FAIR VALUE MEASUREMENT OF EXOTIC OPTIONS:
VOLATILITY ASSUMPTIONS AND MODEL MISSPECIFICATION ERROR

Jacinto Marabel-Romo
BBVA and University of Alcalá, Spain

Andrés Guiral
Yonsei University, South Korea

José Luis Crespo-Espert
University of Alcalá, Spain

José A. Gonzalo
University of Alcalá, Spain

Doocheol Moon
Yonsei University, South Korea

Acknowledgments: This paper has benefited greatly from comments and suggestions by Christopher Humphrey, German Lopez-Espinosa, Manuel Ilueca, Emiliano Ruiz and workshop participants at the VIII Workshop on Empirical Research in Financial Accounting, Seville, 2011. The authors acknowledge the support of the Spanish Ministry of Economy and Competitiveness thought the Project ECO2010-17463.

Áreas temáticas A) (Contabilidad) o B (Valoración y Finanzas)

Corresponding author
FAIR VALUE MEASUREMENT OF EXOTIC OPTIONS:
VOLATILITY ASSUMPTIONS AND MODEL MISSPECIFICATION ERROR

Abstract

Fair Value Accounting (FVA) provides more relevant information to financial statement users, but there are also some concerns about the use of FVA resulting from the reliability of their estimations. We argue that FVA can lead bank managers towards model misspecification error in the valuation of complex financial instruments traded in illiquid markets. This situation is especially problematic considering the high exposure to the aforementioned error of large U.S. and European banks. Further, recent research in auditing suggests that auditors are not in the best position to evaluate complex estimates due to standard uncertainty and lack of training/skills in this area. By pricing two common exotic derivatives (cliquet and barrier options), we illustrate the existence of model misspecification error when comparing two different but commonly used assumptions of volatility (i.e., local volatility vs. stochastic volatility). Our findings have important implications for both accounting and auditing standard setters and bank regulators.

Keywords: Fair value, exotic options, model misspecification error, implied volatility, local volatility, stochastic volatility.

JEL: G12, M42.
1. Introduction

The subprime crisis has provoked intense debate about the accounting rules employed by banks, especially on the use of fair value accounting (FVA) for financial instruments (Cheng 2012; Laux and Leuz 2009; Chen et al. 2013). Initially, the major controversy relied on the possibility that FVA contributed to the Financial Crisis or, at least, exacerbated its severity (Kothari and Lester 2012). However, recent research indicates that FVA played little or even no role in the Financial Crisis (Laux and Leuz 2010; Barth and Landsman 2010). It seems now that users, standard setters and the academia understand better that FVA measurements and other estimates provide benefits in terms of higher potential relevance to users than would be provided by previous accounting measures, such as historical cost (Ahmed et al. 2011; Barth and Taylor 2010; Barth et al. 2001; Christensen et al. 2012; Song et al. 2010). Rather than FVA, it seems that one of the reasons of the Financial Crisis could be the use of inadequate models to value complex financial instruments (Derman and Wilmott 2009). The question is not anymore if we should accept FVA or not (Barth 2006). The remaining issue is how to estimate FVA and, particularly, in the case of extreme fair value measurements.

While FVA provides more relevant information to financial statement users, some concerns focus on the reliability of fair value estimation (Barth 2004). Fair value measurements in the absence of observed price might be unreliable due to intrinsic measurement error (noise) and management-induced error (bias) (Song et al. 2012). Prior studies provide evidence that managers may manipulate inputs for fair value estimates for their own interests (e.g., Aboody et al. 2006; Bartov et al. 2007; Dechow et al. 2010; Choudhary 2011). However, few studies examine fair value measurement error. Our fundamental objective is to analyze whether fair value measurements are subject to model misspecification.

According to the International Accounting Standard Board, fair value is “the price that would be received to sell an asset or paid to transfer a liability in an orderly transaction between market

---

1Typically, financial instruments represent more than 90 percent of the assets and liabilities of bank holding companies and large investment banks (Laux and Leuz 2010, Hirst et al. 2004).
participants at themeasurement date” (IFRS No. 13). The standard also introduces the concept of a fair value hierarchy based on the observability of the inputs. This hierarchy prioritizes the inputs used to measure fair values into three broad levels. Level 1 inputs are quoted prices in active markets for identical assets or liabilities (i.e., pure mark-to-market). Level 2 valuations are based on directly or indirectly observable market data for similar or comparable assets or liabilities. Two types of valuations are typically distinguished within Level 2: (i) adjusted mark-to-market relies on quoted market prices in active markets for similar items, or in inactive markets for identical items; (ii) mark-to-model valuation uses such inputs as yield curves, exchange rates, implied volatilities, credit spreads empirical correlations, etc. Level 3 valuations are based on unobservable inputs that reflect the reporting entity’s own assumptions (i.e., pure mark-to-model).

The standard gives highest priority to (unadjusted) quoted prices in active markets for identical assets or liabilities and the lowest priority to unobservable inputs. Level 1 inputs, i.e., those with market prices, are the only ones truly meeting the definition of fair value, making the information asymmetry between preparers and users very low (Song et al. 2010). However, the standard is silent regarding any difficulties related to market friction, including those resulting from imperfect and incomplete markets (Meder et al. 2011). Thus, the controversial part of the standard is how to value an asset or a liability when an active market does not exist, i.e., in the case of Level 2 and Level 3 valuations (Badertscher et al. 2012). Since it is difficult for users to observe directly how bank managers adapt those inputs to generate reported fair values, the information asymmetry between preparers and users is expected to be very high for Level 2 and Level 3 fair value estimates. Furthermore, in comparison to Level 1 fair value estimates, Level 2 and Level 3 fair value estimates are more costly to determine (Benston 2008) and very difficult for auditors to verify (Bell and Griffin 2008).

---

2 The Financial Accounting Standard Board, i.e. the U.S. accounting standard setter, defines fair value in a similar way (SFAS 157).

3 Examples of financial instruments classified as Level 1 fair value estimates include treasuries, derivatives, equity and cash products when all of them are traded on high-liquidity exchanges. Examples of Level 2 fair value estimates include many over-the-counter (OTC) derivatives, such as interest rate swaps, foreign currency swaps, commodity swaps, and certain options and forward contracts. Other financial instruments classified as Level 2 are mortgage-backed securities, mortgage loans, many investment-grade listed credit bonds, some credit default swaps (CDS), many collateralized debt obligations (CDO), and less-liquid equity instruments. Examples of Level 3 estimates include complex and highly structured derivatives, distressed debt, highly-structured bonds, illiquid asset-backed securities (ABS), illiquid CDOs, private equity placements, and illiquid loans.
For these reasons, fair value estimates of complex or illiquid financial instruments have been denoted by critics as “marking to myth” (Bratten et al. 2012; Meder et al. 2011).

The problem with the fair value hierarchy is that fair value measurements in the absence of observed prices might be unreliable due to intrinsic model misspecification error (Barth 2004; Song et al. 2010; Derman and Wilmott 2009). Model misspecification error is rooted in the nonexistence of well-developed models to estimate fair values of all assets and liabilities (Barth 2004). This error can be defined as the risk to use a valuation model that does not reflect the market conditions for a financial instrument at a particular point of the time. An inadequate valuation model produces wrong measures that disturb the decision making process, either internally or externally, and could deny all the benefits associated with the use of FVA if the amount of the associated estimate error is material. While for Level 1 fair value estimates the exposure to model misspecification error is minimum, for Level 2 and 3 fair values model misspecification error depends on the precision of the estimates (Barth 2004).

