

Too-Systemic-To-Fail: What Option Markets Imply About Sector-wide Government Guarantees*

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Abstract

We examine the pricing of financial crash insurance during the 2007-2009 financial crisis in U.S. option markets. A large amount of aggregate tail risk is missing from the price of financial sector crash insurance during the financial crisis. The difference in costs of out-of-the-money put options for individual banks and puts on the financial sector index increases fourfold from its pre-crisis 2003-2007 level. We provide evidence that a collective government guarantee for the financial sector, which lowers index put prices far more than those of individual banks, explains the divergence in the basket-index put spread.

Keywords: systemic risk, government bailout, too-big-to-fail, option pricing models, financial crisis

JEL codes: G12, G13, G18, G21, G28, E44, E60, H23

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During the 2007-2009 financial crisis, an episode of elevated systemic risk, the price of crash insurance for the U.S. financial sector was surprisingly low. Our paper documents that out-of-the-money (OTM) put options on the financial sector stock index were cheap relative to OTM put options on the individual banks that comprise the index. The difference between the cost of a basket of individual bank put options and the cost of a financial sector index put option reached 12.1 cents per dollar insured in March 2009, or 68% of the cost of the index put. Between 2003 and 2007, before the onset of the crisis, this basket-index put spread never exceeded 2.3 cents on the dollar.

The behavior of the basket-index spread in the financial sector during the crisis is puzzling. The basket of put options provides insurance against both sector-wide and idiosyncratic bank stock crashes, while the index put option only insures against a sector-wide crash. Standard option pricing logic therefore implies that a disproportionate increase in idiosyncratic risk (relative to aggregate risk) is needed to explain the dramatic increase in the basket-index put spread during the crisis. This creates a puzzle because, as is common in times of market turbulence, the correlation of financial stocks also surged throughout the crisis. The drastic rise in idiosyncratic risk necessary to explain the put spread counter-factually implies a sharp decrease in stock return correlations.

We hypothesize that a sector-wide bailout guarantee in the financial sector is largely responsible for the divergence of individual and index put prices during the recent financial crisis. The anticipation of future government intervention during a financial sector collapse lowers the market price of crash insurance. In effect, implicit bailout guarantees are crash insurance subsidies for anyone holding stock in the banking sector, and this subsidy drives down the market prices that investors were willing to pay for the traded, private version of insurance. Since any individual bank may still fail amid a collective guarantee, or the failure of a single firm may not be sufficient to trigger government intervention, the downward pressure on individual bank puts is much weaker than the effect on index puts.

We provide direct and indirect evidence in favor of this hypothesis. First, we carefully document the rise in the basket-index put spread for the financial sector during the crisis (Section I). We compare across sectors and find that no other sector experienced such a run-up in put spreads. We also show that the divergence in basket and index option prices pertains only to OTM put options. Consistent with the rise in observed correlations, the prices of the OTM call options on individual stocks and indices converge in all sectors during the financial crisis. We then show that return correlations rose more in the financial sector than in other sectors. We also show that

put option-implied correlations in the financial sector fell, while simultaneously call-implied correlations rose in the same manner as realized correlations. Our estimates imply that, if anything, idiosyncratic downside risk was less prominent among banks than among stocks in other sectors. Each of these facts indicate that a relative rise in idiosyncratic bank risk is not responsible for the large increase in crisis put spreads for the financial sector.

Second, we show that these two facts, the simultaneous increase in financial sector correlations and the financial sector basket-index put spread, are at odds with standard asset pricing models (Section II). If anything, the standard model suggests that the rapid increase in return correlations should have raised the price of OTM index options relative to the option basket, causing the put spread to shrink. To demonstrate this point, we theoretically derive joint pricing formulas for options on a sector index and individual stocks in a model that incorporates both common and idiosyncratic shocks. In its simplest form our model reduces to the well-known Black and Scholes (1973) and Merton (1973) model. The transparency of the Black-Scholes version of our model is useful for developing the intuition of our approach. Furthermore, it directly maps time-series fluctuations in risk into option prices as a function of the underlying index and individual stock volatilities without requiring estimation of parameters. We show that Black-Scholes cannot reconcile the financial sector put spread dynamics, even after taking into account rising volatilities and correlations during the financial crisis. In contrast, Black-Scholes successfully matches put spread dynamics for non-financial sectors both before and during the crisis.

