Greenspan Put

Sandeep Dahiya
Georgetown University, Washington, DC 20057, USA

Bardia Kamrad
Georgetown University, Washington, DC 20057, USA

Valerio Poti
University College Dublin, Dublin, Ireland

Akhtar Siddique
Office of the Comptroller of the Currency, Washington, DC, USA

Abstract
We use data from the options market to understand the impact of monetary policy on derivatives pricing. We document the existence of the Greenspan Put in the form of a decline in the price of out of the money puts when the Fed supports the markets via lower discount rates. Discount rate cuts did not have differential impacts on financial versus non-financial stocks. We also find that, when the "Greenspan Put" existed, out of the money calls were also more valuable.

Keywords: Volatility Skew Surface, Greenspan Put

Preliminary and Incomplete. Please, do not quote without permission.
March 2, 2017

The views expressed in this paper are those of the authors only and do not represent the views of the Comptroller of the Currency.

"It's official: there is a Greenspan put option. Yesterday's half a percentage point interest rate cut by the US Federal Reserve may not have been designed explicitly to bail out the stock market. But that is exactly what it is in danger of doing - especially since the cut came between official meetings, thereby heightening its impact"

The Financial Times, January 4, 2001

1 Introduction

Equity investors can protect themselves against a fall in value of their investment by purchasing put options. The prices of exchange traded put options (ETPO) reflect the cost of buying such insurance. A number of industry professionals believe that in the last two decades, equity investors have been able to reap the benefit of such a down-side protection without incurring the full cost of purchasing ETPOs. This belief is based on an assumption that the central banks will intervene to prevent a significant drop in equity values. The implicit back-stop guarantee against significant capital losses has become known as the "Greenspan Put"— a phrase that is sometimes attributed to Kim (2000) who used it to argue that the then-chairman of Federal Reserve Board, Allan Greenspan, will prop up the equity markets by lowering interest rates.[1] That action was undertaken in response to the large drop in the US equities markets after the collapse of the hedge fund Long-Term Capital Management (LTCM) and followed other cuts such as

[1]For examples of the association of the Greenspan Put with the LTCM episode, see the blog by Willem Buiter, former chief economist of the European Bank for Reconstruction and Development and external member of the Bank of England Monetary Policy Committee, at http://blogs.ft.com/maverecon/2008/04/the-greenspan-fed-a-tragedy-of-errors/#axzz416j5zITS

following the Black Monday Crash of 1987.[2] Ever since, it has been claimed frequently in the business press that a sudden and large drop in equity markets will draw a significant response (e.g. lowering of interest rates) from the central banks. Figure 1 illustrates how this phrase has entered the business lexicon. Not surprisingly, this phrase appeared in over 250 news stories in 2007 when the fear of large decline in equity markets became wide-spread.

In spite of the frequent reference to the "Greenspan Put" in the press, there exists no academic study that shows either its existence or its impact on capital markets. In this paper, we provide empirical evidence that this implicit down-side guarantee was widely priced in the capital market. We do this by focusing on the interaction between equity derivatives markets and Federal Reserve's monetary policy. The interpretation of the Greenspan Put is that investors need not fear a sudden loss of equity value as the actions of central banks will provide downside protection. Typically, investors who want to hedge themselves against a large drop in value of their investment can do so by buying a put option with a strike price which reflects their maximum acceptable loss bearing capacity. However, this strategy is expensive as it requires an up-front cash investment to pay for the put premiums. If, however, central banks intervene to prop up the stock market and the belief in central bank intervention is widely-shared, all equity investors get to enjoy the downside protection without paying for it. Thus, in effect, all equity investors have a cost-less (for the investors) "put" option. The empirical implications of an increasing faith in the "Greenspan Put" are fairly straightforward. The value of exchange traded equity put options should decline as the belief in the Greenspan Put grows and vice versa. In other words, time-series variation in the value of put options (after controlling for other factors) should reflect the evolution of "credibility" of the "Greenspan

[2] Reuters column dated October 19, 2012. http://blogs.reuters.com/james-saft/2012/10/19/black-monday-and-the-greenspan-put-james-saft/

Put".

Establishing the exact nature of implicit down side guarantee is an important issue. The first major implication is the rise of moral-hazard. Poole (2008), Rosenblum (2008) and Allen, et. al. (2015) discuss the role of moral hazard in the context of central bank supports to financial institutions. The former two, published in Federal Reserve outlets, reveal that policymakers paid attention even in the midst of the extraordinary monetary interventions carried out during the Crisis. The other big issue relates to distortions in prices. Quite a few studies have addressed how central banks should react to distortions in prices, particularly asset bubbles. Brunnermeier and Schnabel (2016) provide a survey of this larger literature. Fewer have looked at when central bank policies themselves can distort prices. Bhattacharya and Xu (2008) summarize many of the drivers of asset bubbles in the context of the rise in the US stock markets in the period 1996-2000.

More broadly, our paper falls in the literature on the interaction of monetary policy and the financial markets. Bernanke and Kuttner (2005) point out that, even though the ultimate objectives of Federal Reserve monetary policy are about macroeconomic variables like output, employment, and inflation, the more immediate impact of monetary policy actions are on the financial markets, such as equity markets, via changes in the value of the private wealth, cost of capital, etc. They also argue that, by affecting the asset prices and interest rates in these markets, policymakers aim to alter economic behavior. We analyze whether the Federal Reserve's monetary actions to reduce uncertainty can end up providing downside protection. While reducing uncertainty may be viewed as incontrovertibly positive, providing downside protections can give rise to concerns about moral hazard and asset bubbles. Nevertheless, it is conceivable that, in pursuing its mandates for "maximum employment, stable prices, and moderate long-term interest rates", the Federal Reserve ends up providing downside protection as a byproduct. Our empirical focus is on the time series variation in the volatility skew surface of equity options and its interaction with the Federal Reserve monetary policy.

The volatility skew surface is typically constructed using the Black-Scholes option pricing formula. However, as noted by [26], this implied volatility surface displays a distinct curvature across "moneyness" (ratio of strike price to the closing stock price) and the time to expiration. This is referred to as the Volatility Skew (hereafter VOLSKEW). Because of its shape, this is also sometimes referred to as the volatility smile. For short-dated expiration options, the cross-section of implied volatilities as a function of strike price is roughly U-shaped. Generally this U-shape becomes flatter for longer maturities. Various causes such as leverage effect ([27]), risk aversion ([5]), negative volatility risk premium ([5]), and asymmetries or skewness in the underlying distributions ([9]) have been cited as the reason for the existence of the volatility skew.

This feature is illustrated in the two panels of Figure 2, which show the volatility smile surfaces constructed from the closing market prices of out of the money calls and out of the money puts on American Express on two dates: September 6, 2006 and September 5, 2007.[3] The x-axis shows the "moneyness" of the option in terms of ratio of strike price to the closing stock price of America Express scaled by 100. Thus, an option that is exactly at the money has a moneyness ratio of 100. As discussed above, the deep V shaped edge of the surface shows how volatility implied by the Black-Scholes formula increases rapidly as the option becomes more out of the money. For example, on September 6, 2006, an at-the-money call or put option with 11 days left to maturity has an implied annualized volatility of 15.49%. For the same maturity an out of the money put option with a moneyness of 50% has an implied volatility of 43.85%. For the same maturity of 11 days, an out

[3]The surface to the left of the at-the-money volatility is constructed using out of the money puts and to the right is constructed using out of the money calls.

of the money call option with a moneyness of 150% has an implied volatility of 45.05%. Thus, a drop or rise of moneyness by half causes the implied volatility to rise by about 3 times.

Not only does the implied volatility of the same underlying asset changes as the moneyness of the option changes, the resulting implied volatility surface itself buckles and heaves through time. This time series variation in the volskew surface, for options on indices and individual equities, has also been well documented. This is best illustrated by comparing the volatility surfaces on the two dates in Figure 2. Both show the implied volatility surface for the same underlying asset (American Express common stock), albeit one year apart. The contours of the volatility surface are considerably different across the two figures. Both the implications of and reasons for these changes have been studied in the literature. For example, Bates (1991) documented that the out-of-the-money index puts became especially expensive in the year leading up to the October 1987 crash. Bakshi, Kapadia and Madan (2003) explain the presence and evolution of riskneutral skewness over time and in the cross section of individual stocks via the impact of risk aversion on the skewness of the risk neutral density.

To our knowledge, our paper is the first to investigate whether a "Greenspan Put" existed in the form of having lower traded equity put prices when the Federal Reserve provided support to the financial markets with lower interest rates.[4] A corollary is whether, with Fed Support, traded calls are more valuable, i.e. whether the "Greenspan Put" also had an impact on the upside.

Another question that we explore is whether the Greenspan Put has declined or disappeared as a result of the Great Recession of 2007-2009 and the legal and regulatory reforms in its aftermath. Many commentators in the Press appear to think this is the case.[5] Many of the elements of the

[4]There have been studies such Miller, Weller, Zhang (2002) that have investigated whether the market risk premium is lower as a result of the Greenspan Put.

[5]Bloomberg article "Yellen Leaves Greenspan 'Put Behind as She Charts Rate

Dodd-Frank Act in the US were designed to reduce moral hazard and the probability of government support.[6]

Finally, we also investigate whether the responsiveness of the implied volatility surface to stock market moves has changed in the aftermath of the Great Recession. There has been evidence (such as in Whaley 2000) of a statistically significant negative relationship between stock returns and implied volatility, particularly for stock indices: positive stock index returns lead to decreased implied volatility levels, while negative returns lead to higher implied volatility levels. However, the relationship between the stock returns and options likely also will depend on the possibility of Central Bank intervention.

Central banks are not passive institutions that spring into action only sporadically. There is a wide variety of actions and pronouncements that central banks undertake regularly. Any empirical strategy that seeks to examine the "intervention" of a central bank needs to define which of the many actions and/or announcement constitute "interventions" while the others are "routine". We employ the "Taylor Rule", a widely discussed model for predicting and guiding rate setting by Federal Reserve Board to identify non-routine interventions.[7] Our results depend on the assumption that Taylor Rule is a reasonable guide as to how Central Banks should behave. Therefore, deviations from the Taylor Rule are indicators of interventions into the market

Increase" http://www.bloomberg.com/news/articles/2015-01-15/yellen-leaves-greenspan-put-behind-as-she-charts-rate-increase.

[6]The Dodd Frank Act, particularly its title II, has explicitly been written "to promote the financial stability of the United States by improving accountability and transparency in the financial system, to end 'too big to fail, [and] to protect the American taxpayer by ending bailouts."

[7]As an example, in a Federal Open Market Committee meeting, then Governor Yellen commented "John Taylor, a Stanford professor who was a member of the Council of Economic Advisers, devised a very simple monetary policy rule that I look at to provide a rough sense of whether or not the funds rate is at a reasonable level." FOMC Transcripts, January 31-February 1, 1995, page 101.

place and are considered as such by equity investors.

Therefore, when central banks follow the Taylor Rule, we view them as *not* intervening. In contrast, when the Central banks deviate from the Taylor Rule, it is an indication of intervention. The value or credibility of the "Greenspan Put" relates to the possibility of Central Bank actions to enhance financial stability increasing moral hazard. It is also important to note that the credibility of the "Greenspan Put" depends on both the willingness and ability to intervene on the part of the central bank.