In recent years there has been a remarkable growth of structured products with embedded exotic options (Hull and Suo 2002). These exotic options are a clear example of Level 2 valuations (i.e., mark-to-model) which are quite model dependent. Financial institutions that commercialize these structured products are exposed to the existence of model misspecification risk. The key point of the model misspecification risk is that different models can yield the same price for plain vanilla options but, at the same time, very different prices for complex exotic options depending on their assumptions corresponding to the evolution of the underlying asset price and its volatility.

In this article, we consider the model misspecification error associated with the price of two classes of exotic options, usually embedded in structured products. These options are the barrier

---

4 Interestingly, auditors charge significantly higher audit fees when a client firm is exposed to Level 2 and Level 3 fair value estimations in comparison with Level 1 ones (Goncharov et al. 2013).
5 Bank regulators have claimed sound processes for model development and validation (Basel Committee on Banking Supervision 2009, Principle §4; Board of Governorsof the Federal Reserve System 2011: Sections IV & V).
6 In the literature there are a number of articles focused on the model misspecification error from a model evaluation perspective. In this sense, Hull and Suo (2002) analyze the performance of different models in the pricing of barrier options. On the other hand, Marabel (2012) shows that the standard adjustment used in the literature to price quanto options can be subject to significant model misspecification error. Marabel (2011a) studies the model risk associated with the valuation of multi-asset exotic options when the correlation between the underlying assets is assumed to be constant. Gordy and Willemann (2012) show that the introduction of stochastic volatility is a key element for the correct valuation of complex credit derivatives. Finally, Marabel (2013) illustrates the possibility of model misspecification error between single-factor and multifactor stochastic volatility models in the pricing of equity-linked exotic options.
options and cliquet options. Both kind of derivatives are building blocks for structured products, but their valuation can be highly model dependent. In an attempt to obtain adequate fair value estimates, we consider the most widely used models by financial institutions to price exotic options, namely, stochastic volatility models and local volatility models. Stochastic volatility models leave the constant instantaneous volatility assumption of the Black-Scholes (1973) model and assume that volatility follows a stochastic process possibly correlated with the process for the stock price. Within this group are Hull and White (1987) and Heston (1993) stochastic volatility models. Recently Chockalingam and Muthuraman (2011) have considered the valuation of American options under the existence of stochastic volatility. The local volatility model postulates that the instantaneous volatility (called local volatility) is a deterministic function of the underlying asset price and time. Within this group we have the works of Dupire (1994), Derman and Kani (1994) Rubinstein (1994) or Andersen and Brotherton-Ratcliffe (1998).

Following the way in which practitioners price exotic options, we calibrate the model parameters to the market price of vanilla options corresponding to the Standard and Poor’s 500 equity index and we use these parameters to price barrier options as well as cliquet structures. The empirical results suggest that outcome prices significantly differ depending on the assumptions pertaining to the volatility, indicating that the consideration of stochastic volatility is a key element for the correct valuation of forward skew dependent derivatives such as cliquets. Thus, our findings indicate that the measurement bias in Level 2 fair value estimates may be very wide. We contribute to the literature by examining the reliability of models to estimate fair values of Level 2 and whether the model specifications related to volatility affect fair value estimates. While the other related studies also examine management induced fair value measurement error, the do not examine intrinsic measurement error. Our results have important implications for both accounting and auditing standard setters, as well as for bank regulators. The remainder of this paper is organized as follows. In §2, we illustrate the relevance of our study by providing a brief descriptive analysis of the impact that Level 2 and Level 3 fair value estimates have on U.S., European, Australian and Asian banks’ financial

---

7These models are two of the most profusely used models by financial institutions.
positions. In §3, we present the volatility models we use to examine the potential model misspecification error. In §4, we compare the resulting prices from the aforementioned models in the valuation of barrier and cliquet exotic options. Finally, in §5, we present our conclusions and the implications of our findings.

2. Fair Value Measurements of Illiquid Financial Instruments by Banks

In this section we provide a brief descriptive analysis of the weight of Level 2 and Level 3 fair value estimates on the financial position of large banks. To illustrate the potential model misspecification error exposure (PME) faced by main U.S., European, Asian and Australian bank holding companies and investment banks, we computed the ratios of (i) total financial instruments measured at Level 2 and Level 3 fair values (both assets and liabilities) to total assets, and (ii) total financial instruments measured at Level 2 and Level 3 fair values (both assets and liabilities) to equity. The sample consists of a total of 47 banks for the fiscal year 2011. The financial information is taken from the consolidated Balance Sheets and the notes to the financial statements (i.e., fair value measurements).

Tables 1, 2 and 3 present the PME faced by main U.S., European, and Asia-Pacific banks, respectively. At first glance, these tables show that Level 2 fair value estimates are significantly higher than Level 3 ones. However, the most salient finding is that several large banks faced Level 2 value estimates with uncertainty ranges that are many times larger than materiality for the financial statements taken as a whole. This situation is extreme in the case of the largest U.S. and certain European banks. Table 1 showsthat the PME over equity ratio for U.S. banks ranges from 15.3 percent to 2,324.4 percent, with six U.S. banks facing an exposure higher than 500 percent (JPMorgan Chase, Bank of America, Citigroup, Goldman Sachs, State Street, and Charles Schwab). The PME over assets ratio for U.S. banks ranges from 1.8 percent to 201.6 percent, with four large U.S. firms facing an exposure higher than 100 percent (JPMorgan Chase, Bank of America, Citigroup, and Goldman

---

8 Using quarterly reports of U.S. banking firms in 2008, Song et al. (2010) suggest that the value relevance of Level 3 fair values are significantly lower than those of Level 1 and Level 2 fair values.

9 This is interesting since previous auditing research has only shown concern regarding Level 3 estimates (Bell and Griffin 2012; Meder et al. 2011).
Sachs). According to Table 2, the PME is also considerably and even higher for main European banking firms. The minimum and maximum values for the PME over equity ratio are 69.1 percent and 7,164.9 percent, respectively, with eleven European banks facing an exposure above 500 percent (BNP Paribas, Deutsche Bank, Credit Agricole, ING Group, Groupe BPCE, Société Générale, UniCredit S.P.A., Commerzbank, Barclays, UBS, and Credit Suisse). The PME over assets ratio ranges from 4.2 to 230 percent, with two banks facing an exposure above 100 percent (Deutsche Bank and Credit Suisse). Credit Suisse shows the maximum exposure, which is higher than the exposure of any other U.S. bank.

On the contrary, Table 3 shows that PME is relatively low for most of Asian banks. While the minimum value of the PME over equity is 84.8 percent, the maximum is 954.5 percent, with two Asian banks facing an exposure above 500 percent (HSBC and Mizuho). On the other hand, the PME over assets ratio ranges from 5 percent to 38 percent. Table 3 also provides the PME of Australian banks, where the PME over equity ratio has a minimum and a maximum value of 280.2 percent and 821.7 percent. Only the National Australia Bank has an exposure above 500 percent. Further, the PME over assets ratio of Australian banks ranges from 15.6 percent to 46 percent. Therefore, while several U.S. and European banks show PME ratios that are many times larger than materiality in terms of either equity or assets, only few Asia-Pacific Banks (HSBC, Mizuho and National Australia Bank) have a considerable high exposure in terms of equity.

(Insert Table 1, 2 and 3 about here)

All of the banks were audited by international accounting firms who issued favorable opinions stating that the consolidated financial statements gave the true and fair view of (or present fairly) the firms’ financial position in all material respects. In their reports, auditors also expressed that, as a part of their responsibilities, their audits included an evaluation of the appropriateness of accounting policies used and the reasonableness of accounting estimates made by management. Interestingly,

---

10 Auditors also assessed the effectiveness of the internal control over financial reporting. Only one European bank (UBS) received an unfavorable opinion on this matter.
none of the 47 audit reports of our sample included an *emphasis of matter paragraph* to draw users’ attention to significant uncertainty surrounding accounting estimates.\footnote{An emphasis of matter paragraph may be included in the auditor’s report to indicate that, in the auditor’s judgment, a matter appropriately disclosed in the financial statements is of such importance that it is fundamental to users’ understanding of the financial statements.}

### 3. Stochastic Volatility Models and Local Volatility Models

In the case of derivatives, PME in Level 2 and Level 3 fair value estimates may be due to different assumptions regarding the evolution of the underlying assets. In this sense, one of the key assumptions has to do with the behavior of the instantaneous volatility. Hence, in this section we present two of the most widely used models to price equity derivatives by financial institutions.