One shortcoming of Black-Scholes is that it fails to capture the high *levels* of OTM index option prices. We therefore extend model to include stochastic volatility for both sector-wide and stock-specific return shocks, as well as price jumps. We show that this state-of-the-art model explains pre-crisis basket and index put price levels much better than the Black-Scholes model in *all* sectors. It continues to explain non-financial-sector spreads during the crisis. This is notable because the model's crisis fits are purely done out-of-sample. Stochastic volatility models require estimated parameters, and we only use pre-crisis data to estimate our model. The fact that we accurately fit out-of-sample spreads in non-financial sectors is reassuring: It shows that our model provides an appropriate mapping from observed risks to option prices. However, this sophisticated option pricing model still fails to explain the large basket-index spread among financials during the crisis. Even after carefully accounting for the observed index and individual stock return risk dynamics, the observed price of financial sector crash insurance remains cheap relative to the one predicted by the model.

The third step of our analysis asks whether a simple model of sector-wide bailout guarantees helps in matching the financial sector put spread during the crisis. After embedding a government guarantee in our option pricing model, the realized volatility and correlation dynamics in the financial sector produce a model-implied put spread that is strikingly similar to that in the data during the 2007-2009 financial crisis. This analysis provides indirect evidence that a government guarantee can account for dynamics of the basket-index put spread over our sample.

By comparing the bailout-adjusted and the bailout-free cost of an option-based hedge against a financial sector crash, we obtain an estimate of the value of the collective government guarantee for the equity holders in the financial sector. During the crisis, we find that the guarantee lowers the insurance premium for financial sector crash insurance by 5.35 percentage points or 49% of the actual cost of the insurance. This subsidy increases to 60% in the last quarter of 2008 and the first quarter of 2009, and is as high as 91% of the cost of insurance on October 8, 2008. In dollar terms, option prices imply an average subsidy to equity holders of \$49.5 billion during the crisis, \$63.1 billion over 2008Q4 and 2009Q1, and more than \$100 billion on October 8, 2008. These numbers imply a substantial reduction in the cost of equity for systemically risky financial firms.¹

The fourth step in our analysis is to provide corroborative evidence in favor of the bailout hypothesis (Section III). We conduct an event study around key government announcements during the crisis to provide direct evidence of option price sensitivity to bailout guarantees. The basket-index put spread increased on average by 0.73 cents more in the financial sector than in the non-financial sectors in the first five days after those government announcements that ex-ante increased the probability of a government bailout. The relative put spread decreased on average by 0.61 cents after announcements that had the opposite effect. Both effects adjust for changes in financial sector risk, and are large compared to the average financial sector crisis spread.

From 2000 to 2002, the technology sector index crashed in a similar fashion as the 2007 to 2009 finance sector index crash. Unlike the financial sector spread during the financial crisis, we find little evidence of a divergence between risk-adjusted basket and index put prices for the technology sector in the early 2000s. The *absence* of a large put spread in tech sector collapse supports our bailout interpretation of financial sector option market behavior during the recent crisis.

While our emphasis is on collective or “too-systemic-to-fail” guarantees, some fi-

¹O’Hara and Shaw (1990) estimate large positive wealth effects for shareholders of banks who were declared too-big-to-fail by the Comptroller of the Currency in 1984, and negative wealth effects for those banks that were not included.

financial institutions may benefit more than others. We document differences in put prices and credit default swap rates across banks. Risk-adjusted crash insurance prices for large banks are significantly lower than those of their smaller peers, indicating investors perceive differences in bailout likelihoods across institutions consistent with an implicit “too-big-to-fail” guarantee.

We explore a number of alternative explanations for the increase in the basket-index put spread in Section IV. Transaction costs can be ruled out because the basket-index put spread constructed with the most costly combination of bid and ask quotes is still large. Liquidity differences across various types of options (index versus individual, puts versus calls, or financial firms versus non-financials) are inconsistent with the put spread arising due to illiquidity. Mispricing due to capital constraints, counter-party risk, and short sale restrictions are unlikely culprits. A trade that takes advantage of the basket-index spread ties up relatively little capital (due to implicit leverage in options) and occurs through exchanges with a clearing house. These option positions are marked-to-market daily and ultimately guaranteed by the AAA-rated Options Clearing Corporation. The short sale ban was in place only for a brief portion of the financial crisis, applied equally to individual and index options, and market makers were exempted from it. Nor do short sale lending fees for financial stocks line up with the put spread dynamics that we document.