As an empirical strategy our objective, in part, is to study the sensitivity of the value of traded put options to the "credibility" of the Greenspan put in terms of likelihood of central bank intervention. While the put option prices are observable, the credibility of intervention by the central bank has to be inferred. We construct a proxy to measure the likelihood (i.e. credibility) that the Federal Reserve will intervene to support the financial market. The proxy measures the absolute (as opposed to percentage) deviation of the effective Fed Funds rate from the "Target Rate" as estimated by the Taylor Rule. The basic Taylor Rule suggests the following expression for the Fed Funds rate policy.

$$i = r^* + \pi + 0.5\,(\pi - \pi^*) + 0.5\,(y - y^*) \tag{1}$$

where

$$\begin{aligned} i &= \text{nominal fed funds rate} \\ r^* &= \text{target real federal funds rate(2\%)} \\ \pi &= \text{inflation rate} \\ \pi^* &= \text{target inflation rate} \\ y &= \text{logarithm of real output} \\ y^* &= \text{logarithm of potential output} \end{aligned} \tag{2}$$

Here we assume a 2% inflation target.

Our results show that out of the money equity puts are significantly less expensive when the Federal Reserve provides support in the form of a lower Fed Funds rate compared to what would be appropriate under the Taylor Rule.

Concurrent with the Greenspan Put, we also find evidence that out of the money calls being were more valuable. One interpretation is that, by reducing downside risk, Fed support also increased the upside, i.e. a promotion of an asset bubble.

We then also study the financial and non-financial equity options separately. We find that providing a lower Fed funds rate did not have significantly different impacts on financial versus non-financial equity options.

2 Data

Our daily option implied data comes from the Option Metrics Ivy DB database. OptionMetrics compiles the IvyDB data from raw 3:59PM EST price information provided by Spryware, LLC. The standardized option prices and implied volatilities in the database are calculated using linear interpolation from the Volatility Surface file. First, for each option expiry date, the forward price of the underlying security is calculated using the zero curve. Next, the volatility surface points are linearly interpolated to the forward price and the target expiration, to generate an at-the-money-forward implied volatility surface. The volatility surface is constructed using a kernel-smoothing technique without relying on forward-looking information.[8]

We firstly use index options, the S&P100 (OEX on CBOE) and the S&P500 (SPX). The period covered by the index options is from January

[8]A very large number of studies in finance and accounting have relied on this options data. An, Ang, Bali, and Cakici (2014), Boyer and Vorkink (2014) and Barraclough and Whaley (2012) are some such studies.

4, 1996 to August 31, 2014. We also use individual (single name) equity options. The individual stock options data cover August 31, 2000 to September 1, 2014. We combine the options data with stock prices from CRSP. We then reconstruct the volatility surface using a cubic spline.[9] We consider weekly observations for analyzing the impact over longer time periods.

For the weekly analysis, we take the observations every Wednesday. We consider options with maturities under 100 days, i.e. short dated options because of liquidity considerations.[10] We consider the constituents of the S&P100 index. There have been 187 equities that have been among the 100 constituents of the index over the period January 2000 to September 2014. After matching and merging, we are left with 140 individual equities over this period. These add up to 88461 weekly observations on the individual equity options and the cash markets.

We obtain the weekly effective Fed funds rate from the Federal Reserve website. This is the H15 series. The data for computing the target Fed Funds rate according to the Taylor rule was obtained from Ben Bernankes website at http://www.brookings.edu/ /media/Blogs/Ben-Bernanke/2015/04/Taylor-Rule-data.xlsx?la=en. This contains the data on real GDP, PCE Inflation. Over this period there have been 35 cuts in the Federal Funds rate.

We also considered the 20 constituents of the Major Market Index (MMI) as a robustness check.

[9]The applied computational finance literature suggests several interpolations for the surface with spline interpolations suggested as the simplest and most widely used. See for example, Alexander, C. *Market Models: A Guide to Financial Data Analysis*

[10]We constructed the relative spread by maturity for all the options in the OEX and find that it drops as maturity increases from 30 days to 180 days.

3 Results

3.1. Variation in Fed discount rates

Figure 3 plots the effective Fed Funds rate over the period from the fourth quarter of 1996 to the end of 2014, along with what it should be under the Taylor Rule. It illustrates the significant variation in the Federal funds rate. The shaded areas mark the periods when the the effective Federal Funds rate was below what the Taylor Rule suggests.

3.2. Federal Reserve actions and equity derivatives

Over the period covered by our data, there were 362 weeks when the Federal Funds rate was above the Taylor Rule guidance versus the 596 weeks when the Federal Funds rate was below the Taylor Rule guidance.[11]

First, we compare the at-the-money volatilities for index options between the weeks when the Fed Funds rate was below the Taylor Rule guidance versus those weeks when the Fed Funds rate was above the Taylor Rule guidance. These results are presented in table 1 and 2, where we compare both the mean and median ATM volatilties. In terms of the volatility surface, this is comparing the bottom of the V. For both the S&P500 and S&P100, the mean at-the-money volatilities are significantly lower for the weeks when Fed Funds are below Taylor Rule guidance for longer maturities. We also compute the medians for the two regimes, and test if those medians are different. Using the standardized Wilcoxon test, we reject that the medians are the same. We also carry out non-parametric 2 sample Kolmogorov-Smirnov test to compare the distributions of the at-the-money volatilities and find that the differences are significant at the 1% level. The differences increase over the maturity of the options and are much more pronounced for the S&P100 as opposed to

[11]For the single name options, the corresponding numbers are 327 and 466.

the S&P500. These results confirm our belief that Federal Reserve support reduces uncertainty and lowers volatility.

3.3. Appearance of the Greenspan Put

Our next step, moving beyond the at-the-money volatilities, is to assess whether the VOLSKEW surface is different when the Federal Reserve sets the Fed Funds rate below Taylor Rule guidance versus when it does not. This requires analyzing out of the money volatilities.

We begin with a few illustrations of the impact of the Federal Reserves Federal Funds rate varying from the Taylor Rule. Figure 4 shows the volatility smile on the S&P100 (OEX) for two dates at 31 days to maturity: October 23, 2002 and January 15, 2003. On October 23, 2002 the Fed Funds rate was below what the Taylor Rule suggests. In contrast, on January 15, 2003, the Fed Funds rate was above what the Taylor Rule suggests.[12]

The figure fits our prior beliefs that with the Greenspan Put present, traded puts have lower implied volatilities (i.e. are less valuable.) For example, at 50% moneyness, the implied volatility was 0.55 on October 23, 2002 versus 0.75 for the January 25, 2003

However, a comparison between two weeks explicitly chosen to illustrate a feature is not the same as a statistical test. Therefore, we average the volatility surface to maturity for the 362 weeks when the Federal Funds rate was above the Taylor Rule guidance versus the 596 weeks when the Federal Funds rate was below the Taylor Rule guidance. The resulting surfaces for the puts, with expiration over 10 days and moneyness at 90% or less are plotted in figure 6 for options on the S&P100 and in figure 7 for the options on the S&P500. The surfaces do look apart from each other, though the difference is much greater for the S&P100 compared to the S&P500.

[12]the two dates are chosen in close proximity so that other factors that drive movement in the volatility surface do not change significantly.

3.C.1 Distance between surfaces with and without Fed Support

Moving beyond graphical illustration, we quantify and statistically assess the differences between the volatility skew surfaces with and without Fed support using a variety of methods. First, We compute distance measures between the volatility surfaces with and without Fed support. We choose three such measures, also referred to as similarity metrics, namely the Chebyshev, Minkowski (with $p = 4$), and Mahalanobis with the outer product of the means as the weighting matrix. The Minkowski distance is the generalized p-Norm distance i.e. $(\sum_i^n |x_i - y_i|^p)^{\frac{1}{p}}$. The Chebyshev distance is defined as the L_∞ norm of the difference between two n-dimensional objects, i.e. $\underset{i}{Max} |x_i - y_i|$. The Mahalanobis distance is defined as $\sqrt{(\mathbf{x} - \mathbf{y})^T S^{-1} (\mathbf{x} - \mathbf{y})}$ where S is the variance-covariance matrix. These metrics are commonly used in the natural sciences as well as computer science and do not rely on distributional or parametric assumptions. These have been used for purposes as varied as face recognition in computer science, species differentiation in biology, assays in chemistry, and astronomy to compute distances between objects in finite dimensional spaces.[13] The distance metrics are widely used in settings where there is a need to compare objects with multiple dimensions or attributes, The Mahalanobis distance was initially developed to analyze and classify human skulls into groups, based on various properties.

As an example, several commonly used algorithms in face recognition reduce the multidimensional measurement data on a face to a set of principal components. Distance measures then can be computed between the principal components on a pair of faces to see if they match. In most of these applications, formal statistical testing has not been a primary focus. In finance, Chow, et. al. (1999) and Kritzman and Li (2010) have used the Mahalanobis distance to measure financial turbulence i.e. outliers from a normal period.

[13]See for example, DeMaesschalck, Jouan-Rimbaud, and Massart (2000) and Xiang, Nie and Zhang (2008).

They define outliers as more than a single standard deviation from the average. A distance of zero implies that the two objects are identical whereas a positive distance implies a difference.

Given our desire to assess the statistical significance of these metrics, we follow a bootstrap based strategy. We boostrap the standard errors of the Mahalanobis distance.[14]

The volatility surface plots implied volatility as a function of moneyness (delta) and time to expiration (maturity). We compute the volatility surface as a function of moneyness on ten different days to maturity (11, 21, 31, 41, 51, 61, 71, 81, and 91), i.e. compute ten separate curves and measure the distances between the surfaces with Fed Support and without Fed support for these ten curves separately.

For each of these ten curves, implied volatility is computed for nine equally spaced strike prices, as a function of moneyness ranging from 50% to 90%. We repeat this process each week for the 946 weeks over our sample period. We then compare the average of these curves at each moneyness level for the 368 weeks when the Fed Funds rate was at or below what the Taylor Rule suggests [i.e. Fed Support for the Markets] versus for average for the 578 weeks when the Fed Funds rate was above what the Taylor Rule suggests [i.e. No Fed Support for the Markets]. The two sets of averages (two 1×9 vectors for each day to maturity) are compared using the Chebyshev, Minkowski (with a $p = 4$) and Mahalonobis metrics. That is, for each maturity, we measure the distance between the weeks with Fed Support and without Fed

[14] Efron and Tibshirani (1986) provide a review of how standard errors can be computed using a bootstrap. One standard choice for an approximating distribution is the empirical distribution function of the observed data. Assuming that the a set of observations come from an independently and identically distributed population, the empirical distribution function can be constructed by constructing a number of resamples with replacement, of the observed dataset (and of equal size to the observed dataset) The statistic of interest, such as the Mahalanobis distance, is constructed for each of the resamples. The distribution of the resampled statistic is then used to compute the standard error.

support at each moneyness level.

Table 3 presents the distances between the average volatility surfaces with Fed Support versus without for the OEX and the SPX. The results show that the implied volatility for the surface with Fed Support is significantly different versus when there is no Fed Support. The difference is much greater for the OEX (S&P100) than for the SPX (S&P500).

We then bootstrap the distribution of the Mahalanobis distance for each of the expirations. Table 4 presents those results. The distances are again much less for the S&P500 than for the S&P100. But they are all significant.