#### 3.1. Local Volatility Model

The local volatility model was introduced by Derman and Kani (1994), Dupire (1994) and Rubinstein (1994). This model postulates that the instantaneous volatility corresponding to the underlying asset, called local volatility, is a deterministic function of time and the asset price. In particular, let \( S_t \) denotes the price associated with the underlying asset at time \( t \). The local volatility model postulates the following process to characterize its behavior under the risk-neutral probability measure \( Q \):

\[
\frac{dS_t}{S_t} = (r - q) dt + \sigma(t, S_t) dW_t^Q
\]

where \( \sigma(t, S_t) \) is the local volatility function and \( W_t^Q \) is a Wiener process under the risk-neutral probability measure. For simplicity, we assume that the continuously compounded risk-free rate \( r \) and the dividend yield \( q \) are constant. The local volatility model is able to capture quite accurately the existence of volatility skew (Derman and Kani, 1994; Dupire, 1994; Derman, 2003). The term volatility skew accounts for the negative relation between strike prices and volatilities widely observed in equity options markets since the stock market crash on October 1987. In particular, Dupire (1994)
shows that the following relationship holds between time $t = 0$ European call option prices of strike price $K$ and maturity $T$, $C_{OT}(K)$, and the one dimensional local volatility function:

$$\sigma(T, S_T = K) = \sqrt{2 \left[ \frac{\partial C_{OT}(K)}{\partial T} + K \frac{\partial^2 C_{OT}(K)}{\partial K^2} (r - q) + q C_{OT}(K) \right] K^2 \frac{\partial C_{OT}(K)}{\partial K^2}}$$

Equation (2) shows that it is possible to recover the local volatility function using the market price of European options. Let $D(S_t, t)$ denote the time $t$ price of a derivative, which can path-dependent, on an asset whose time $t$ price is given by $S_t$. If the underlying asset price follows the risk-neutral process of equation (1), replication arguments show that the derivative asset satisfies the backward-Kolmogorov equation:

$$\frac{\partial D(S_t, t)}{\partial t} + (r - q) S_t \frac{\partial D(S_t, t)}{\partial S_t} + \frac{1}{2} \sigma^2(t, S_t) S_t^2 \frac{\partial^2 D(S_t, t)}{\partial S_t^2} - r D(S_t, t) = 0$$

where $\sigma(t, S_t)$ is given by equation (2). Hence, options can be priced through a Monte Carlo simulation, based on the asset price dynamics of equation (1) or through a finite-difference scheme, based on equation (3). This approach is particularly useful for instruments with early-exercise features.

### 3.2. Heston Model

The second group of models considered is the class of stochastic volatility models. These models assume that the asset price and its instantaneous volatility follow stochastic processes that may be correlated. These models are able to account for second order effects, such as the existence of volatility in the volatility, that are of key importance in the correct valuation of some exotic derivatives. Moreover, under the assumption of a negative correlation between the asset price process and its instantaneous volatility, these models are able to generate a negative volatility skew. Within the group of stochastic volatility models, this article considers the Heston (1993) model, which is one of the most commonly used among financial institutions to price exotic derivatives. This model offers
semi-closed form solutions for the price of European options and, hence, it is possible to calibrate the model parameters to the market prices of the European options quoted in the market.

The Heston model (1993) postulates the following dynamics for the asset return and its instantaneous volatility \( v_t \), under the risk-neutral measure \( Q \):

\[
dS = (r - q) dt + \sqrt{v_t} dW^Q_{S,t} \\
dv_t = \kappa (\theta - v_t) dt + \eta \sqrt{v_t} dW^Q_{v,t}
\]

where \( \theta \) represents the long-term mean corresponding to the instantaneous variance, \( \kappa \) denotes the speed of mean reversion and \( \eta \) is the volatility of variance. \( W^Q_{S,t} \) and \( W^Q_{v,t} \) are two Wiener processes under the risk-neutral probability measure \( Q \). Both processes are correlated so that:

\[
dW^Q_{S,t} dW^Q_{v,t} = \rho dt
\]

There are two parameters that affect crucially options prices regarding the distribution corresponding to asset returns. The correlation parameter \( \rho \), affects the symmetry of the distribution and, hence, it accounts for the volatility skew. In this sense, a negative correlation level implies higher variance in the market downside. This fact generates higher prices for out-of-the-money puts.

On the other hand, the volatility of variance \( \eta \) has an effect on the kurtosis of the distribution. The higher \( \eta \), the fatter the tails of the distribution. This effect increases the prices corresponding to out-of-the-money calls and puts, given that it is more likely that these options expire in-the-money.

Let us consider a European call with strike price \( K \) and maturity \( T \). Its payoff at maturity can be expressed as:

\[
(S_T - K)^+ = (S_T - K) 1_{(S_T > K)}
\]

12 Although in the original paper Heston does not consider the existence of dividends, here we present the model assuming a continuous dividend yield \( q \) for the underlying asset.
where \( I_{S_0 > K} \) is the indicator function of Heaviside step function. Hence, the option price under the risk-neutral probability measure is given by:

\[
C_{0f}(K) = e^{-qT}S_0P_1 - P\left(0, T\right)KP_2
\]

(6)

where \( P\left(0, T\right) = e^{-rT} \) is the time \( t = 0 \) price of a zero coupon bond that pays a monetary unit at time \( t = T \) and \( E_R[.] \) represents the expected value under the risk neutral probability measure \( Q \).

Heston (1993) shows that the functions \( P_j \) (for \( j = 1, 2 \)) can be obtained via the Fourier inverse transform:

\[
P_j = \frac{1}{2} + \frac{1}{\pi} \int_0^\infty \text{Re} \left( \frac{e^{-iz\ln(K)}}{iz} \right) d\zeta
\]

(7)

where \( i = \sqrt{-1} \) and \( f_j \) for \( j = 1, 2 \), are the characteristic functions corresponding to \( P_j \) and are given by:

\[
f_j = e^{C_j + D_j \ln(S_0)}
\]

\[
C_j = (r - q)izT + \frac{\kappa \Theta}{\eta^2} \left( b_j - \rho \eta iz + d_j \right) T - 2 \ln \left( \frac{1 - g_j e^{\eta d_j}}{1 - g_j} \right)
\]

\[
D_j = \frac{b_j - \rho \eta iz + d_j}{\eta^2} \left[ \frac{1 - e^{\eta d_j}}{1 - g_j e^{\eta d_j}} \right]
\]

\[
g_j = \frac{b_j - \rho \eta iz + d_j}{b_j - \rho \eta iz - d_j}
\]

\[
d_j = \left[ \left( \rho \eta iz - b_j \right)^2 - \eta^2 \left( 2a jiz - \zeta^2 \right) \right]^\frac{1}{2}
\]

with \( u_1 = \frac{1}{2} \), \( u_2 = -\frac{1}{2} \), \( b_1 = \kappa - \rho \eta \) and \( b_2 = \kappa \). Therefore, to calculate the price of a European option using the formula of equation (6) it is necessary to solve the integrals of equation (7) numerically.

