split into three parts The first part considers financial markets in general and looks at the complex models needed to handle observed structures reviewing models based on diffusions including stochastic local volatility models and pure jump processes It shows the possible risk neutral densities implied volatility surfaces option pricing and typical paths for a variety of models including SABR Heston Bates Bates Hull White Displaced Heston or stochastic volatility versions of Variance Gamma respectively Normal Inverse Gaussian models and finally multi dimensional models The stochastic local volatility Libor market model with time dependent parameters is considered and as an application how to price and risk manage CMS spread products is demonstrated The second part of the book deals with numerical methods which enables the reader to use the models of the first part for pricing and risk management covering methods based on direct integration and Fourier transforms and detailing the implementation of the COS CONV Carr Madan method or Fourier Space Time Stepping This is applied to pricing of European Bermudan and exotic options as well as the calculation of the Greeks The Monte Carlo simulation technique is outlined and bridge sampling is discussed in a Gaussian setting and for L vy processes Computation of Greeks is covered using likelihood ratio methods and adjoint techniques A chapter on state of the art optimization algorithms rounds up the toolkit for applying advanced mathematical models to financial problems and the last chapter in this section of the book also serves as an introduction to model risk The third part is devoted to the usage of Matlab introducing the software package by describing the basic functions applied for financial engineering The programming is approached from an object oriented perspective with examples to propose a framework for calibration hedging and the adjoint method for calculating Greeks in a Libor market model Source code used for producing the results and analysing the models is provided on the author s dedicated website http www mathworks de matlabcentral fileexchange authors 246981 **Quantitative Finance** Maria Cristina Mariani,Ionut Florescu,2019-11-06 Presents a multitude of topics relevant to the quantitative finance community by combining the best of the theory with the usefulness of applications Written by accomplished teachers and researchers in the field this book

presents quantitative finance theory through applications to specific practical problems and comes with accompanying coding techniques in R and MATLAB and some generic pseudo algorithms to modern finance It also offers over 300 examples and exercises that are appropriate for the beginning student as well as the practitioner in the field The Quantitative Finance book is divided into four parts Part One begins by providing readers with the theoretical backdrop needed from probability and stochastic processes We also present some useful finance concepts used throughout the book In part two of the book we present the classical Black Scholes Merton model in a uniquely accessible and understandable way Implied volatility as well as local volatility surfaces are also discussed Next solutions to Partial Differential Equations PDE wavelets and Fourier transforms are presented Several methodologies for pricing options namely tree methods finite difference method and Monte Carlo simulation methods are also discussed We conclude this part with a discussion on stochastic differential equations SDE s In the third part of this book several new and advanced models from current literature such as general Lvy processes nonlinear PDE s for stochastic volatility models in a transaction fee market PDE s in a jump diffusion with stochastic volatility models and factor and copulas models are discussed In part four of the book we conclude with a solid presentation of the typical topics in fixed income securities and derivatives We discuss models for pricing bonds market marketable securities credit default swaps CDS and securitizations Classroom tested over a three year period with the input of students and experienced practitioners Emphasizes the volatility of financial analyses and interpretations Weaves theory with application throughout the book Utilizes R and MATLAB software programs Presents pseudo algorithms for readers who do not have access to any particular programming system Supplemented with extensive author maintained web site that includes helpful teaching hints data sets software programs and additional content Quantitative Finance is an ideal textbook for upper undergraduate and beginning graduate students in statistics financial engineering quantitative finance and mathematical finance programs It will also appeal to practitioners in the same fields Smile Pricing Explained P. Austing,2014-08-29 Smile Pricing Explained provides a clear and thorough explanation of the concepts of smile modelling that are at the forefront of modern derivatives pricing The key models used in practice are covered together with numerical techniques and calibration **Financial Derivative Investments: An Introduction To Structured Products** Richard Bateson,2011-06-07 Structured products are sold to a wide range of retail high net worth and institutional investors with over 15bn of structured investments sold in the UK in 2009 Based on a non specialist graduate lecture course given at University College London UCL this book provides an invaluable introduction to the fast growing world of derivative investments and the technology used in their design pricing and structuring The book gives a comprehensive overview of structuring and trading products based on the author s extensive international experience in structuring investment products across a range of underlying asset classes including equities interest rates credit and hybrids The product coverage ranges from equity investments such as reverse convertibles and basket correlation products to credit products such as first to