3.C.2 Statistical tests of differences between surfaces with and without Fed Support

Next, we use conventional statistical tests to compare the surfaces. For the S&P500 at 50% moneyness, the average implied volatility with Fed Funds rate below the Taylor Rule is 0.72 versus 0.76 for when the Fed Funds rate is above the Taylor Rule. For the S&P500 at 50% moneyness, the average implied volatility with Fed Funds rate below the Taylor Rule is 0.73 versus 0.76 for when the Fed Funds rate is above the Taylor Rule. These differences at 50% moneyness are significant at the 5% significance level using a simple Cochrans t-test. Therefore, on the average when the Federal Reserve sets the Fed Funds rate below what Taylor Rule guides, out of the money puts are significantly lower in price than when the Federal Reserve sets the Fed Funds rate at or above the Taylor Rule guidance. Interestingly, when the Fed Funds rate is below the Taylor Rule guidance, out of the money calls are more expensive compared to when the Fed Funds rate is above the Fed funds rate. This holds true for options on both the S&P100 and S&P500. These results suggest that, when the Federal Funds rate is below the Taylor Rule Guidance (i.e. the Fed supports the markets), the volatility surface is different from when the Fed does not support the market. These results are supportive of the existence of a Greenspan Put in the equity derivatives markets, in that they suggest that the volatility surface smirk (i.e., the difference between OTM put and cal volatility) is less pronounced when Fed support is more plentiful. Table 5 present the results of such t-tests at different levels of moneyness.

It is remarkable that the presence of the Greenspan Put is detectable even by such a simple analysis. Because the Fed, to support the market, must intervene at times of market stress, it is reasonable to expect the effect of such intervention to be obscured by some reverse causality. In other words, to proof of the existence of the Greenspan Put in equity markets requires both that the Fed provides support at times of market stress and that the market is less stressed than it would be without support. In our context, this requires that the volatility skewness surface has less of a smirk as a consequence of Fed support, though such support comes at the time when the smirk is pronounced because of market stress. Hence, the true reduction of the smirk is likely higher than the one revealed by the simple difference of prices of OTM options with and without Fed support.

Our final comparison involves out of the money puts at all the expirations and all the moneyness levels jointly. We carry out a comparison of multiple means, comparing implied volatility with Federal Reserve support versus without. This test needs to account for the correlation between implied volatility on the surface for points with the same expiration and moneyness. Such a test is effectively the "combined" version of table 5, i.e. replacing the eleven t-tests with a single test. We rely upon the multivariate t-test with Bonferroni adjustment and find that the overall difference is significant at 0.001 level for the SPX (S&P500) and OEX (S&P100). For the SPX, the average implied volatility is 0.488 with Federal Reserve support and an average of 0.402 without support. The corresponding estimates are 0.441 and 0.576 for the OEX.

A different way to view the impact of the Fed support on the markets is to compare the implied risk neutral probability distribution functions for the underlying asset when the Federal Reserve supports the markets to when the Federal Reserve does not. Many studies such as Melick and Thomas (1997) have investigated the probability density function implied by option prices. Figure 8 presents the probability density functions when the Federal Reserve supports the markets versus when it does not. The figure supports the belief that there is a rightward shift in the probabilities.

3.4. Estimates of how much the VolSkew surface changed as a result of a cut in Fed Funds rate

Whilst measures of distance are useful for assessing the impact of Federal Reserve policy, they do not formally show whether out of the money options become more or less expensive as a result of such actions. A potentially significant confounding effect is the impact on the at-the money volatilities. To account for this confounding effect, we focus on the slope of the VOLSKEW surface. We expect the slope to change in response to Federal Reserve providing support to the markets or not.

Therefore, we regress the implied volatilities on a dummy that indicates whether there was Federal Reserve support or not. We estimate

$$\sigma_{Put} = \alpha_{put} + \beta_{put} Moneyness + \gamma_{put} Expiration + \delta_{put} I_{FedSupport}$$

where $I_{FedSupport}$ represents periods when there was the Federal Funds rate was below Taylor Rule Guidance. The objective is to estimate the difference between the surfaces of the put halves of the volatility surface in 6 for options on the S&P100 and in figure 7 for options on the S&P500. We expect β_{put} to be negative.

If the out of the money puts become less expensive relative to at the money options, β_{put} should become less negative. Given our hypothesis, we expect with the Federal Reserve Support, we expect β_{put} to become less negative. Therefore, We expect δ_{put} to be negative.[15]

We use weekly data for 946 weeks over Jan 4, 1996 to Aug 31, 2014, using the entire volatility surface each week. The surface each week has implied volatility across grid of 11 days to maturity i.e. expiration (1, 11, 21, 31, 41, 51, 61, 71, 81, 91 days) and 31 points on moneyness ranging from 50% to 100%, i.e. 341 observations on implied volatility each week. Over the period January 4, 1996 to August 31, 2014, there have been 596 weeks when the Federal Funds rate was below the Taylor Rule guidance and 362 weeks when the Federal Funds rate was above the Taylor Rule guidance. Table 6 compares the results from the comparison of the VOLSKEW surfaces for the two regimes for options on the S&P500 (SPX) and S&P100 (OEX.) For the SPX puts, δ is significant at 1% level with an estimate of -1.475. For the OEX the estimates are -12.501. This means that with Fed Support, the out of the money puts become 12.5% less expensive.

The magnitudes of the difference are consistent with what we see in figures 6 for options on the S&P100 and in figure 7 for options on the S&P500. This can be interpreted to mean that out of the money puts are significantly less valuable when the Federal Reserve provides support to the markets versus when they do not.[16]

[15]For robustness purposes we have also carried out other permutations such as comparing the slopes for the periods with Fed Support and without separately and then comparing the two sets of slopes. We have also computed quadratic forms of Moneyness as well

[16]The differences between the S&P100 and the S&P500 are surprising at first glance. However, several studies have found that significant differences exist between the two index options.

3.5. What happened to the calls when the Greenspan Put appeared

We find that when the Federal Reserve supports the markets, along with the Greenspan Put, there is also a shift in the calls. Looking at table 7, we see that for both the S&P500 and S&P100, out of the money calls are significantly more valuable at each moneyness.

Bernanke and Kuttner (2005) showed that stock "market reacts fairly strongly to surprise funds rate changes." They estimated that with each 25 basis point surprise cut in the Fed Funds rate, the value-weighted CRSP index gained 1% in a day. They found that the market reacted, little if at all, to Fed funds rate cuts that were anticipated.

In our work, without distinguishing between anticipated and surprise cuts, we find that the impact is most significant for deep out of the money calls. For the S&P500, at a 150% moneyness, the implied volatility with Fed support is 0.516 versus 0.387 without Fed support. Assuming a normal distribution and 90 days to maturity, that implies that with Fed Support, the S&P500 could rise by an annualized rate of 17.88%. Whereas without Fed support, the same growth rate is only 13.40%.

We then estimate if the surfaces on the call side are significantly shifted by Federal Reserve support. As we had estimated for puts, we regress the implied volatilities on a dummy that indicates whether there was Federal Reserve support or not. We estimate

$$\sigma_{Call} = \alpha_{Call} + \beta_{call} Moneyness + \gamma_{call} Expiration + \delta_{Call} I_{FedSupport}$$

where $I_{FedSupport}$ represents periods when there was the Federal Funds rate was below Taylor Rule Guidance. The objective is to estimate the steepness of the slope of the call half of the volatility surface. We expect $\beta_{call}^{Expiration^i}$ to be positive.

If the out of the money calls become more (or less) expensive relative to at the money options, β_{call} should become more (or less) positive. We therefore expect $\delta call$ to be positive.

We use weekly data for 946 weeks over Jan 4, 1996 to Aug 31, 2014, using the entire volatility surface each week. The surface each week has implied volatility across grid of 11 days to maturity i.e. expiration (1, 11, 21, 31, 41, 51, 61, 71, 81, 91 days) and 31 points on moneyness ranging from 100% to 200%, i.e. 341 observations on implied volatility each week. Over the period January 4, 1996 to August 31, 2014, there have been 596 weeks when the Federal Funds rate was below the Taylor Rule guidance and 362 weeks when the Federal Funds rate was above the Taylor Rule guidance.

8 presents the results of these regressions. As hypothesized, we do find that calls are significantly more valuable with Fed support. δ is 13.423 for the S&P500. For the S&P100 it is 25.961.

Finally we construct the implied risk neutral probability distribution functions from calls for the underlying asset when the Federal Reserve supports the markets to when the Federal Reserve does not. Similar to the case for puts, figure 9 shows that the probability density function has a rightward shift when the Federal Reserve supports the markets versus when it does not.

3.6. Greenspan Put and individual equity options

Our next analysis is of the individual equity options. Individual options (single name options in professional parlance) are useful for our ability to ascertain if Federal Reserve's monetary policies have had differential impacts on financial and non-financial sectors. As before, we compute the surface each week and obtain 88461 weekly estimates of the slopes on the put half and the call half and summary measures such as the at-the money volatility for different expirations. The slopes are estimated from the following specification:

$$\begin{aligned}
\sigma_{Put} &= \alpha_{put} + \beta_{put} MoneyNess + \gamma_{put} MoneyNess^2 + \xi_{put} Expiration \\
\sigma_{Call} &= \alpha_{Call} + \beta_{Call} MoneyNess + \gamma_{Call} MoneyNess^2 + \xi_{Call} Expiration
\end{aligned}$$

As one would expect, the slope on puts is generally negative whereas the slope on calls is generally positive. This is because out of the money puts and out of the money calls are more expensive than at the money puts and calls.

Table 9 presents the results for the parameter estimates. As can be seen, when the Fed Funds rate is below the Taylor Rule guidance, at-the money volatilities are significantly lower. The slope of the put half of the VOLSKEW surface is flatter as evidenced by the significantly lower β_{put}. On the other hand, the slope of the call half is steeper as evidenced by the significantly higher β_{call}. We conduct F-test on the difference of the means as well as a median test of the differences. We also conduct the tests separately on the options on financial stocks (S&P Economic sector 800) versus the rest. These are aggregate tests without differentiating stock by stock.

We also test these difference stock by stock. We conduct two separate tests. The first is a two-sample median test and the second one is an asymptotic Kolmogorov-Smirnov test. The results in this case not as stark as for the aggregate case. Out of the 187 components of the OEX, 132 have been traded both when the Federal Funds Rate was below the Taylor Rule guidance and above the guidance. For 98 of the stocks, the difference in the put half of the surface is significant at least for the 10% significance level whereas for 114 of the stocks the difference is significant for the call half of the surface. For the at-the-money volatilities, the difference is significant for almost all the stocks, with the volatilities being lower when the Federal Funds rate is below the Taylor Rule guidance.

3.7. Greenspan Put After the Great Recession

We next analyze the impact of the Great Recession on how Fed Support affects the VOLSKEW surface. We estimate a dummy for Fed Support as well as an interaction term for whether the impact of Fed Support has changed after 2008.

$$
\begin{aligned}
\sigma_{Put} &= \alpha_{put} + \beta_{put} Moneyness + \gamma_{put} Expiration + \delta_{put} I_{FedSupport} \\
&\quad + \nu_{put} I_{Recession} + \eta_{put} I_{FedSupport} \times I_{Recession} \\
\sigma_{call} &= \alpha_{call} + \beta_{call} Moneyness + \gamma_{call} Expiration + \delta_{call} I_{FedSupport} \\
&\quad + \nu_{call} I_{Recession} + \eta_{call} I_{FedSupport} \times I_{Recession}
\end{aligned}
$$

where $I_{FedSupport}$ represents periods when there was the Federal Funds rate was below Taylor Rule Guidance.where $I_{FedSupport}$ and $I_{Recession}$ respectively represent periods when there was the Federal Funds rate was below Taylor Rule Guidance and post 2008.