Let \( D\left(S_t\right) \) denote the terminal value corresponding to a derivative on \( S \). Its time \( t \) value, denoted as \( D\left(S_t, v, t\right) \), verifies the following partial differential equation:
Note that the previous equation includes additional terms that were not present in the backward-Kolmogorov equation associated with the local volatility model. In particular, the term 

\[ \frac{\partial D_t}{\partial v_i} \]

is related to the vega of the derivative, the convexity factor with respect to volatility \[ \frac{\partial^2 D_t}{\partial v_i^2} \] has to do with the volga and, finally, the cross-convexity term \[ \frac{\partial^2 D_t}{\partial S_i \partial v_i} \] is related to the vanna of the derivative. The use of valuation models that do not properly account for these effects to price derivatives which are sensitive to them can lead to important price discrepancies as we will see in this article.

4. Calibration to Market Data

In this article we follow the methodology introduced by Hull and Suo (2002) to measure the model risk embedded in the pricing of exotic options. To this end, we mimic the way in which practitioners price these options. They typically use a model to price a particular exotic option in terms of the observed market prices at a particular time. In this sense, they calibrate the model parameters to the market prices of vanilla instruments at a point in time and use the model parameters to price exotic options at the same time. Following Hull and Suo (2002), we assume that market prices are governed by a stochastic volatility model. In particular, we consider the Heston (1993) model and we determine the model parameters fitting it to representative market data. The main reason for this choice is that this model is one of the most popular models within the class of stochastic volatility models.

Option prices are usually quoted using implied volatilities obtained from the Black-Scholes (1973) option pricing formula. Let \( C_{K_T} \) denote the market price of a European call with strike price \( K \).
and maturity $T$, on an asset whose time $t$ price is given by $S_t$. The Black-Scholes (1973) implied volatility $\Sigma$ is defined by:

$$C_{KT}^* = C_{KT}^{BS}(\Sigma)$$

where $C_{KT}^{BS}$ is the option price obtained using the Black-Scholes (1973) formula. The implied volatility expressed as a function of the strike price and the maturity is known as the time $t$ implied volatility surface. We consider the implied volatility surface, associated with listed options, for the Standard and Poor's 500 equity index corresponding to February 3, 2012. The implied volatilities as well as dividend yield and interest rate are obtained from Bloomberg. We have 12 maturities and 13 values of moneyness$^{13}$, ranging from 70% to 130%. Therefore, a total of 156 points on the implied volatility surface are provided. The reference spot price for the index was 1,344.9 and the data include options expiring in September 2012, December 2012, March 2013, June 2013, September 2013, December 2013, June 2014, December 2014, December 2015, December 2016, December 2017 and December 2018.

Figure 1 shows the market implied volatility surface for the Standard and Poor's 500 index corresponding to February 3, 2012. The figure reveals the existence of negative volatility skew, which is most pronounced for near-term options. This is a common pattern of behavior that has been widely observed in equity options markets. Some examples can be found in Derman et al. (1995) or Gatheral (2006).

(Insert Figure 1 about here)

We choose the model parameters to provide as close a fit as possible to the observed implied volatility surface associated with the Standard and Poor's 500 index. Table 4 provides the fitted values corresponding to the parameters of the Heston (1993) model.

(Insert Table 4 about here)

---

$^{13}$ The moneyness is defined as $K/S$, where $K$ is the strike price and $S$ is the spot price.
The calibration results are fairly good. In particular, the total mean absolute error (MAE) corresponding to the difference between the market implied volatility surface and the implied volatility calibrated using the Heston (1993) model is 0.766%, whereas the MAE associated with at-the-money options is 0.539%. Hence, the Heston (1993) model provides an accurate fit to the market implied volatility surface corresponding to the Standard and Poor's 500 index. Figure 2 shows the implied volatility surface generated by the calibrated parameters corresponding to the Heston (1993) model.

(Insert Figure 2 about here)

We calibrate the local volatility model to the implied volatility surface generated by the Heston (1993) stochastic volatility model using the approach introduced by Marabel (2012b) to calculate the local volatility. This methodology consists of smoothing the implied volatility through a flexible parametric function, which is consistent with the no-arbitrage conditions developed by Lee (2004) for the asymptotic behavior of the implied volatility at extreme strikes. The local volatility function is then calculated analytically. This approach allows obtaining smooth and stable local volatility surfaces while capturing the prices of vanilla options quite accurately. In this sense, the MAE corresponding to the difference between the implied volatility surface calibrated using the local volatility model and the implied volatilities generated by the Heston (1993) specification of table 4 is 0.102%, whereas the MAE associated with at-the-money options is 0.120%. Figure 3 provides the implied volatility surface associated with the local volatility specification. We can see from the figure that it is quite similar to the implied volatility surface of figure 2 associated with the Heston (1993) model. On the other hand, figure 4 displays the local volatility surface \( \sigma(t,S_t) \). The figure shows that the resulting local volatility surface is quite smooth and it has the properties that we would expect from a reasonable local volatility surface. In particular, the local volatility surface corresponding to the Standard and Poor's 500 index has a pronounced skew for near-term options that decays for longer-term options. A similar pattern is found by Derman et al. (1995) for the local volatility surface corresponding to the same equity index.
Once we have calibrated the models to the prices of European options under both specifications, it is possible to compare the pricing performance of the local volatility model in the valuation of exotic options.

5. On the Fair Valuation of Exotic Options

This section provides a numerical illustration which shows the importance of using a valuation model that properly accounts for PME associated with the exotic derivatives. The key point of the model risk is that different models can yield the same price for European options but, at the same time, very different prices for exotic options depending on their assumptions corresponding to the evolution of the underlying asset price and its volatility.

5.1. Up-and-Out Call Option

The up-and-out calls have become a pretty used derivative by the investors that are interested in assuming a long exposure in the underlying asset. If investors believe that the underlying asset price is going to increase without exceeding a certain level, they can invest in an up-and-out call at a cheaper price than a European call or a call spread.

Formally, the payoff at maturity of an up-and-out call with barrier $H$, strike price $K$ and maturity $t=T$ is given by:

$$(S_T - K)^+ 1_{(N_T < H)}$$

$$N_T = \max_{0 \leq t \leq T} S_t \quad H > K$$

where $1_{(N_T < H)}$ represents the indicator function. Under the assumptions of the Black-Scholes (1973) model, it is well known (see for instance Derman and Kani 1997) that it is possible to calculate the price associated with the up-and-out call using the following expression:


\[
UOC_{0T}(K,H) = C_{0T}^{BS}(S_0,K) - C_{0T}^{BS}(S_0,H) - (H - K) DC_{0T}^{BS}(S_0,H)
\]

\[
= \left( \frac{S_0}{H} \right)^{2\lambda} \left[ C_{0T}^{BS} \left( \frac{H^2}{S_0}, K \right) - C_{0T}^{BS} \left( \frac{H^2}{S_0}, H \right) - (H - K) DC_{0T}^{BS} \left( \frac{H^2}{S_0}, H \right) \right]
\]  

(9)

with:

\[
\lambda = \frac{1}{2} \frac{(r - q) \Sigma^2}{4}
\]

where \( \Sigma \) is the implied volatility and where \( C_{0T}(K) \) represents the price of a European call with strike price \( K \) and maturity \( T \), and \( CD_{0T}(K) \) is the price of a digital call that pays one currency unit if at the expiration of the option the asset price is above the strike price. Under the assumptions of the Black-Scholes (1973) model it is easy to obtain analytic solutions for the price of these options. Therefore, in this case, equation (9) offers a closed-form solution for the price of an up-and-out call as a function of the prices corresponding to plain vanilla options.

