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Crash risk and risk neutral densities

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A B S T R A C T

"Crash risk" has been one of the major focuses in the recent asset pricing literature. Motivated by the recent literature that suggests an increase in crash risk since Fall 2008 and the recent troubles in the Euro zone, we use EUR/USD FX options for January 2, 2008 to March 18, 2015 to study option-implied risk-neutral densities (RND). We find that RND, especially higher moments, has superior explanatory power in predicting and explaining crash risk and its risk premiums. Furthermore, the higher moments of RND co-move closely with macroeconomic variables. Consistently, we find RND moments outperform the implied volatility from the Black–Scholes model.

1. Introduction

The information contents of implied volatility pioneered by Chiras and Manaster (1978) and Canina and Figlewski (1993) has sparked a wide interest in learning how option-implied parameters, which are forward-looking by definition, can carry useful information of the future of the financial markets. Instead of retrieving one single parameter (implied volatility), recent studies retrieve the entire risk-neutral density (RND) function. There are two advantages of using RND. First, RND is model-free (in loose terms) as opposed to the implied volatility that requires a parametric model (such as Black–Scholes). Secondly, the multiple moments of the RND carry much more granular information than a single volatility number. In particular, the skewness that is highly correlated with risk premiums and kurtosis that reflects fat tails provide investors much more useful information than the volatility.

Given that RND carries useful forward-looking information, the literature has in general used RND for in the following areas. The first strand of literature is use RND for prediction. This includes the prediction of (1) future movements of the underlying asset (e.g. Gemmill and Saflekos (2000)); (2) future option prices (e.g. Khrapov (2014)); (3) future volatility/variance (e.g. Jiang and Tian (2005))[1]; and (4) future distributions of the underlying asset (e.g. Xu and Taylor (1994) and Chen and Gwati (2012) for the volatility term structure and Christoffersen and Mazzotta (2005) for the entire density.

The second strand is reflecting economic events. This includes Datta et al. (2016) who study RNDs estimated around episodes of high geopolitical tensions, oil supply disruptions, and macroeconomic data releases in the oil market; Malz (1997) who studies the peso problem; Cooper and Talbot (1999) who study the yen crisis in the September of 1998; Birru and Figlewski (2012) and Chen and Gwati (2012) who study the global meltdown of 2008; Melick and Thomas (1997) who study the Gulf crisis in 1990; Gemmill and Saflekos (2000) who study major economic events such as 1987 crash and British elections; Castren (2004) who finds interventions

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[1] Also see Christensen and Prabhala (1998) and Jorion (1995).

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on the exchange rate coincide with systematic changes in all moments of the estimated RNDs and finds that RND moments from three newly joined E.U. member states (Poland, Czech Republic and Hungary) move around policy news (Castren, 2005); and lastly Kitsul et al. (2013) who find that RNDs assign considerably more mass to extreme outcomes (either deflation or high inflation) than do their time series counterparts.

The third stand is explaining risk premiums. This is represented by Dennis and Mayhew (2002) who discover that the skewness of the RND tends to be more negative for stocks that have larger betas, suggesting that options contain useful information about the market risk. Bliss and Panigirtzoglou (2004) directly estimate risk aversion using the RND by option prices. Malz (1997) finds higher moments explain currency excess returns much better than the CAPM. Similarly, Chen and Gwati (2013) also find that higher moments consistently explain subsequent currency excess returns for horizons between one week to twelve months. Nitteberg (2011) finds RNDs to be highly skewed and claim evidence of market sentiment in FX and Oil markets respectively. Breuer (2011) argues that the volatility of implied volatility are considered here as a proxy for the risk premium and studies how the volatility risk premium affect the informational content of currency options. Jurek and Xu (2014) study currency risk premiums by comparing RNDs with parametrically estimated currency dynamics and conclude that option-implied currency risk premiums provide an unbiased forecast of monthly currency excess returns. Similarly, Ait-Sahalia et al. (2001) who compare RNDs with historically estimated density functions and reject the hypothesis that the S&P 500 options are efficiently priced given the S&P 500 index dynamics.[2] Carr and Wu (2007) and Bakshi et al. (2008) find strong skewness in RNDs over time derive models to accommodate stochastic skewness and risk premiums.