As before we expect δ_{Put} to be negative and δ_{Call} to be positive. If we conjecture the impact to Fed Support to have declined after 2008, then ν_{Put} should be positive and ν_{Call} should be negative. In other words, after the Great Recession, out of the money puts will be more valuable and out of the money calls less valuable with Fed Support than before the Great Recession. Table 10 presents the results with the S&P100 and S&P500 Index options. The results are mixed.

4 Implications for Public Policy

Our results provide a retrospective view, and to our knowledge, the first quantification of what the Greenspan Put was when the Federal Reserve kept the Fed Funds below what the Taylor Rule suggests. In contrast, we do not find a significant evidence of the Greenspan existing after the Great

Recession. This is also the period with Quantitative Easing. Our results suggest, but do not prove, that the Great Recession has substantially reduced the market's expectations of protection against downside risk. We are not able to deduce whether this decline is because of historically low discount rates or because the market's expectations have been permanently altered, such as the so-called Yellen call.

5 Conclusions

Using data from the equity derivatives markets on index options as well as individual equities, we analyze how Federal Reserve monetary policy both before and after the Great Recession affected the pricing of the derivatives. Our premise is that out of the money puts traded in the market are less valuable (and out of the money calls are more valuable) if the market believes that the Federal Reserve is supporting the markets. This is the so called Greenspan Put. We find that before the Great Recession, the value of the Greenspan Put was greater when the Federal Reserve supported the markets. In contrast, the value of the Greenspan put has declined substantially after the Great Recession. In investigating alternative explanations, we find that announcement effects show significant declines of volatility, but do not explain the Greenspan Put.

References

[1] Alexander, C. 2001, *Market Models: A Guide to Financial Data Analysis*, Wiley, London. United Kingdom.

[2] Allen, F., C. 2015, Moral Hazard and Government Guarantees in the Banking Industry, *Journal of Financial Regulation*, 1(1), 1-21.

[3] An, B-J, Ang, A. Bali, T, Cakici, N., 2014, The Joint Cross Section of Stocks and Options, *Journal of Finance,* 59 (5), 2279-2337.

[4] Asso, P-F, G. Kahn, R. Leeson, 2010, The Taylor Rule and the Practice of Central Banking, Research Working Paper, Federal Reserve Bank of Kansas City,

[5] Bakshi, G., and N. Kapadia. 2003. Delta-Hedged Gains and the Negative Market Volatility Risk Premium. *Review of Financial Studies* 16 (2):527-566.

[6] Bakshi, G., N. Kapadia, and D. Madan. 2003. Stock Return Characteristics, Skew Laws, and the Differential Pricing of In dividual Equity Options. *Review of Financial Studies,* 16 (1):101-143.

[7] Barraclough, K. and R. Whaley, 2012, Early Exercise of Put Options on Stocks, *Journal of Finance,* 67, 14231456.

[8] Bates, D. S. 1991. The Crash of '87: Was It Expected? The Evidence from Options Markets. *Journal of Finance* 46 (3):1009-1044.

[9] Bates, D. S. 2000. Post-'87 Crash Fears in the S&p 500 Futures Option Market. *Journal of Econometrics*, 94 (1-2):181-238.

[10] Bernanke, B., and K. Kuttner. 2005. What Explains the Stock Market's Reaction to Federal Reserve Policy? *Journal of Finance*, 60 (3), 12211257.

[11] Bhattacharya, U. and X. Yu. 2008. The Causes and Consequences of Recent Financial Market Bubbles *Review of Financial Studies,* 21 (1), 3-10

[12] Blackburn, D, and A. Ukhov, 2006, Estimating Preferences Toward Risk: Evidence From Dow Jones, Working paper, Indiana University.

[13] Boyer, B., and K. Vorkink, 2014, Stock Options as Lotteries, *Journal of Finance,* 69, 14851527.

[14] Brunnermeier, M., and I. Schnabel, 2016. *Bubbles and Central Banks: Historical Perspectives. Central Banks at a Crossroads: What Can We Learn from History?* Cambridge, UK: Cambridge University Press, 2016. Web.

[15] Chow, G., E. Jacquier, K. Lowrey, and M. Kritzman. 1999. Optimal Portfolios in Good Times and Bad. *Financial Analysts Journal*, 55, (3) (May/June):6573.

[16] DeMaesschalck, R., D. Jouan-Rimbaud, D.L. Massart, 2000, The Mahalanobis distance, *Chemometrics and Intelligent Laboratory Systems*, 50, 1-18.

[17] Efron, B. and R. Tibshirani, 1986, Bootstrap Methods for Standard Errors, Confidence Intervals, and Other Measures of Statistical Accuracy, Statistical Science, 1, 54-75.

[18] Gagnon, J., M. Raskin, J. Remache, B. Sack, 2010, Large-Scale Asset Purchases by the Federal Reserve: Did They Work? Federal Reserve Bank of New York, Staff Report.

[19] Kritzman, M., and Y. Li, 2010. Skulls, financial turbulence, and risk management. *Financial Analysts Journal*, 66, 30-41. http://dx.doi.org/10.2469/faj.v66.n5.3.

[20] Melick, W., and C. Thomas. 1997. Recovering an Assets Implied PDF from Option Prices: An Application to Crude Oil During the Gulf Crisis. *Journal of Financial and Quantitative Analysis*, 32, 91-115.

[21] Miller, M., P. Weller, L. Zhang, 2002, Moral Hazard and the U.S. Stock Market: Analyzing the Greenspan Put? *Economic Journal*, 112, C171-C186.

[22] Nagai, T., H. Takahiro, and K. Uchikawa, 2011, Statistical Significance Testing with Mahalanobis Distance for Thresholds Estimated from Constant Stimuli Method, *Seeing and Perceiving*, 24 (2), 91 124.

[23] Pèrignon, C. and C. Villa, 2002, Extracting Information from Options Markets: Smiles, State-price Densities and Risk-Aversion

[24] Poole, W., 2008, Market Bailouts and the Fed Put, *Federal Reserve Bank of St. Louis Review*, March/April 2008, 90 (2), pp. 65-73.

[25] Rosenblum, H., D. DiMartino, J. Renier, R. Alm, 2008, Fed Intervention: Managing Moral Hazard in Financial Crises, *Federal Reserve Bank of Dallas Economic Letter* October 2008, 3 (10), pp. 1-12.

[26] Rubenstein, M., 1994, Implied Binomial Trees, *Journal of Finance*, 49, 771-818.

[27] Toft, K. B., and B. Prucyk, 1997, Options on leveraged equity:theory and empirical tests, *Journal of Finance*, 52, 1151-1180.

[28] Whaley, R.E., 2000, The investor fear gauge, *Journal of Portfolio Management*, 26, 1217.

[29] Shiming, X., F. Nie and C. Zhang, 2008, Learning a Mahalanobis distance metric for data clustering and classification, *Pattern Recognition*, 41, 3600-3612.

Figure 1: **Number of News Stories about ”The Greenspan Put”**

The figure is provides the year by year count of news stories that mention the phrase ”the Greenspan put”. The source for the data is Factiva news source.

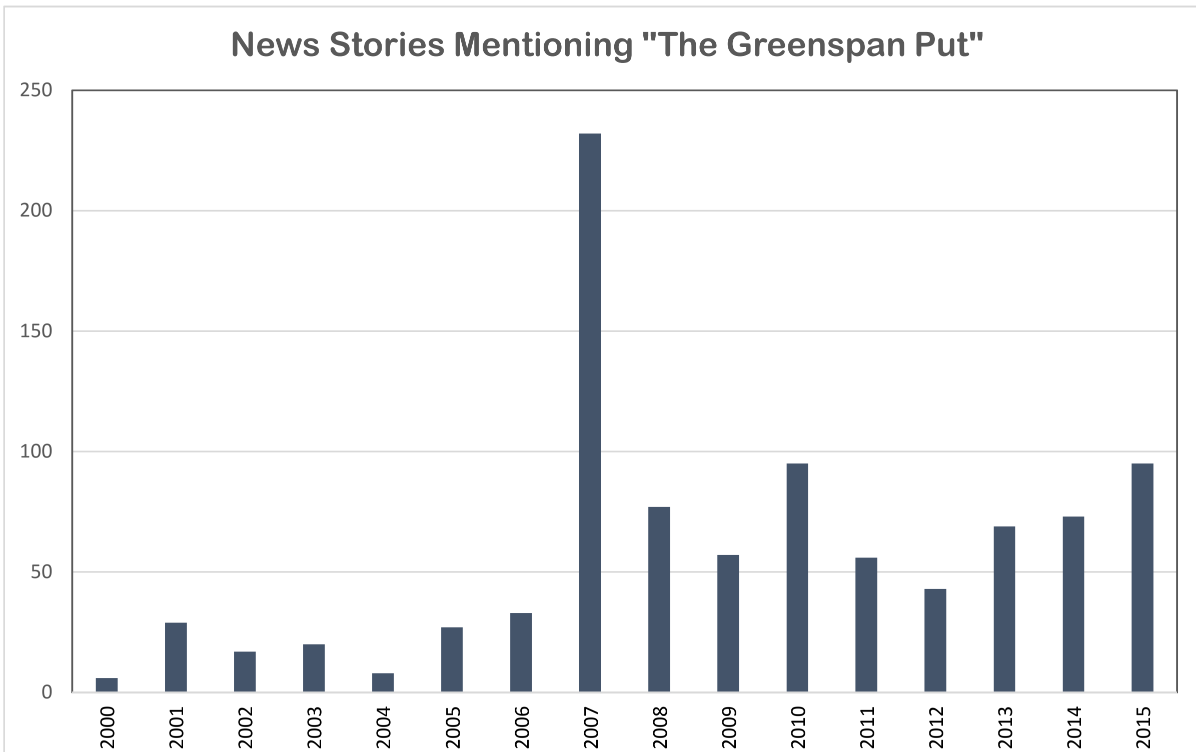
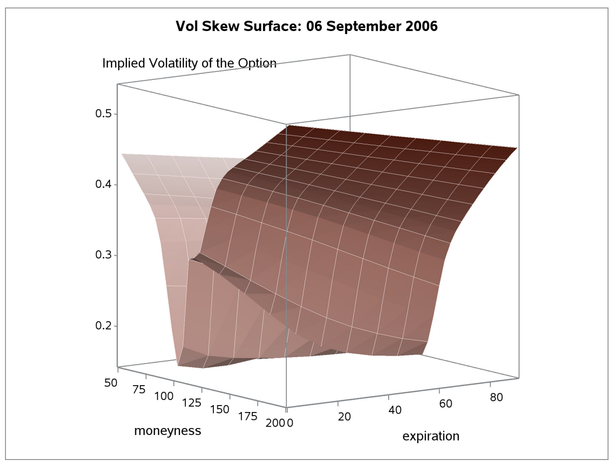


Figure 2: Volatility Skew Surfaces for American Express: September 6, 2006 and September 5, 2007

The figures are based on the closing market prices of options on American Express Corporation stock. The x-axis represents the ratio of strike price to the closing stock price. The y-axis denotes the remaining time to maturity in days. The z-axis shows the annualized implied volatility computed using Black-Scholes option pricing formula based on the prevailing stock price and option prices and the one-month t-bill yield.