Unfortunately, under the other two models considered in the article we do not have closed-form solutions for the price of barrier options. Therefore, it is necessary to use numerical methods to calculate the prices. To this end, we use Monte Carlo simulations with daily time steps and 80,000 trials and we apply the antithetic variable technique described in Boyle (1977) to reduce the variance of the estimates. For the Heston (1993) model we implement a Milstein discretization scheme as described in Gatheral (2006). Finally, for the Black-Scholes (1973) model, we use the analytic expression of equation (9).

Table 5 displays the prices, expressed as percentage of the asset price, corresponding to up-and-out calls with maturity within two years and at-the-money strike price for different barrier levels. The table offers the prices obtained under the Heston (1993) model. For the rest of models, the table shows the percentage error defined as \( \frac{P_{\text{model}}}{P_{\text{Heston}}} - 1 \), where \( P_{\text{model}} \) is the price under the corresponding model and \( P_{\text{Heston}} \) is the price obtained under the Heston (1993) model.
Regarding the price denoted as Black-Scholes atm in the table, we consider that the implied constant volatility is equal to the at-the-money implied volatility associated with the options with maturity within two years corresponding to the specification of table 4. On the other hand, regarding the price denoted as Black-Scholes barrier, we use the implied volatility corresponding to European options with maturity within two years and strike equal to the barrier level.

(The Insert Table 5 about here)

The results obtained under the Black-Scholes (1973) model using the at-the-money volatility do not account for the existence of volatility skew and for the existence of stochastic volatility. Hence, the prices obtained under this approach are much lower than the ones generated by the other two models. When we use the implied volatility associated with the barrier level, the prices are higher than in the previous case. The reason is that, in this case, the lower the implied volatility the lower the probability of reaching the barrier and, hence, the higher the price of the call up-and-out. But, even in this case, we have important discrepancies with respect to the local volatility model and the stochastic volatility model. In the past, some financial institutions used this kind of rude adjustments in the implied volatility to price barrier options using the Black-Scholes (1973) model. This example shows that this practice can generate quite big valuation errors.

The local volatility function accounts for the existence of volatility skew. Hence, the prices obtained under this model are closer to the prices generated by the Heston (1993) model. Nevertheless, the local volatility model does not properly account for second order effects such as the volatility of volatility. The omission of these effects generates the price differences between the local volatility model and the stochastic volatility model.

5.2. Monthly Cliquet Option

Let us consider a cliquet option with maturity equal to three years, whose payoff at expiration is given by the accrued sum of monthly returns with a maximum monthly revalorization of 2% and a minimum monthly revalorization equal to -2%. Moreover, the investor has a performance of 2% guaranteed at maturity. The maximum monthly revalorization of 2% is the local cap, whereas the
minimum monthly revalorization is denoted *local floor*. Finally, the 2% coupon guaranteed at expiration is the *global floor*.

This strategy is denoted as cliquet option with caps and floors and it represents an example of structured products that financial institutions typically offer to their clients. The reason why investors can be interested in this product is because this cliquet option allows them to benefit from the possible increase of the underlying asset while at the same time they have a minimum coupon guaranteed.

The payoff at maturity associated with this strategy is given by the following expression:

$$\max \left\{ \sum_{t=1}^{36} \max \left[ \min \left( \frac{S_t}{S_{t-1}} - 1.2\%, -2\% \right), 2\% \right] \right\}$$

In the previous expression, \( t \) represents the month, where the total number of months is equal to 36. The fact that, under the cliquet option, the performance of the underlying asset is measured, at any observation date, with respect to the price of the underlying asset in the previous period instead of with respect to the initial level, makes the cliquet option quite sensitive to the forward volatility skew. Therefore, this kind of options is pretty model dependent.

Table 6 compares the prices corresponding to the cliquet option of the previous example obtained under the three models considered in the article. We use Monte Carlo simulations with daily time steps and 80,000 trials. The table displays the price obtained under the Heston (1993) model as well as the percentage error associated with the local volatility model and the Black-Scholes (1973) model. In this case, we use the market at-the-money volatility associated with options with expiry within three years to calculate the price under the Black-Scholes (1973) specification.

(Insert Table 6 about here)

As in the previous example the lowest price corresponds to the Black-Scholes (1973) model. As said previously, cliquet options are quite sensitive to the forward volatility skew. But, as Derman (2003) points out, the local volatility model generates future volatility skews much flatter than the current ones. This is an uncomfortable and unrealistic forecast that contradicts the omnipresent nature
of the skew. As a consequence, the prices obtained under the local volatility model are considerably lower than the ones generated by the Heston (1993) model.

The previous examples show the importance of choosing a correct valuation model to price exotic options. In this sense, it would be interesting to distinguish between the model and the valuation method. A model can be implemented using different valuation methods. For instance, we can price a cliquet option under the local volatility model through Monte Carlo simulations or through a finite difference approach. In both cases we should have the same price for the option if both methods are correctly implemented. Hence, although the valuation method is relevant, the key question to correctly price an exotic derivative has to do with the model assumptions. In this sense, Gaudenzi and Zanette (2011) introduce a novel methodology, based on a tree method, to price cliquet options. Unfortunately, these authors consider the Black-Scholes (1973) that, as we have seen, misprices the cliquet options. Importantly, the choice of an appropriate model is relevant not only to obtain a correct price for the derivative but also to manage adequately the market risks associated with the derivative.

Hull and Suo (2002) use the finite-difference method introduced by Andersen and Brotherton-Ratcliffe (1998) to price exotic options on equities and exchange rates under the local volatility model. They also used a stochastic volatility model similar to the Heston (1993) model. These authors conclude that the goodness of the local volatility model with respect to the stochastic volatility framework is a function of the degree of path dependence in the exotic option being priced, where the degree of path dependence is defined as the number of times that the asset price must be observed to calculate the payoff. The higher the degree of path dependence, the worse the local volatility model is expected to perform. Importantly, note that in the example of table 6, corresponding to a monthly cliquet option with lower degree of path dependency, the percentage error associated with the local volatility model is considerably high. This result shows that, although the degree of path dependency has influence on the model error associated with the price of an exotic option, there are other key factors, such as the convexity of the option premium with respect to volatility.

5. Conclusion and Implications
In this paper we investigate whether FVA can lead bank managers towards model misspecification error in the valuation of complex financial instruments traded in illiquid markets. We argue that one critical factor influencing the pricing of exotic options (Level 2 fair value estimates) is the assumption made about volatility. By pricing cliquet and barrier options we illustrate the existence of model misspecification error when comparing two different assumptions pertaining to volatility (local volatility vs. stochastic volatility). Our findings are relevant for at least two reasons: (i) the high exposure of U.S. and European banks to PME and (ii) many other derivatives and financial products which are also subject to being biased from misspecified valuation models. For instance, consider the case of Deutsche Bank, where just the fair value estimates of derivatives classified as Level 2 (1,636,705 million euros, non-tabulated) and Level 3 (59,246 million euros, non-tabulated) represent 88.6 percent of the bank’s total PME (1,914,727 million euros).

Our findings have important implications for regulators, and auditors. If bank regulators truly want to enhance the credibility of Level 2 and Level 3 fair value estimates, more specific guidance should be provided to preparers. It would be helpful to elaborate guidelines to select the most appropriate assumptions, including volatility, and valuation techniques for illiquid financial instruments. Importantly, financial innovation continues to develop new derivatives that increase the set of investment opportunities. Hence, such guidelines should be updated in a timely manner to include guidance for the valuation of new complex financial products. Further, according to our results, bank regulators should retake the debate about establishing especial regulatory capital requirements for those banks with a high exposure to critical FVA estimates. Even though certain regulators have expressed some degree of concern (Basel Committee on Banking Supervision 2009), there exists no a clear position on this issue yet.