Gabaix et al. (2016) uncover that since the Fall of 2008, “crash risk” has increased dramatically, implied by the FX options data. Motivated by Gabaix et al. and the literature, and furthermore the recent troubles in the Euro zone (since 2008), we use the EUR/USD exchange rate to study the information contents of its RNDs since the crisis.[3] We believe that the option implied RND can provide good insights, or even early warnings of the turbulences. In this paper, we study information contents of the risk-neutral densities (RND) implied by EUR–USD foreign currency (FX) option prices. The data cover the period from January 2, 2008 till March 18, 2015. For each day, prices of 40 options (5 moneyness levels and 8 maturities) are reported on Bloomberg. We discover the following: (1) the third and the fourth moments of the RND have a substantial explanatory power of FX swap spreads that represent term risk premiums, relative to the implied volatility; (2) the third and fourth moments of the RND can successfully predict catastrophic events (Lehman crisis, Flash Crash, and European sovereign crisis)[4]; (3) the third and the fourth moments of the RND can predict future FX rates well; (4) shorter term fourth moments (less than 3 months) are driven by speculative activities and yet longer term fourth moments (greater than 3 months) are driven by imports and exports; (5) higher order moments can predict the Economic Policy Uncertainty index and the USD influence index; and (6) fourth moments outperform third and second moments in predicting realized volatility.

Retrieving risk-neutral densities (RND) from option prices is a challenging exercise and has attracted a lot of attention, in that the number of options traded in the market place is finite and hence the RND is not uniquely defined. In the large body of literature, Britten-Jones and Neuberger (2000) and Jackwerth and Rubinstein (1996) are most related to our paper, yet our proposed RND method is simpler and faster in estimating model-free moments. Our next section shall briefly illustrate other popular methods and discuss the difference between our approach and the approaches of Britten-Jones and Neuberger (2000) and Jackwerth and Rubinstein (1996). Though seeking a methodology that can best retrieve information from option prices could be an interesting research topic on its own right, it is not the main focus of our paper. We have implemented the major popular methods in the literature for our empirical study as a robust check.[5]

There are literally an infinite number of ways to retrieve the RND (to be discussed in details in the next section). In this paper, we adopt a piece-wise flat RND that matches exactly the options traded in the marketplace. There are two advantages of using the piece-wise flat RND. First, it is shown empirically, when compared to more complicated methods, such RNDs are very stable over time. Second, the RND is a closed-form solution which is easy and fast to solve. Third, the number of options can vary from one maturity to another (a term structure of RNDs) and yet by construction all options are priced perfectly.

2. Methodology

The pioneer work of Breeden and Litzenberger (1978) demonstrates that the probability distribution of the price/return of an asset can be derived from its options (e.g. calls) by taking the derivative of the option price with respect to the strike price as follows:

$$F(S) = \frac{\partial C}{\partial K} \tag{1}$$

where C is the option (e.g. call), K is the strike, and $F(S)$ is the cumulative density function (c.d.f.) for the underlying asset S. In the case of the Black–Scholes model, Eq. (1) equals $N(d_2)$.[6] While a c.d.f. is all we need to price an option, it is more intuitive to write a p.d.f. (probability density function):

$$f(S) = \frac{\partial F(S)}{\partial K} \tag{2}$$

[2] Note that Ait-Sahalia and Lo (1998) have estimated density function via a stochastic discount function. This is not the same as taking differences in option prices (as in Breeden and Litzenberger (1978)) and belongs to a separate line of literature.

[3] Farhi and Gabaix (2016) relate rare disasters and exchange rate moves.

[4] In a broader measure, we use the VIX index to proxy rare events.

[5] The results are available upon request and we have a short discussion of these results.

[6] We assume that readers have good familiarity of the Black–Scholes model where $N(d_2)$ is the in-the-money probability of the European call option. In fact, within the option community, $N(d_1)$ (which is know as delta) and $N(d_2)$ are frequently used expressions.