07:46 Thursday, July 21, 2016 1



07:46 Thursday, July 21, 2016 1

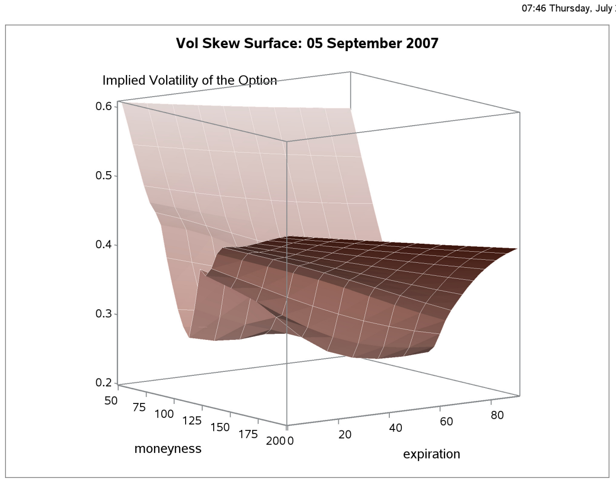


Figure 3: Fed Funds Rate: Actual versus Taylor Rule Guidance

Over the period from the 4th Quarter of 1996 to the end of 2014, we plot the effective Fed funds rate versus what should be the Fed Funds rate if the Federal Reserve followed the Taylor Rule as described int he text of the paper. In the figure, the periods when the Federal Reserve set the Fed Funds rate below what is appropriate under the Taylor Rule are shaded.

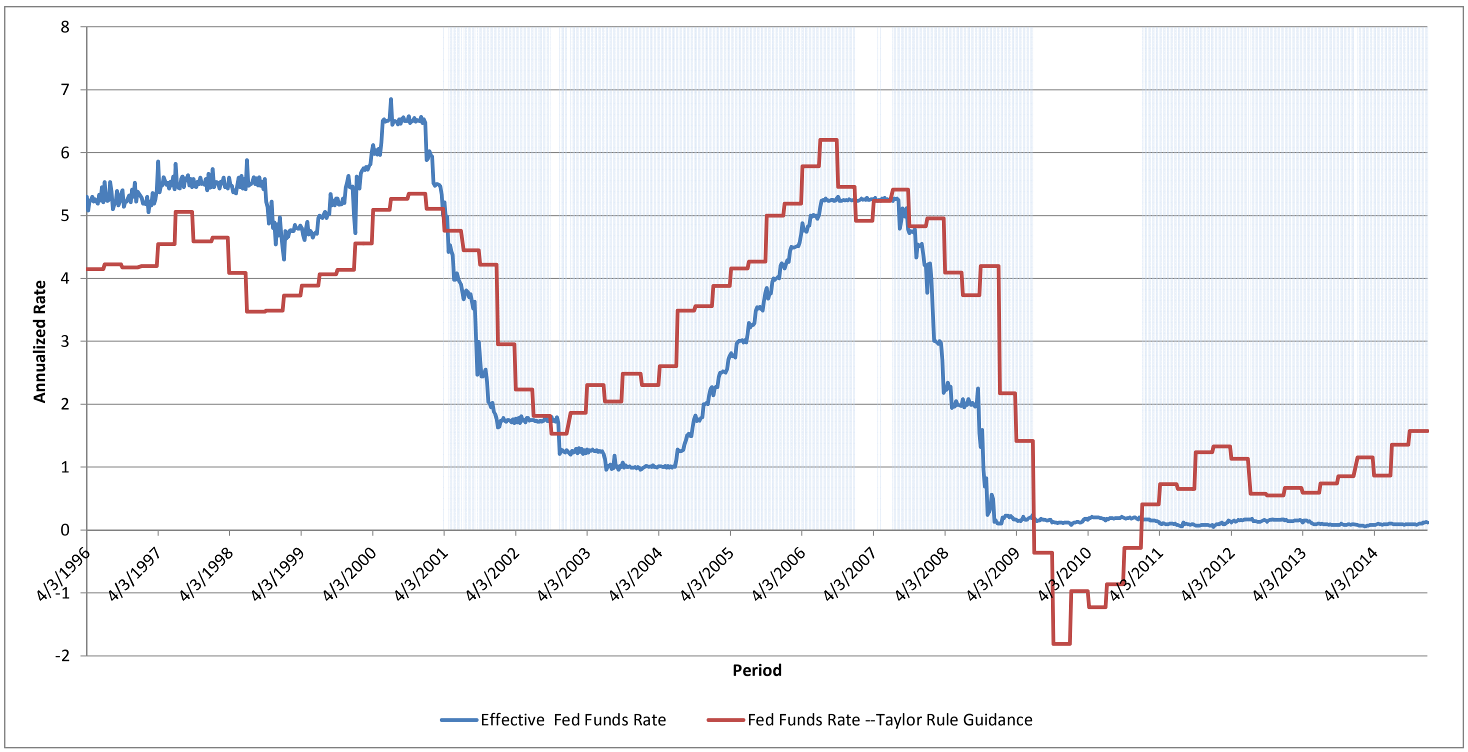


Figure 4: Comparison of Volatilities for Options on S&P100 for two dates: with and without Fed Support

The figure is based on the closing market prices of options on S&P100 index (OEX). The y-axis shows the annualized implied volatilities for two dates: October 23, 2002 when the effective Fed Funds rate was above what the Taylor Rule suggested (i.e. without Fed Support) and January 15, 2003 when the effective Fed Funds rate was below the Taylor Rule guidance (i.e. with Fed Support). The implied volatilities are computed using Black-Scholes option pricing formula based on the prevailing stock price and option prices and the one-month t-bill yield. The x-axis displays the ratio of strike price to the closing stock price, i.e. moneyness.

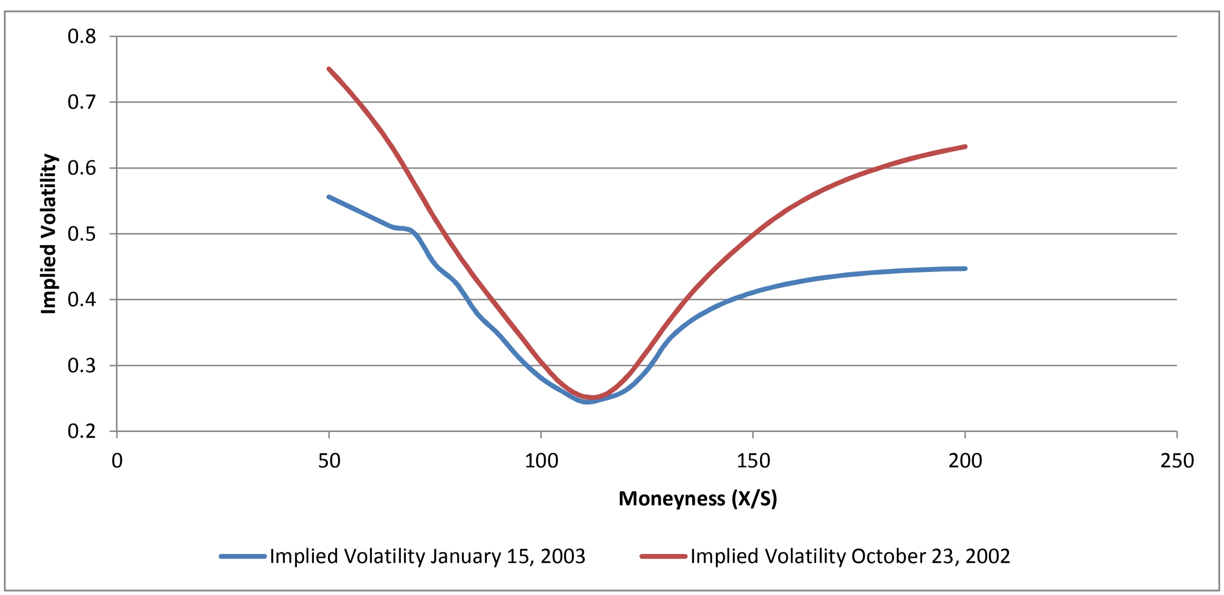


Figure 5: Comparison of Volatilities for Options on S&P100 for two dates: with and without Fed Support

The figure is based on the closing market prices of options on S&P500 index (SPX). The y-axis shows the annualized implied volatilities for two dates: October 23, 2002 when the effective Fed Funds rate was above what the Taylor Rule suggested (i.e. without Fed Support) and January 15, 2003 when the effective Fed Funds rate was below the Taylor Rule guidance (i.e. with Fed Support). The implied volatilities are computed using Black-Scholes option pricing formula based on the prevailing stock price and option prices and the one-month t-bill yield. The x-axis displays the ratio of strike price to the closing stock price, i.e. moneyness.

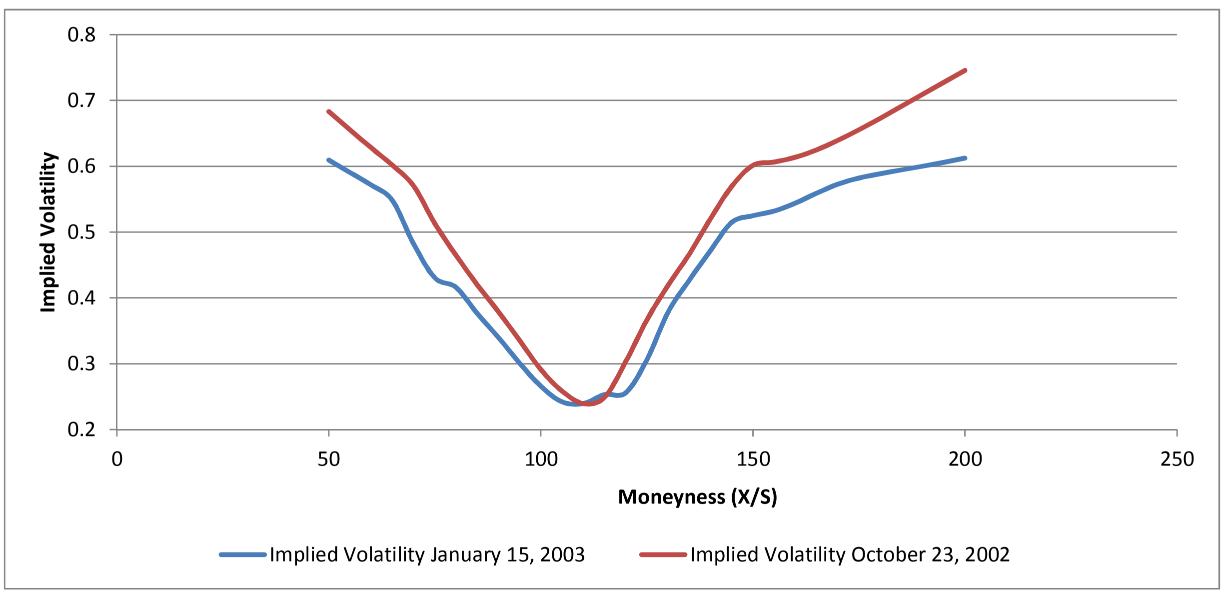


Figure 6: Comparison of Average Volatilities for Options on S&P100: with and without Fed Support

The figure is based on the closing market prices of options on S&P100 index (OEX). Out of the 946 weeks in our sample for the index options, there were 368 weeks when the Fed Funds rate was at or below what the Taylor Rule suggests [i.e. Fed Support for the Markets] versus 578 weeks when the Fed Funds rate was above what the Taylor Rule suggests [i.e. No Fed Support for the Markets]. The y-axis shows the average annualized implied volatilities for the weeks with Fed support and for the weeks without Fed Support. The implied volatilities are computed using Black-Scholes option pricing formula based on the prevailing stock price and option prices and the one-month t-bill yield. The x-axis displays the ratio of strike price to the closing stock price, i.e. moneyness.