default notes and the notorious CDO2 Written in a simple and accessible manner this book will be of interest to students bankers investors and other finance professionals a The Complete Guide to Option Pricing Formulas Espen Gaarder Haug,2007-01-08 Accompanying CD ROM contains all pricing formulas with VBA code and ready to use Excel spreadsheets and 3D charts for Greeks or Option Sensitivities Jacket **Pricing Continuously Monitored Barrier Options Under the Sabr Model** Nian Yang,2019 The stochastic alpha beta rho SABR model introduced by Hagan et al 2002 is widely used in both fixed income and the foreign exchange FX markets Continuously monitored barrier option contracts are among the most popular derivative contracts in the FX markets In this paper we develop closed form formulas to approximate various types of barrier option prices down and out in up and out in under the SABR model We first derive an approximate formula for the survival density The barrier option price is the one dimensional integral of its payoff function and the survival density which can be easily implemented and quickly evaluated The approximation error of the survival density is also analyzed To the best of our knowledge it is the first time that analytical approximate formulas for the survival density and the barrier option prices for the SABR model are derived Numerical experiments demonstrate the validity and efficiency of these formulas

Valuation of Barrier Options Using Sequential Monte Carlo Pavel V. Shevchenko,2015 Sequential Monte Carlo SMC methods have successfully been used in many applications in engineering statistics and physics However these are seldom used in financial option pricing literature and practice This paper presents SMC method for pricing barrier options with continuous and discrete monitoring of the barrier condition Under the SMC method simulated asset values rejected due to barrier condition are re sampled from asset samples that do not breach the barrier condition improving the efficiency of the option price estimator while under the standard Monte Carlo many simulated asset paths can be rejected by the barrier condition making it harder to estimate option price accurately We compare SMC with the standard Monte Carlo method and demonstrate that the extra effort to implement SMC when compared with the standard Monte Carlo is very little while improvement in price estimate can be significant Both methods result in unbiased estimators for the price converging to the true value as 1 sqrt M where M is the number of simulations asset paths However the variance of SMCestimator is smaller and does not grow with the number of time steps when compared to the standard Monte Carlo In this paper we demonstrate that SMC can successfully be used for pricing barrier options SMC can also be used for pricing other exotic options and also for cases with many underlying assets and additional stochastic factors such as stochastic volatility we provide general formulas and references Variance Reduction for Monte Carlo Simulation of European, American Or Barrier Options in a Stochastic Volatility Environment ,2002 In this work we develop a methodology to reduce the variance when applying Monte Carlo simulation to the pricing of a European American or Barrier option in a stochastic volatility environment We begin by presenting some applicable concepts in the theory of stochastic differential equations Secondly we develop the model for the evolution of an asset price under constant volatility We next present the replicating portfolio and equivalent martingale