Current accounting standards are not only ambiguous pertaining to the valuation of complex financial instruments traded in illiquid markets but also opaque. Accounting regulators could contribute

---

14 For instance, in recent years there has been a remarkable growth of volatility options. These options exhibit upward sloping volatility skew and the shape of the skew is largely independent of the volatility level. In equity options markets, the slope of the skew is also quite independent of the volatility level (Derman 1999). In this sense, new models arise to account for this stylized fact. In particular, Christoffersen et al. (2009) and da Fonseca et al. (2008) propose different multifactor stochastic volatility models that allows for the existence of stochastic skew.
to reduce users’ uncertainty regarding Level 2 and 3 fair value estimates by requiring additional disclosure. A plausible solution could be to convey on the face of the main financial statements (i.e., balance sheet, profit and loss, and cash flows) the accounts whose values are subject to extreme fair value estimates (Christensen et al. 2012). Preparers could be required to either flag or highlight critical accounts with significant uncertainty surrounding Level 2 and 3 financial instrument estimates to draw users’ attention. Accounting regulators could also require further disclosure on the notes to the financial statements. Consider again the case of the notes to the financial statements of Deutsche Bank for the fiscal year 2011. In spite of the fact that Level 2 fair values of derivatives are many times larger than materiality for the financial statements taken as a whole, the management of the bank did not present a disaggregated disclosure of such derivatives by type of product or valuation technique. Instead, there is only a generic description of the valuation of OTC derivatives without providing any specific quantitative or qualitative information pertaining to materiality in terms of the significance of FVA to the bank’s financial position and performance, volatility assumptions, or confidence intervals (i.e., reasonable ranges) around reported estimates.  

Further, recent research suggests that auditors face challenges and considerable risks in evaluating fair value measurements for at least two reasons. First, auditing standards on fair value estimates are lacking of interpretative guidance (Committee of European Banking Supervision 2008). Instead of forming an independent opinion, auditors may be seduced to use auditing standard ambiguity to support bank managers’ fair value estimates (Griffith et al. 2012; Bratten et al. 2013). Second, auditors may not have sufficient access to information and/or the necessary skills/training or expertise to form an independent opinion on fair value estimates (International Auditing and Assurance Standards Board 2008; Center for Audit Quality 2011). Therefore, it is debatable that auditors are able to provide reasonable assurance on mark-to-model valuations considering the current auditing standard uncertainty and the lack of auditors’ valuation knowledge (Bratten et al. 2013). A further issue in audit is that the approach normally used to verify the estimations is one based on the consistency over time of the calculations (correctness), when the main problem in fair value is one of

---

15 This information is available at https://annualreport.deutschebank.com/2011/ar/notes/notestotheconsolidatedbalancesheet/14financialinstrumentsatfairvalue.html
precision, as long as the estimation is just an attempt to determine the market price (accuracy). Therefore, auditing standard setters should also consider the challenges of dealing with high-uncertainty fair value estimates. Most derivatives, like barrier options and cliquet options, are not quoted in markets in any time over their lives, and therefore the estimations of their fair values never can be contrasted by means of observable transactions. Auditing standard ambiguity and the lack of valuation knowledge may lead auditors to collude with bank managers’ fair value estimates and merely serve to rubber stamp the preparer’s report. Under the current system, in order to issue a clean opinion on the financial statements of a bank, an auditor must provide positive assurance on the financial statements by stating that they are presented fairly, *in all material respects*.

This is the case of the audit reports on the financial statements of the 47 banks examined in this paper. All of them expressed a favorable opinion without alerting about the potential impact that Level 2 and 3 financial instruments estimates may have on the financial position of the banks. Despite regulators allow auditors to use a paragraph emphasis to draw the user’s attention to a significant uncertainty (International Auditing and Assurance Standards Board 2008), none of the 47 audit reports reviewed in this paper added such a paragraph. Perhaps one possibility to improve the current situation could be to require auditors to provide negative assurance with respect to high-uncertainty fair value estimates (Christensen et al. 2012; Bell and Griffin 2012). Negative assurance might alert users on the fact that the auditor is not able to support management’s estimates on certain Level 2 and Level 3 fair value estimates due to high uncertainty. Further, auditors could benefit from negative assurance as a shield against potential litigation risk, i.e., the possibility of being sued for negligence on the audit of banks and other firms with extreme fair value estimates.

16 Alternatively, instead of negative assurance, auditing standard setters could consider different levels of assurance for extreme fair value estimates, such as high, moderate and low (Christensen et al. 2012).
References


Financial Accounting Standard Board. 2006. SFAS 157, Fair Value Measurements. FASB, Norwalk, CT.


### Table 1. Potential Model Misspecification Error Exposure of U.S. Bank Holding Companies/Investment Banks, Ranked by Total Assets (From Consolidated and Audited Financial Statements for the year 2011)

<table>
<thead>
<tr>
<th>Company name</th>
<th>Auditor*</th>
<th>Financial instruments at fair value (Assets)</th>
<th>Financial instruments at fair value (Liabilities)</th>
<th>Total potential model risk exposure (PME) (1)+(2)</th>
<th>Total Shareholders’ Equity (3)</th>
<th>Total Assets (4)</th>
<th>PME over Equity (%) [(1)+(2)]/ (3)</th>
<th>PME over Assets (%) [(1)+(2)]/ (4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>JPMorgan Chase</td>
<td>PWC</td>
<td>2,245,722</td>
<td>113,489</td>
<td>2,359,211</td>
<td>1,864,603</td>
<td>43,091</td>
<td>2,324.4</td>
<td>188.3</td>
</tr>
<tr>
<td>Bank of America</td>
<td>PWC</td>
<td>2,279,427</td>
<td>51,577</td>
<td>2,331,004</td>
<td>1,950,513</td>
<td>11,571</td>
<td>2,129.046</td>
<td>201.6</td>
</tr>
<tr>
<td>Citigroup</td>
<td>KPMG</td>
<td>1,480,981</td>
<td>60,765</td>
<td>1,541,746</td>
<td>1,147,726</td>
<td>22,902</td>
<td>1,795.73</td>
<td>144.7</td>
</tr>
<tr>
<td>Wells Fargo</td>
<td>KPMG</td>
<td>390,839</td>
<td>53,273</td>
<td>444,112</td>
<td>106,784</td>
<td>4,620</td>
<td>141.687</td>
<td>42.3</td>
</tr>
<tr>
<td>Goldman Sachs</td>
<td>PWC</td>
<td>587,416</td>
<td>47,937</td>
<td>635,353</td>
<td>778,639</td>
<td>83,624</td>
<td>923.225</td>
<td>162.2</td>
</tr>
<tr>
<td>Morgan Stanley</td>
<td>D&amp;T</td>
<td>235,174</td>
<td>32,326</td>
<td>267,500</td>
<td>3,678</td>
<td>732</td>
<td>749.898</td>
<td>36.8</td>
</tr>
<tr>
<td>U.S. Bancorp</td>
<td>E&amp;Y</td>
<td>57,315</td>
<td>4,693</td>
<td>62,006</td>
<td>3,039</td>
<td>53</td>
<td>186.12</td>
<td>19.1</td>
</tr>
<tr>
<td>Bank of New York Mellon</td>
<td>KPMG</td>
<td>28,489</td>
<td>160</td>
<td>28,649</td>
<td>8,759</td>
<td>314</td>
<td>110.7</td>
<td>11.6</td>
</tr>
<tr>
<td>PNC Financials</td>
<td>D&amp;T</td>
<td>53,480</td>
<td>15,051</td>
<td>68,531</td>
<td>7,320</td>
<td>308</td>
<td>191.1</td>
<td>26.2</td>
</tr>
<tr>
<td>State Street</td>
<td>E&amp;Y</td>
<td>103,570</td>
<td>8,691</td>
<td>112,261</td>
<td>14,162</td>
<td>201</td>
<td>216.827</td>
<td>58.4</td>
</tr>
<tr>
<td>Capital One</td>
<td>E&amp;Y</td>
<td>39,671</td>
<td>854</td>
<td>40,525</td>
<td>702</td>
<td>291</td>
<td>266.019</td>
<td>20.2</td>
</tr>
<tr>
<td>Sun Trust Bank</td>
<td>E&amp;Y</td>
<td>65,685</td>
<td>1,091</td>
<td>66,729</td>
<td>5,083</td>
<td>301</td>
<td>359.44</td>
<td>40.8</td>
</tr>
<tr>
<td>BB&amp;T</td>
<td>PWC</td>
<td>26,758</td>
<td>1,869</td>
<td>28,627</td>
<td>1,623</td>
<td>1</td>
<td>174.579</td>
<td>17.3</td>
</tr>
<tr>
<td>Charles Schwab</td>
<td>D&amp;T</td>
<td>38,636</td>
<td>0</td>
<td>38,636</td>
<td>0</td>
<td>0</td>
<td>108.553</td>
<td>35.6</td>
</tr>
<tr>
<td>Northern Trust</td>
<td>KPMG</td>
<td>29,454</td>
<td>178</td>
<td>29,632</td>
<td>3,224</td>
<td>101</td>
<td>100.223</td>
<td>32.9</td>
</tr>
<tr>
<td>M&amp;T Bank</td>
<td>PWC</td>
<td>5,848</td>
<td>1,211</td>
<td>7,059</td>
<td>440</td>
<td>1</td>
<td>77.924</td>
<td>9.6</td>
</tr>
<tr>
<td>Discover Financial</td>
<td>D&amp;T</td>
<td>813</td>
<td>0</td>
<td>813</td>
<td>448</td>
<td>0</td>
<td>68.784</td>
<td>15.3</td>
</tr>
</tbody>
</table>