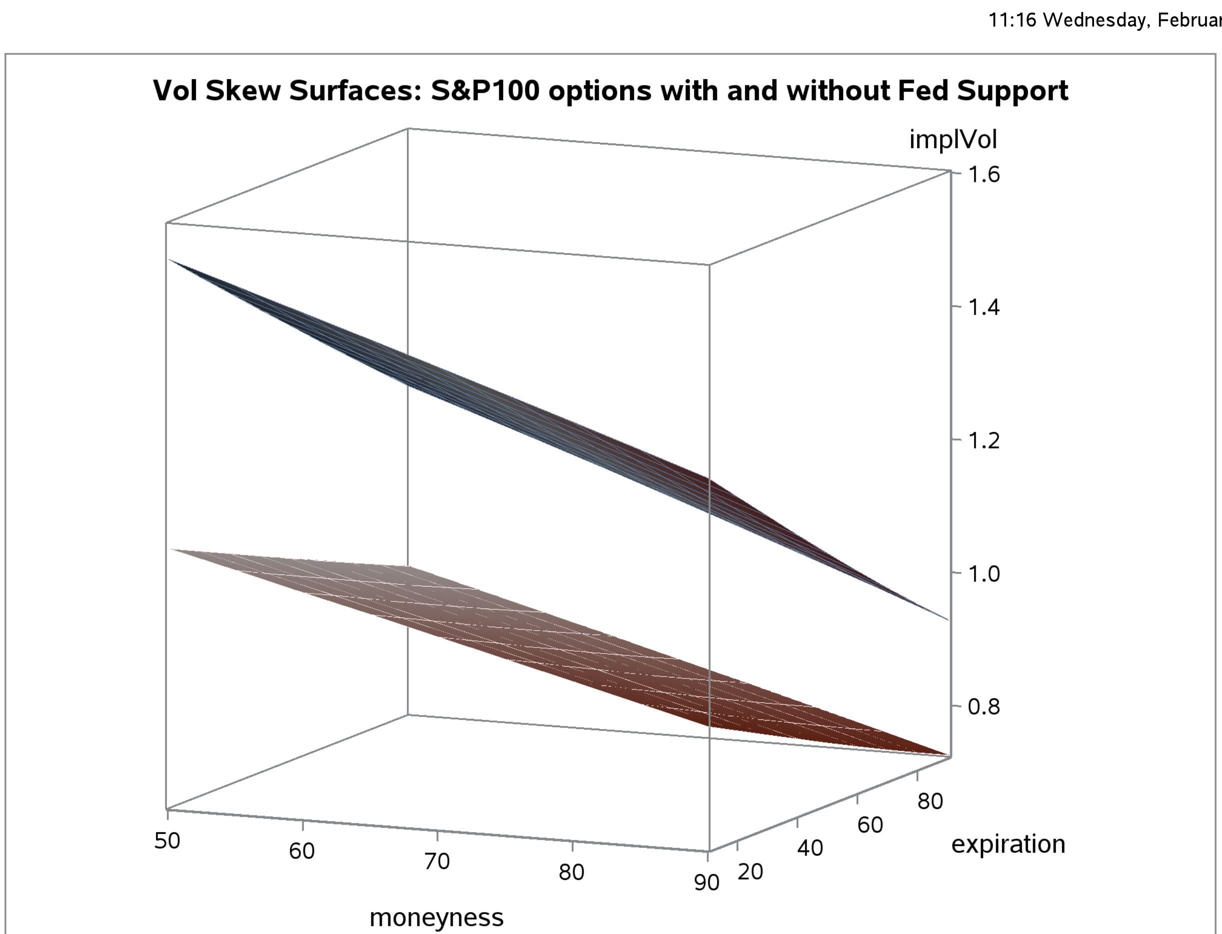


Figure 7: Comparison of Average Volatilities for Options on S&P500: with and without Fed Support

The figure is based on the closing market prices of options on S&P500 index (SPX). Out of the 946 weeks in our sample for the index options, there were 368 weeks when the Fed Funds rate was at or below what the Taylor Rule suggests [i.e. Fed Support for the Markets] versus 578 weeks when the Fed Funds rate was above what the Taylor Rule suggests [i.e. No Fed Support for the Markets]. The y-axis shows the average annualized implied volatilities for the weeks with Fed support and for the weeks without Fed Support. The implied volatilities are computed using Black-Scholes option pricing formula based on the prevailing stock price and option prices and the one-month t-bill yield. The x-axis displays the ratio of strike price to the closing stock price, i.e. moneyness.

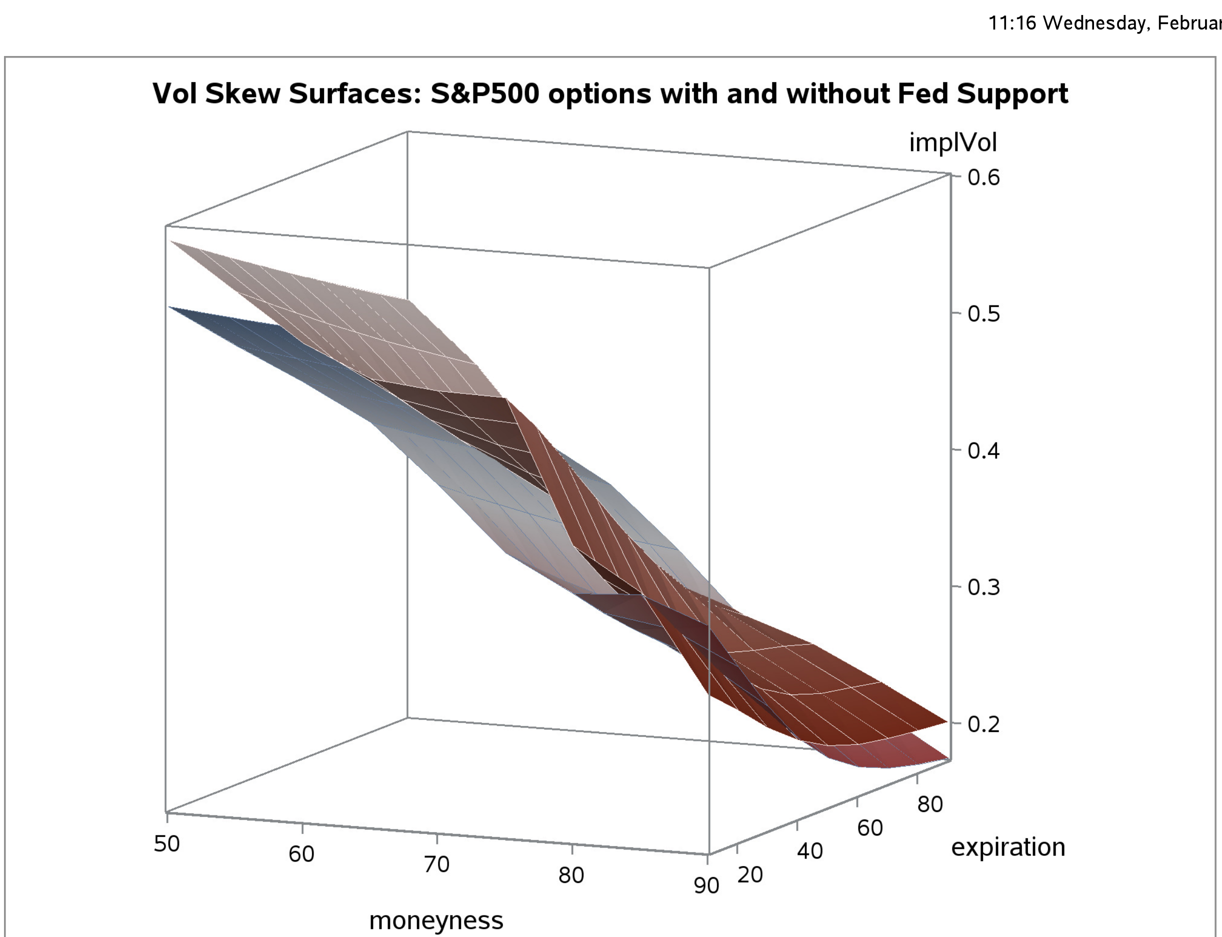


Figure 8: Risk Neutral Probabilities for Puts with and without Fed Support

The figure is based on the closing market prices of options on S&P500. The x-axis represents moneyness. The y-axis shows the probability.

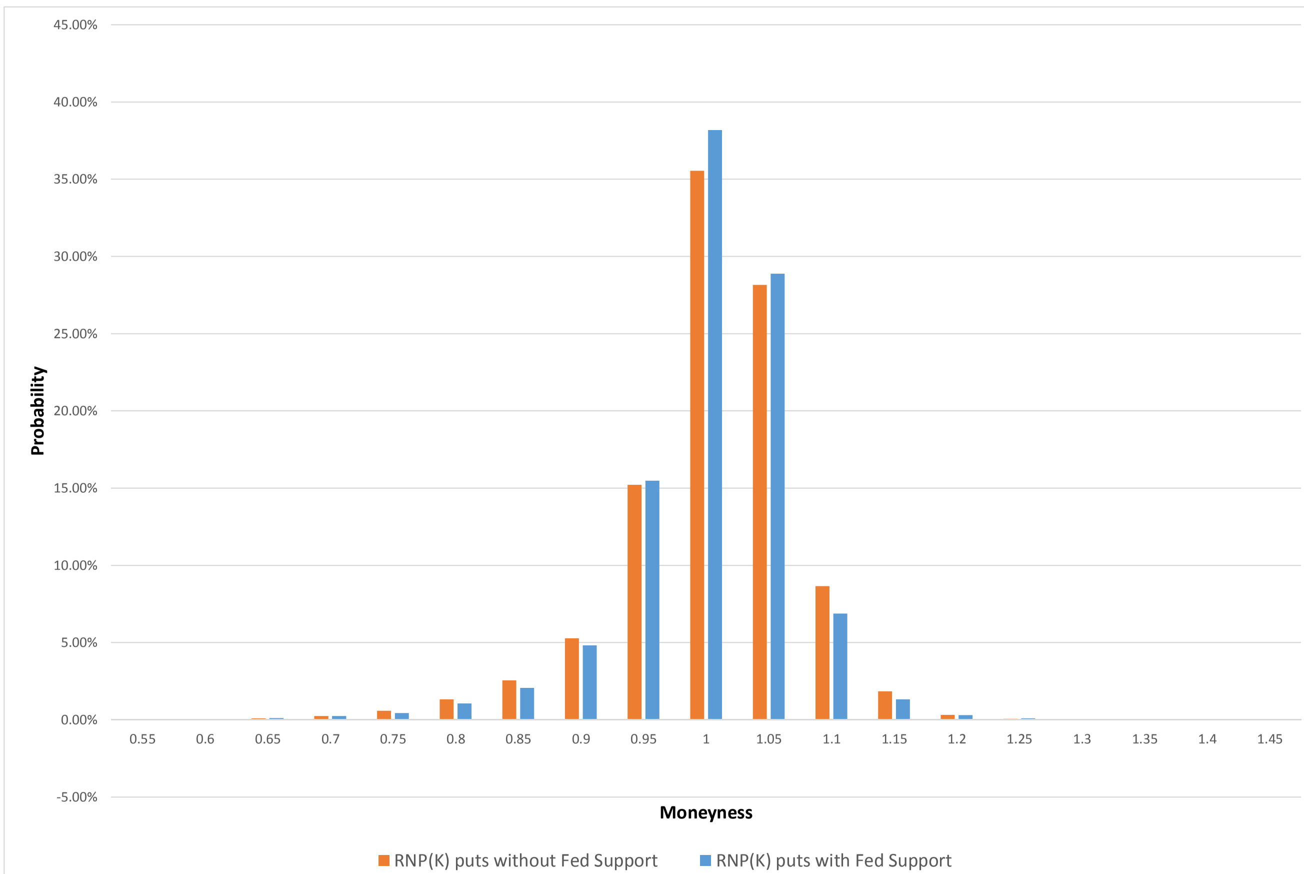


Figure 9: Risk Neutral Probabilities for Calls with and without Fed Support

The figure is based on the closing market prices of options on S&P500. The x-axis represents moneyness. The y-axis shows the probability.