measure approaches to the pricing of a European style option Modeling an asset price utilizing constant volatility has been shown to be an inefficient model 8 16 One way to compensate for this inefficiency is the use of stochastic volatility models which involves modeling the volatility as a function of a stochastic process 26 A class of these models is presented and a discussion is given on how to price European options in this framework After developing the methods of how to price we begin our discussion on Monte Carlo simulation of European options in a stochastic volatility environment We start by describing how to simulate Monte Carlo for a diffusion process modeled as a stochastic differential equation The essential element to our variance reduction technique which is known as importance sampling is hereafter presented Importance sampling requires a preliminary approximation to the expectation of interest which we obtain by a fast mean reversion expansion of the pricing partial differential equation 22 6 A detailed discussion is given on this fast mean reversion expansion technique which was first presented in 10 We shall compare utilizing this method of expansion with that developed in 11 which is know as small noise expansion and demonstrate numerically the efficiency of the fast mean reversion expansion in particular in the presence of a skew We next wish to apply our variance reduction technique to the pricing of an American and barrier option A discussion is given on how to price *An Asymptotic Expansion Formula for Up-and-Out Barrier Option Price Under Stochastic Volatility Model* Takashi Kato,Akihiko Takahashi,Toshihiro Yamada,2014 This paper derives a new semi closed form approximation formula for pricing an up and out barrier option under a certain type of stochastic volatility model including SABR model by applying a rigorous asymptotic expansion method developed by Kato Takahashi and Yamada 2012 We also demonstrate the validity of our approximation method through numerical examples **Approximate Arbitrage-Free Option Pricing Under the SABR Model** Nian Yang,2017 The stochastic alpha beta rho SABR model introduced by Hagan et al 2002 provides a popular vehicle to model the implied volatilities in the interest rate and foreign exchange markets To exclude arbitrage opportunities we need to specify an absorbing boundary at zero for this model which the existing analytical approaches to pricing derivatives under the SABR model typically ignore This paper develops closed form approximations to the prices of vanilla options to incorporate the effect of such a boundary condition Different from the traditional normal distribution based approximations our method stems from an expansion around a one dimensional Bessel process Extensive numerical experiments demonstrate its accuracy and efficiency Furthermore the explicit expression yielded from our method is appealing from the practical perspective because it can lead to fast calibration pricing and hedging **A Second Order Discretization with Malliavin Weight and Quasi-Monte Carlo Method for Option Pricing** Toshihiro Yamada,2018 This paper shows an efficient second order discretization scheme of expectations of stochastic differential equations We introduce smart Malliavin weight which is given by a simple polynomials of Brownian motions as an improvement of the scheme of Yamada 2017 A new quasi Monte Carlo simulation is proposed to attain an efficient option pricing scheme Numerical examples for the SABR model are shown to illustrate the validity of the scheme

Calibration and Monte Carlo Pricing of the SABR-Hull-White Model for Long-Maturity Equity Derivatives Bin Chen,2014 We model the joint dynamics of stock and interest rate by a hybrid SABR Hull White model in which the asset price dynamics are modeled by the SABR model and the interest rate dynamics by the Hull White short rate model We propose a projection formula mapping the SABR HW model parameters onto the parameters of the nearest SABR model A time dependent parameter extension of this SABR HW model is adopted to make the calibration of the model consistent across maturity times The calibration procedure is then finalized by employing the weighted Monte Carlo technique The Monte Carlo weights are not uniform and chosen to replicate the calibration market instruments On an Efficient Multiple Time-Step Monte Carlo Simulation of the SABR Model Alvaro Leitao Rodriguez,2018 In this paper we will present a multiple time step Monte Carlo simulation technique for pricing options under the Stochastic Alpha Beta Rho SABR model The proposed method is an extension of the one time step Monte Carlo method that we proposed in an accompanying paper for pricing European options in the context of the model calibration A highly efficient method results with many highly interesting and nontrivial components like Fourier inversion for the sum of log normals stochastic collocation Gumbel copula correlation approximation that are not yet seen in combination within a Monte Carlo simulation The present multiple time step Monte Carlo method is especially useful for long term options and for exotic options **The Time-Dependent FX-SABR Model** Anthonie van der Stoep,2015 We present a framework for efficient calibration of the time dependent SABR model in an FX context In a similar fashion as in Piterbarg 2005 we derive effective parameters which yield an accurate and efficient calibration On top of the calibrated FX SABR model we add a non parametric local volatility component which naturally compensates for possible calibration errors By means of Monte Carlo pricing experiments we show that the time dependent FX SABR model enables an accurate and consistent pricing of barrier options and outperforms the constant parameter SABR model and the traditional Local Volatility model We also consider the role of the local volatility component in pricing barrier options Using Monte Carlo Simulation and Importance Sampling to Rapidly Obtain Jump-Diffusion Prices of Continuous Barrier Options Mark S. Joshi,2007 The problem of pricing a continuous barrier option in a jump diffusion model is studied It is shown that via an effective combination of importance sampling and analytic formulas thatsubstantial speed ups can be achieved These techniques are shown to be particularly effective for computing deltas

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