



Anatomy of a meltdown: The risk neutral density for the S&P 500 in the fall of 2008[☆]

Justin Birru¹, Stephen Figlewski*

New York University Stern School of Business, 44 West 4th Street, Suite 9-160, New York, NY 10012-1126, United States

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Abstract

We examine the risk neutral probability density (RND) for the S&P 500 extracted from real-time bid and ask quotes for index options, under extreme market stress during the fall of 2008. The RND provides exceptional detail about investors' expectations as intraday volatility increased to a level five times higher than it had been two years earlier. Arbitrage keeps the mean of the RND closely tied to the market index, but its autocorrelation is very different. We also find a strong pattern in the RND's response to stock index movements: The middle portion amplifies the index change by more than 50% in some cases. This overshooting increased during the crisis and, surprisingly, was stronger in up moves than down moves.

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*Corresponding author. Tel.: +1 212 998 0712.

E-mail addresses: jbirru@stern.nyu.edu (J. Birru), sfiglews@stern.nyu.edu (S. Figlewski).

¹Tel.: +1 212 998 0345.

1. Introduction

The financial crisis that struck with fury in the fall of 2008 began in the credit market and particularly the market for mortgage-backed collateralized debt obligations in the summer of 2007. It did not have a visible impact on the stock market right away. In fact, U.S. stock prices hit their all-time high in October 2007, when the S&P 500 Index reached 1,576.09. Although it has since been determined that the economy entered a recession in December 2007, the S&P was still around 1,300 at the end of August 2008.

Over the next few months, it would fall more than 500 points, and would trade below 800 by mid-November 2008. The so-called “meltdown” of fall 2008 ushered in a period of extreme price volatility, and general economic uncertainty, such as had not been seen in the U.S. since the Great Depression of the 1930s. Not only were expectations about the future of the U.S. and the world economy both highly uncertain and highly volatile, the enormous financial losses sustained by investors sharply reduced their willingness, and their ability, to bear risk.

Risk attitudes and price expectations are both reflected in the prices of options and are encapsulated in the market’s “risk neutral” probability distribution. The risk neutral density (RND) is the market’s objective estimate of the probability distribution for the level of the stock index on option expiration date modified by investors’ risk aversion when the objective probabilities are incorporated into market option prices. In this paper, we examine how the RND was affected during this extraordinary period.

Thirty years ago, [Breedon and Litzenberger \(1978\)](#) showed how the RND could be extracted from the prices of options with a continuum of strikes. There are significant difficulties in adapting their theoretical result for use with option prices observed in the market. [Figlewski \(2009\)](#) reviews the pros and cons of common approaches and develops a methodology that performs well. We will apply it to an extraordinarily detailed dataset of real-time best bid and offer quotes in the consolidated national options market, which allows a very close look at the behavior of the RND, essentially in real-time.

This is one of the first studies of the “instantaneous” RND for the U.S. stock market and there are a number of interesting results, not just about the “meltdown” period. In periods of both high and low volatility, we find the RND to be strongly left-skewed, in sharp contrast to the lognormal density assumed in the Black-Scholes model. Also, to avoid profitable arbitrage between markets, the RND mean should equal the forward level of the index, and we find that they are very close to each other, even at the shortest time intervals during periods of extreme market disruption. However, the RND is always much more volatile than the forward index and it exhibits very strong negative autocorrelation. We explore several hypotheses that might help explain this seeming anomaly, and are able to eliminate some that are based in one way or another on bad data. We offer two potential explanations based on the process of marketmaking in options, which are consistent with the data, although we are not able to test them rigorously in this study.

The next section offers a brief review of the literature on using RNDs extracted from option prices to look at financial market events. [Section 3](#) gives an overview of the procedure for constructing RNDs. [Section 4](#) describes the real-time S&P 500 Index options data used in the analysis. In [Section 5](#), we present summary statistics that illustrate along several dimensions how sharply the behavior of the stock market changed in the fall of 2008, as reflected in the RND. In [Section 6](#), we look more closely at how the minute-to-minute changes in the different quantiles of the RND are related to fluctuations in the level of the stock market (the forward index). [Section 7](#) is a summary of our results. The

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