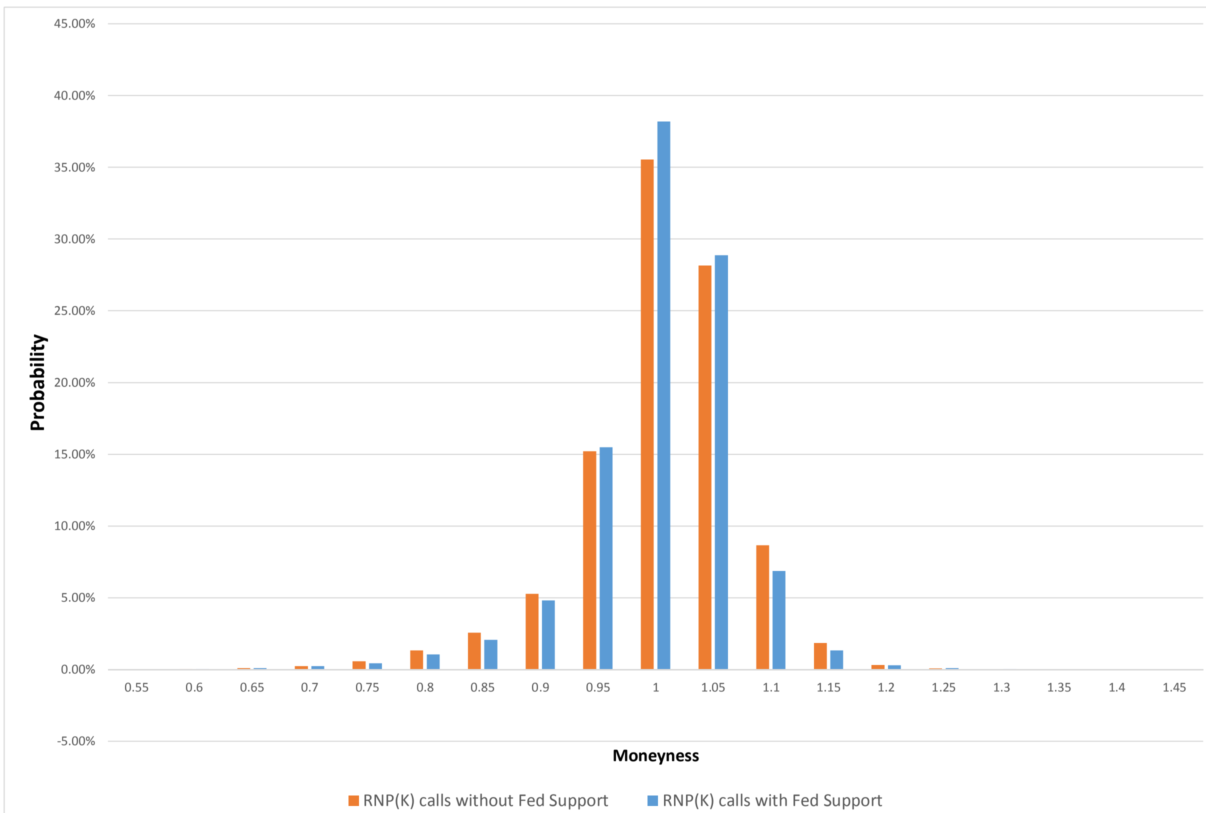


Table 1: **Comparison of At the Money Volatilities with Fed Support versus without: S&P100**
There are 362 weeks when the Federal Funds rate was above the Taylor Rule guidance and 596 weeks when the Federal Funds rate was below the Taylor Rule guidance. For these two subsamples, We then compute the mean and medians of implied volatilities on options expiring in 11 days, 21 days, 31 days, ..., to 91 days. We then test if the means are different using the t-test and if the medians are different using the Wilcoxon signed ranks test.

Expiration	Means		T-statistic	Medians		Wilcoxon
	Fed Support	No Support		Fed Support	No Support	
σ_{11}	21.586	22.703	6.86	16.510	39.673	9.85
σ_{21}	19.391	21.449	7.35	14.795	37.526	10.88
σ_{31}	19.064	21.337	7.67	15.060	36.639	11.52
σ_{41}	19.559	22.261	7.86	15.513	36.222	11.80
σ_{51}	20.004	22.904	8.02	15.985	35.752	11.90
σ_{61}	20.134	23.377	8.22	16.473	35.132	12.06
σ_{71}	20.032	23.481	8.47	16.575	34.401	12.28
σ_{81}	19.906	23.491	8.74	16.482	33.704	12.53
σ_{91}	19.852	23.593	8.97	16.627	33.071	12.74

Table 2: **Comparison of At the Money Volatilities with Fed Support versus without: S&P500**
There are 362 weeks when the Federal Funds rate was above the Taylor Rule guidance and 596 weeks when the Federal Funds rate was below the Taylor Rule guidance. For these two subsamples, We then compute the mean and medians of implied volatilities on options expiring in 11 days, 21 days, 31 days, ..., to 91 days. We then test if the means are different using the t-test and if the medians are different using the Wilcoxon signed ranks test.

Expiration	Means		T-statistic	Medians		Wilcoxon
	Fed Support	No Support		Fed Support	No Support	
σ_{11}	19.974	21.183	2.16	16.406	20.481	7.02
σ_{21}	18.600	20.209	3.22	15.514	19.808	7.96
σ_{31}	18.395	20.184	3.86	15.540	19.824	8.36
σ_{41}	18.522	20.441	4.31	15.928	20.103	8.54
σ_{51}	18.656	20.697	4.72	16.002	20.499	8.68
σ_{61}	18.752	20.920	5.14	16.121	20.842	8.88
σ_{71}	18.845	21.083	5.41	16.432	21.144	8.98
σ_{81}	18.931	21.214	5.60	16.690	21.359	9.08
σ_{91}	19.000	21.325	5.80	16.751	21.541	9.15

Table 3: **Distance between the Volatility Skew Surface for Puts with Fed Support versus without**

The volatility surface plots implied volatility as a function of moneyness (delta) and time to expiration (maturity). On this surface, we compute volatility as a function of moneyness on ten different days to maturity (11, 21, 31, 41, 51, 61, 71, 81, and 91), i.e. get ten separate curves plotting volatility against moneyness. For each of these eleven curves, implied volatility is computed at nine points as a function of moneyness ranging from 50% to 90%, i.e. out of the money puts. We repeat this process each week for the 946 weeks over our sample period. We then compare the average of these curves at each moneyness level for the 368 weeks when the Fed Funds rate was at or below what the Taylor Rule suggests [i.e. Fed Support for the Markets] versus for average for the 578 weeks when the Fed Funds rate was above what the Taylor Rule suggests [i.e. No Fed Support for the Markets]. The two sets of averages (i.e. two 1×9 vectors for each day to maturity) are compared using the Chebyshev, Minkowski (with a p=4) and Mahalonobis metrics. These metrics do not rely on distributional or parametric assumptions. The Minkowski distance is the generalized p-Norm distance i.e. $(\sum_i^n |x_i - y_i|^p)^{\frac{1}{p}}$. The Chebyshev distance is defined as the L_∞ norm of the difference between two n-dimensional objects, i.e. $\underset{i}{Max} |x_i - y_i|$. The Mahalanobis distance is defined as $\sqrt{(\mathbf{x}-\mathbf{y})^T S^{-1} (\mathbf{x}-\mathbf{y})}$ where S is the variance-covariance matrix. The results for the OEX (S&P100) and SPX (S&P500) are presented below

Expiration	S&P100			S&P500		
Days to Maturity	Chebyshev	Minkowski	Mahalonobis	Chebyshev	Minkowski	Mahalonobis
11	0.163	0.202	0.611	0.026	0.031	0.075
21	0.182	0.232	0.628	0.015	0.021	0.061
31	0.184	0.245	0.613	0.032	0.046	0.116
41	0.179	0.250	0.586	0.041	0.057	0.128
51	0.172	0.249	0.559	0.042	0.057	0.119
61	0.167	0.246	0.537	0.043	0.054	0.103
71	0.162	0.242	0.517	0.042	0.050	0.088
81	0.157	0.238	0.499	0.040	0.046	0.076
91	0.152	0.233	0.480	0.037	0.042	0.067

Table 4: **Bootstrapped Mahalanobis Distance between Volatility Skew Surfaces for Puts with Fed Support versus without**

The volatility surface plots implied volatility as a function of moneyness (delta) and time to expiration (maturity). On this surface, we compute volatility as a function of moneyness on eleven different days to maturity (1, 11, 21, 31, 41, 51, 61, 71, 81, and 91), i.e. get eleven separate curves plotting volatility against moneyness. For each of these eleven curves, implied volatility is computed at nine points as a function of moneyness ranging from 50% to 90%. We repeat this process each week for the 946 weeks over our sample period. We then compare the average of these curves at each moneyness level for the 368 weeks when the Fed Funds rate was at or below what the Taylor Rule suggests [i.e. Fed Support for the Markets] versus for average for the 578 weeks when the Fed Funds rate was above what the Taylor Rule suggests [i.e. No Fed Support for the Markets]. The two sets of averages (i.e. two 1×9 vectors for each day to maturity) are compared using Mahalanobis metric. These distance are bootstrapped by resampling without replacement 100 times and standard errors are computed. The results for the OEX (S&P100) and SPX (S&P500) are presented below The distance and standard errors for the S&P500 have been scaled by 1000.

Expiration	S&P100			S&P500		
Days to Maturity	Avg. Distance	Std. Error	Z-statistic	Avg. Distance	Std. Error	Z-statistic
1	1.295	0.068	19.17	0.001	0.001	2.51
11	2.858	0.146	19.64	0.004	0.001	4.10
21	4.821	0.190	25.36	0.013	0.002	7.64
31	6.010	0.232	25.90	0.025	0.003	9.43
41	5.524	0.182	30.43	0.035	0.003	10.40
51	4.577	0.185	24.69	0.041	0.003	12.25
61	4.341	0.135	32.04	0.049	0.003	14.51
71	4.342	0.139	31.15	0.060	0.005	13.08
81	4.125	0.130	31.76	0.067	0.004	15.46
91	3.943	0.118	33.33	0.072	0.006	12.16

Table 5: **Tests of whether the Volatility skew surface for Puts on the Index is different with Fed Support versus without**

The volatility surface plots implied volatility as a function of moneyness (delta) and time to expiration (maturity). On this surface, We compute volatility as a function of moneyness on eleven different days to maturity (1, 11, 21, 31, 41, 51, 61, 71, 81, and 91), i.e. compute eleven separate curves of volatility against moneyness. For each of these eleven curves, implied volatility is computed at 11 points as a function of moneyness ranging from 50% to 100%. We repeat this process each week for the 946 weeks over our sample period, Jan 4, 1996 to Aug 31, 2014. We then compare the average of these curves at each moneyness level for the 368 weeks when the Fed Funds rate was at or below what the Taylor Rule suggests [i.e. Fed Support for the Markets] versus for average for the 578 weeks when the Fed Funds rate was above what the Taylor Rule suggests [i.e. No Fed Support for the Markets]. For each moneyness level starting at 50%, we average implied volatility (and compute the option premium that corresponds to that volatility) across maturity (1, 11, 21, 31, 41, 51, 61, 71, 81, and 91 days) for the weeks without Fed Support and the weeks without Fed Support. We then carry out a t-test comparing the two averages. We present the results for the S&P500 and S&P100 index options. The premium is multiplied by 10,000.