* PWC = PricewaterCoopers; KPMG = KPMG Peat Marwick; D&T = Deloitte Touche Tohmatsu; E&Y = Ernst & Young.
Table 2. Potential Model Misspecification Error Exposure of European Bank Holding Companies/Investment Banks, Ranked by Total Assets
(From Consolidated and Audited Financial Statements for year 2011)

<table>
<thead>
<tr>
<th>Company name</th>
<th>Country</th>
<th>Auditor*</th>
<th>Financial instruments at fair value (Assets)</th>
<th>Financial instruments at fair value (Liabilities)</th>
<th>Total potential model risk exposure (PME) (1)+(2)</th>
<th>Total Shareholders’ Equity (3)</th>
<th>Total Assets (4)</th>
<th>PME over Equity (%) [(1)+(2)]/ (3)</th>
<th>PME over Assets (%) [(1)+(2)]/ (4)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>in million of Euros</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BNP Paribas</td>
<td>France</td>
<td>D&amp;T/PWC</td>
<td>652,469</td>
<td>23,059</td>
<td>675,528</td>
<td>616,789</td>
<td>33,904</td>
<td>650,693</td>
<td>1,326,221</td>
</tr>
<tr>
<td>Deutsche Bank</td>
<td>Germany</td>
<td>KPMG</td>
<td>1,158,870</td>
<td>47,573</td>
<td>1,206,443</td>
<td>696,611</td>
<td>11,673</td>
<td>708,284</td>
<td>1,914,727</td>
</tr>
<tr>
<td>Credit Agricole</td>
<td>France</td>
<td>PWC</td>
<td>458,810</td>
<td>15,468</td>
<td>474,278</td>
<td>970,949</td>
<td>13,421</td>
<td>984,370</td>
<td>1,458,648</td>
</tr>
<tr>
<td>ING Group</td>
<td>Netherlands</td>
<td>E&amp;Y</td>
<td>193,446</td>
<td>11,092</td>
<td>204,538</td>
<td>116,489</td>
<td>7,406</td>
<td>123,895</td>
<td>328,433</td>
</tr>
<tr>
<td>Santander Group</td>
<td>Spain</td>
<td>D&amp;T</td>
<td>162,637</td>
<td>1,037</td>
<td>163,674</td>
<td>224,857</td>
<td>279</td>
<td>225,136</td>
<td>388,810</td>
</tr>
<tr>
<td>Groupe BPCE</td>
<td>France</td>
<td>KPMG/PWC</td>
<td>204,885</td>
<td>15,040</td>
<td>219,925</td>
<td>199,561</td>
<td>275</td>
<td>199,836</td>
<td>419,761</td>
</tr>
<tr>
<td>Société Générale</td>
<td>France</td>
<td>D&amp;T/E&amp;Y</td>
<td>322,841</td>
<td>10,006</td>
<td>332,847</td>
<td>359,858</td>
<td>20,666</td>
<td>380,524</td>
<td>713,371</td>
</tr>
<tr>
<td>UniCredit S.P.A.</td>
<td>Italy</td>
<td>KPMG</td>
<td>158,797</td>
<td>12,451</td>
<td>171,248</td>
<td>124,130</td>
<td>4,309</td>
<td>128,439</td>
<td>299,687</td>
</tr>
<tr>
<td>Rabobank</td>
<td>Netherlands</td>
<td>E&amp;Y</td>
<td>6,197</td>
<td>227</td>
<td>6,424</td>
<td>24,528</td>
<td>129</td>
<td>24,657</td>
<td>31,081</td>
</tr>
<tr>
<td>Commerzbank</td>
<td>Germany</td>
<td>PWC</td>
<td>176,500</td>
<td>5,400</td>
<td>181,900</td>
<td>179,500</td>
<td>1,400</td>
<td>180,900</td>
<td>362,800</td>
</tr>
<tr>
<td>BBVA</td>
<td>Spain</td>
<td>D&amp;T</td>
<td>62,783</td>
<td>1,767</td>
<td>64,550</td>
<td>47,297</td>
<td>23</td>
<td>47,320</td>
<td>111,870</td>
</tr>
<tr>
<td><strong>in million of pounds</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barclays</td>
<td>UK</td>
<td>PWC</td>
<td>665,448</td>
<td>32,023</td>
<td>697,471</td>
<td>621,614</td>
<td>11,723</td>
<td>633,337</td>
<td>1,330,808</td>
</tr>
<tr>
<td>Lloyds Bank Group</td>
<td>UK</td>
<td>PWC</td>
<td>106,674</td>
<td>7,646</td>
<td>114,320</td>
<td>79,223</td>
<td>790</td>
<td>80,013</td>
<td>194,333</td>
</tr>
<tr>
<td><strong>in million of CHF</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UBS</td>
<td>Switzerland</td>
<td>E&amp;Y</td>
<td>549,500</td>
<td>25,000</td>
<td>574,500</td>
<td>560,800</td>
<td>23,500</td>
<td>584,300</td>
<td>1,158,800</td>
</tr>
<tr>
<td>Credit Suisse</td>
<td>Switzerland</td>
<td>KPMG</td>
<td>1,174,998</td>
<td>47,203</td>
<td>1,222,201</td>
<td>1,166,138</td>
<td>24,378</td>
<td>1,190,516</td>
<td>2,412,717</td>
</tr>
</tbody>
</table>

* PWC = PricewaterhouseCoopers; KPMG = KPMG Peat Marwick; D&T = Deloitte Touche Tohmatsu; E&Y= Ernst & Young.
Table 3. Potential Model Misspecification Error Exposure of Bank Holding Companies/Investment Banks in Asia, Ranked by Total Assets (From Consolidated and Audited Financial Statements for the year 2011)