		Without Fed Support		With Fed Support		
	Moneyness	Impl. Volatility	Premium	Impl. Volatility	Premium	T-statistic
S&P500	50	0.732	0.189	0.704	0.110	5.91
	55	0.665	0.332	0.640	0.203	5.60
	60	0.604	0.604	0.584	0.409	4.74
	65	0.546	1.102	0.531	0.825	3.45
	70	0.491	2.052	0.483	1.767	1.76
	75	0.442	4.183	0.438	3.900	1.04
	80	0.398	9.211	0.391	8.231	1.96
	85	0.356	20.842	0.345	17.846	3.37
	90	0.310	45.215	0.295	37.776	5.85
	95	0.258	95.863	0.241	81.719	9.27
	100	0.211	222.232	0.194	202.752	11.46
S&P100	50	0.820	0.767	0.748	0.252	7.85
	55	0.772	1.732	0.683	0.459	10.08
	60	0.723	3.558	0.620	0.807	12.18
	65	0.674	6.886	0.555	1.298	14.67
	70	0.623	12.492	0.491	2.052	16.77
	75	0.576	22.884	0.438	3.900	18.05
	80	0.533	42.283	0.390	8.096	19.13
	85	0.495	78.836	0.345	17.846	20.51
	90	0.454	139.806	0.305	42.671	20.80
	95	0.409	237.852	0.253	91.644	22.54
	100	0.366	399.968	0.207	217.648	23.60

Table 6: **Differences between the Surfaces for Index Put Options when Federal Funds Rate is below Taylor Rule Guidance versus When it is not**
We estimate the following regressions for put options on the S&P500 (SPX) and the S&P100 (OEX)

$$\sigma_{Put} = \alpha_{put} + \beta_{put} Moneyness + \gamma_{put} Expiration + \delta_{put} I_{FedSupport}$$

and where $I_{FedSupport}$ represents periods when there was the Federal Funds rate was below Taylor Rule Guidance. We use weekly data for 946 weeks over Jan 4, 1996 to Aug 31, 2014, using the entire volatility surface each week. The surface each week has implied volatility across grid of 11 days to maturity i.e. expiration (1, 11, 21, 31, 41, 51, 61, 71, 81, 91 days) and 31 points on moneyness ranging from 50% to 100%. In each cell, the point estimate is presented followed by the t-statistic.

	S&P100	S&P500
Intercept	149.652	138.076
	266.57	522.85
Moneyness	-1.025	-1.01
	-145.17	-304.21
Expiration	-0.316	-0.365
	-89.64	-219.97
Fed Support	-12.501	-1.475
	-59.96	-15.04
R-square	25.45	59.57
Nobs	95800	95800

Table 7: **Tests of whether the Volatility skew surface for Calls on the Index is different with Fed Support versus without**

The volatility surface plots implied volatility as a function of moneyness (delta) and time to expiration (maturity). On this surface, We compute volatility as a function of moneyness on eleven different days to maturity (1, 11, 21, 31, 41, 51, 61, 71, 81, and 91), i.e. compute eleven separate curves of volatility against moneyness. For each of these eleven curves, implied volatility is computed at 11 points as a function of moneyness ranging from to 100% to 150%. We repeat this process each week for the 946 weeks over our sample period. We then compare the average of these curves at each moneyness level for the 368 weeks when the Fed Funds rate was at or below what the Taylor Rule suggests [i.e. Fed Support for the Markets] versus for average for the 578 weeks when the Fed Funds rate was above what the Taylor Rule suggests [i.e. No Fed Support for the Markets]. For each moneyness level starting at 100%, we average implied volatility (and compute the option premium that corresponds to that volatility) across the points on the expiration curve (1, 11, 21, 31, 41, 51, 61, 71, 81, and 91) for the weeks without Fed Support and the weeks without Fed Support. We then carry out a *t*-test comparing the two averages. We present the results for the S&P500 and S&P100 index options.

		Without Fed Support		With Fed Support		
	Moneyness	Impl. Volatility	Premium	Impl. Volatility	Premium	T-statistic
S&P500	100	0.211	2.22	0.194	2.03	11.46
	105	0.194	5.26	0.180	5.14	8.50
	110	0.200	9.69	0.199	9.69	0.39
	115	0.215	14.56	0.231	14.58	-5.84
	120	0.240	19.51	0.270	19.53	-9.11
	125	0.269	24.49	0.312	24.51	-11.39
	130	0.298	29.46	0.355	29.48	-12.91
	135	0.324	34.44	0.397	34.46	-14.70
	140	0.347	39.42	0.438	39.44	-16.53
	145	0.368	44.40	0.478	44.42	-18.29
	150	0.387	49.38	0.516	49.40	-19.94
S&P100	100	0.366	4.00	0.207	2.18	23.60
	105	0.342	6.71	0.191	5.23	23.10
	110	0.335	10.48	0.208	9.72	20.47
	115	0.339	14.92	0.244	14.60	16.05
	120	0.348	19.67	0.297	19.57	8.83
	125	0.358	24.55	0.358	24.55	-0.06
	130	0.366	29.49	0.420	29.54	-9.60
	135	0.373	34.45	0.482	34.54	-18.84
	140	0.377	39.42	0.542	39.53	-26.88
	145	0.379	44.40	0.598	44.52	-33.25
	150	0.380	49.38	0.651	49.51	-38.22

Table 8: **Differences between the Surfaces for Index Call Options when Federal Funds Rate is below Taylor Rule Guidance versus When it is not**

We estimate the following regressions for call options on the S&P500 (SPX) and the S&P100 (OEX)

$$\sigma_{Call} = \alpha_{Call} + \beta_{call} Moneyness + \gamma_{call} Expiration + \delta_{Call} I_{FedSupport}$$

where $I_{FedSupport}$ represents periods when there was the Federal Funds rate was below Taylor Rule Guidance. We use weekly data for 946 weeks over Jan 4, 1996 to Aug 31, 2014, using the entire volatility surface each week. The surface each week has implied volatility across grid of 11 days to maturity i.e. expiration (1, 11, 21, 31, 41, 51, 61, 71, 81, 91 days) and moneyness ranging from 100% to 200%, i.e. 341 observations on implied volatility each week. In each cell, the point estimate is presented followed by the t-statistic.

	S&P100	S&P500
Intercept	-39.568	-32.873
	-70.75	-70.42
Moneyness	0.582	0.557
	171.81	196.96
Expiration	-0.253	-0.309
	-70.75	-103.49
Fed Support	25.961	13.423
	123.07	76.24
R-square	19.80	21.57
Nobs	201180	201180

Table 9: **Differences between the Surfaces for Individual Options when Federal Funds Rate is below Taylor Rule Guidance versus When it is not**

We estimate the following regressions for options on each stock in the S&P100.

$$\sigma_{Put} = \alpha_{put} + \beta_{put} MoneyNess + \gamma_{put} MoneyNess^2 + \xi_{put} Expiration$$
$$\sigma_{Call} = \alpha_{Call} + \beta_{Call} MoneyNess + \gamma_{Call} MoneyNess^2 + \xi_{Call} Expiration$$

which we estimate separately using the 362 weeks when the Fed Funds rate was above the Taylor rule guidance versus the 466 weeks when it was below. We compute the mean and median parameters for the two subsample. In each cell, the top number presents the mean (or median) for when the Fed Funds rate is above the Taylor Rule guidance and the bottom number presents the mean (or median) for when the Fed Funds rate is below the Taylor Rule guidance. *, ** or *** indicate that the differences are significant at 1%, 5%, or 10% using an F-test for the mean. We compute these statistics for financial institutions (FI) and non-financials (non-FI). We then also compare the mean and median for at-the money volatilities at 1, 11, 21 and 91 days to expiration for these options.

	Mean	Median	Mean (FI)	Median (FI)	Mean (non FI)	Median (non FI)
β_{call}	0.354	0.280	0.190	0.088	0.378	0.309
	0.493	0.512	0.503	0.594	0.492	0.503
β_{put}	-1.141	-0.881	-1.286	-1.092	-1.119	-0.853
	-0.946	-0.738	-1.045	-0.877	-0.931	-0.722
γ_{call}	-0.097	-0.071	-0.098	-0.070	-0.096	-0.071
	-0.120	-0.094	-0.132	-0.113	-0.118	-0.091
γ_{put}	-0.139	-0.110	-0.140	-0.113	-0.139	-0.109
	-0.145	-0.117	-0.167	-0.136	-0.142	-0.114
σ_1	38.915	33.597	43.261	38.780	38.273	32.758
	36.265	30.579	40.832	30.804	35.592	30.558
σ_{11}	37.136	32.148	41.489	37.174	36.494	31.324
	33.461	28.203	37.515	27.643	32.865	28.259
σ_{21}	36.027	31.366	40.371	36.792	35.385	30.483
	31.990	27.008	35.616	25.953	31.456	27.148
σ_{91}	35.474	32.111	39.651	37.599	34.857	31.252
	31.367	27.146	34.077	25.993	30.968	27.293

Table 10: **Differences between the Surfaces when Federal Funds Rate is below Taylor Rule Guidance versus When it is not for Index Options: Pre versus Post Crisis**
We estimate the following regressions for options on the S&P500 (SPX) and the S&P100 (OEX) and

$$\begin{aligned}\sigma_{Put} &= \alpha_{put} + \beta_{put} Moneyness + \gamma_{put} Expiration + \delta_{put} I_{FedSupport} \\ &+ \nu_{put} I_{Recession} + \eta_{put} I_{FedSupport} \times I_{Recession} \\ \sigma_{call} &= \alpha_{call} + \beta_{call} Moneyness + \gamma_{call} Expiration + \delta_{call} I_{FedSupport} \\ &+ \nu_{call} I_{Recession} + \eta_{call} I_{FedSupport} \times I_{Recession}\end{aligned}$$

where $I_{FedSupport}$ represents periods when there was the Federal Funds rate was below Taylor Rule Guidance and $I_{Recession}$ is 1 for the period after the 2008 Financial Crisis. In each cell, the point estimate is presented followed by the t-statistic.

	Puts		Calls	
	S&P100	S&P500	S&P100	S&P500
Intercept	152.948	137.907	-42.327	-33.852
	272.08	520.74	-78.43	-71.9
Moneyness	-1.025	-1.01	0.582	0.557
	-146.65	-306.85	180.18	197.6
Expiration	-0.316	-0.365	-0.253	-0.309
	-90.55	-221.89	-74.2	-103.83
Fed Support	-18.25	-3.515	13.267	17.692
	-72.71	-29.72	54.23	82.88
Recession	-15.354	0.786	12.85	4.561
	-38.93	4.23	33.43	13.6
Fed Support × Recession	20.835	4.149	21.684	-11.912
	44.25	18.7	47.24	-29.75
R-square	26.95	60.27	27.08	22.08
Nobs	95800	95800	201180	201180