<table>
<thead>
<tr>
<th>Company name</th>
<th>Country</th>
<th>Auditor*</th>
<th>Financial instruments at fair value (Assets)</th>
<th>Financial instruments at fair value (Liabilities)</th>
<th>Total potential model risk exposure (PME) [(1)+(2)]</th>
<th>Total Shareholders’ Equity (3)</th>
<th>Total Assets (4)</th>
<th>PME over Equity (%) [(1)+(2)]/ (3)</th>
<th>PME over Assets (%) [(1)+(2)]/ (4)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>In millions of HKdollars</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HSBC</td>
<td>China</td>
<td>KPMG</td>
<td>907,224</td>
<td>23,204</td>
<td>930,428</td>
<td>15,559</td>
<td>1,375,509</td>
<td>183,400</td>
<td>3,615,341</td>
</tr>
<tr>
<td><strong>In millions of RMB</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ICBC</td>
<td>China</td>
<td>E&amp;Y</td>
<td>965,434</td>
<td>5,094</td>
<td>970,528</td>
<td>3,062</td>
<td>184,590</td>
<td>1,155,118</td>
<td>957,823</td>
</tr>
<tr>
<td>China Construction Bank</td>
<td>China</td>
<td>PWC</td>
<td>661,296</td>
<td>18,337</td>
<td>679,633</td>
<td>5,169</td>
<td>46,966</td>
<td>726,599</td>
<td>816,661</td>
</tr>
<tr>
<td>Bank of China</td>
<td>China</td>
<td>PWC</td>
<td>457,953</td>
<td>27,008</td>
<td>484,961</td>
<td>164</td>
<td>587,563</td>
<td>1,072,524</td>
<td>755,894</td>
</tr>
<tr>
<td>Bank of Communications</td>
<td>China</td>
<td>D&amp;T</td>
<td>211,739</td>
<td>1,128</td>
<td>212,867</td>
<td>18,515</td>
<td>231,382</td>
<td>272,788</td>
<td>4,611,177</td>
</tr>
<tr>
<td><strong>In thousand millions of Yens</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mitsubishi UFJ</td>
<td>Japan</td>
<td>D&amp;T</td>
<td>19,148</td>
<td>3,493</td>
<td>22,641</td>
<td>10,352</td>
<td>10,509</td>
<td>33,150</td>
<td>8,671</td>
</tr>
<tr>
<td>Mizuho</td>
<td>Japan</td>
<td>E&amp;Y</td>
<td>22,851</td>
<td>2,808</td>
<td>25,659</td>
<td>12,211</td>
<td>12,855</td>
<td>38,514</td>
<td>4,035</td>
</tr>
<tr>
<td>Sumitomo Mitsui</td>
<td>Japan</td>
<td>KPMG</td>
<td>9,536</td>
<td>1,047</td>
<td>10,583</td>
<td>4,696</td>
<td>7</td>
<td>4,703</td>
<td>7,551</td>
</tr>
<tr>
<td>Sumitomo Trust and Banking</td>
<td>Japan</td>
<td>D&amp;T</td>
<td>1,027</td>
<td>530</td>
<td>1,557</td>
<td>187</td>
<td>1</td>
<td>1,745</td>
<td>632</td>
</tr>
<tr>
<td><strong>In thousand millions of Wons</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Woori Finance</td>
<td>Korea</td>
<td>D&amp;T</td>
<td>16,464</td>
<td>4,017</td>
<td>20,481</td>
<td>7,175</td>
<td>2,693</td>
<td>9,868</td>
<td>30,349</td>
</tr>
<tr>
<td>Shinhan Financial Group</td>
<td>Korea</td>
<td>KPMG</td>
<td>34,980</td>
<td>2,986</td>
<td>37,966</td>
<td>1,674</td>
<td>5,338</td>
<td>43,304</td>
<td>26,858</td>
</tr>
<tr>
<td>KB Financial</td>
<td>Korea</td>
<td>PWC</td>
<td>16,010</td>
<td>1,509</td>
<td>17,519</td>
<td>2,792</td>
<td>345</td>
<td>3,137</td>
<td>20,656</td>
</tr>
<tr>
<td><strong>In millions of AUD</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>National Australia Bank</td>
<td>Australia</td>
<td>E&amp;Y</td>
<td>206,790</td>
<td>2,882</td>
<td>209,672</td>
<td>136,987</td>
<td>4</td>
<td>136,991</td>
<td>346,663</td>
</tr>
<tr>
<td>Westpac Banking Corporation</td>
<td>Australia</td>
<td>PWC</td>
<td>116,333</td>
<td>1,473</td>
<td>117,806</td>
<td>151,221</td>
<td>74</td>
<td>151,295</td>
<td>269,101</td>
</tr>
<tr>
<td>Commonwealth Bank</td>
<td>Australia</td>
<td>PWC</td>
<td>53,480</td>
<td>105</td>
<td>53,585</td>
<td>50,874</td>
<td>8</td>
<td>50,882</td>
<td>104,467</td>
</tr>
</tbody>
</table>

* PWC = PricewaterhouseCoopers; KPMG = KPMG Peat Marwick; D&T = Deloitte Touche Tohmatsu; E&Y = Ernst & Young.
Table 4. Estimated parameters values for the Heston model associated with the Standard and Poor’s market implied volatilities corresponding to February 3, 2012

<table>
<thead>
<tr>
<th>Parameter:</th>
<th>$\kappa$</th>
<th>$\theta$</th>
<th>$\eta$</th>
<th>$\rho$</th>
<th>$\nu_0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value:</td>
<td>0.985</td>
<td>0.130</td>
<td>0.686</td>
<td>-0.900</td>
<td>0.044</td>
</tr>
</tbody>
</table>

Table 5. Prices for up-and-out calls with maturity within two years and strike at-the-money

<table>
<thead>
<tr>
<th>Model/Barrier:</th>
<th>120%</th>
<th>130%</th>
<th>140%</th>
<th>150%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black-Scholes atm</td>
<td>-76.67%</td>
<td>-75.19%</td>
<td>-71.69%</td>
<td>-64.36%</td>
</tr>
<tr>
<td>Black-Scholes barrier</td>
<td>-60.00%</td>
<td>-52.88%</td>
<td>-50.13%</td>
<td>-49.40%</td>
</tr>
<tr>
<td>Local Volatility</td>
<td>-47.50%</td>
<td>-25.31%</td>
<td>-12.04%</td>
<td>-2.91%</td>
</tr>
<tr>
<td>Heston</td>
<td>1.20%</td>
<td>3.99%</td>
<td>7.56%</td>
<td>9.96%</td>
</tr>
</tbody>
</table>

Table 6. Price corresponding to a monthly cliquet option with maturity within three years*

<table>
<thead>
<tr>
<th>Model</th>
<th>Black-Scholes</th>
<th>Local Volatility</th>
<th>Heston</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price</td>
<td>-52.41%</td>
<td>-37.18%</td>
<td>8.93%</td>
</tr>
</tbody>
</table>

* We consider a local cap of 2%, a local floor of -2% and, finally, a global floor of 2%. In the Black-Scholes (1973) specification, we use the at-the-money implied volatility associated with European options with maturity within three years.
Figure 1. Market implied volatility surface for February 3, 2012 market data corresponding to the Standard and Poor’s 500 index. Strike prices are expressed as a percentage of the index price.
Figure 2. Implied volatility surface for the Standard and Poor’s 500 index, corresponding to February 3, 2012 generated by the Heston model. Strike prices are expressed as a percentage of the index price, whereas maturities are expressed in years. The surface is generated using the parameters of table 4.
Figure 3. Implied volatility surface calibrated using the local volatility model, corresponding to February 03, 2012, for the Standard and Poor’s 500 index. Strike prices are expressed as a percentage of the index price, whereas maturities are expressed in years.
Figure 4. Local volatility surface corresponding to February 03, 2012, for the Standard and Poor’s 500 index. Asset prices are expressed as a percentage of the at-the-money strike, whereas maturities are expressed in years.