Our work connects to various strands of the literature. First, it is linked to the problem of measuring systemic risk in the financial sector, one of the major challenges confronting financial and macro-economists.² Our findings highlight a fundamental complication in inferring systemic risk from market prices. All else equal, the basket-index spread for OTM put options would be a natural measure of systemic risk: the smaller the basket-index spread in a sector, the larger the amount of systemic risk in that sector. However, in sectors that benefit from an implicit or explicit collective guarantee, an increase in the basket-index spread may occur when systemic risk rises and the collective bailout guarantee is more likely to be activated. Hence, the anticipation of future government intervention is embedded in market prices today and makes them less informative about the true nature of tail risk.³

The effects of too-systemic-to-fail government are an active topic of investigation.⁴

²See Acharya, Pedersen, Philippon, and Richardson (2010); Adrian and Brunnermeier (2010); Brownless and Engle (2010); Huang, Zhou, and Zhu (2011) for recent advances in systemic risk measurement and Brunnermeier, Hansen, Kashyap, Krishnamurthy, and Lo (2010) for an overview of related research challenges.

³This feedback from anticipated corrective action to market prices echoes the problem of a board of directors monitoring share prices to fire a CEO (Bond, Goldstein, and Prescott, 2010).

⁴A number of papers measure the impact of these guarantees, starting with the seminal work of

Veronesi and Zingales (2010) use CDS data to measure the value of government bailouts to bondholders and stockholders of the largest financial firms from the 2008 Paulson plan. Their focus on credit contracts is consistent with the prevailing notion that bailouts rescue debt holders at the expense of equity holders. We test the hypothesis that collective government guarantees to the financial sector benefit bank equity holders during a financial crisis. The anticipation of a creditor bailouts can benefit shareholders due to uncertainty about the resolution regime (especially for large financial institutions), and the fact that bankruptcy costs start well before the value of bank equity hits zero.⁵ We document that government guarantees pledged substantial value to financial sector equity holders during this crisis, even if the guarantee intended to target debt holders. This finding is useful for understanding potentially unintended consequences of a collective guarantee for the financial system.⁶

I. Measuring the Cost of Sector Crash Insurance

Equity options markets are especially well-suited to gauge the market’s perception of too-systemic-to-fail guarantees. Since collective guarantees are only activated during a financial crisis, their effect should be most visible in the prices of assets that primarily reflect tail risk, like OTM put options. One may insure against a common financial sector crash by buying puts: On each individual financial institution, or on the financial sector index.

We focus on a sector index comprised of different stocks j . To insure the sector using puts on individual stocks, we build a basket of options that matches the sector index composition on each day. Let Sh_j be the number of shares outstanding, respectively, for stock j in the index. The dollar cost of the basket (i.e., corresponding the total market equity of all the firms in the index) is given by $Put^{basket} = \sum_{j=1}^N Put_j Sh_j$. Alternatively, one can insure the sector via put options on the sector index, at a price of Put^{index} .

The basket of put options provides insurance against both common and idiosyncratic stock price crashes, while the index put option only insures states of the world

Merton (1977) on deposit insurance. Lucas and McDonald (2006, 2010) take an option-based approach to valuing guarantees extended to Fannie Mae and Freddie Mac.

⁵See Kareken and Wallace (1978) and Panageas (2010).

⁶Our paper is also related to recent studies of the relative pricing of derivative securities. Coval, Jurek, and Stafford (2009) and Collin-Dufresne, Goldstein, and Yang (2010) compare the prices of CDX tranches to those of index options prior to and during the financial crisis, while Driessen, Maenhout, and Vilkov (2009), Carr and Wu (2009) and Schurhoff and Ziegler (2011) study prices of index versus individual options prior to the crisis.

that prompt a common crash. The difference between the costs of these insurance schemes is informative about the relative importance of aggregate and idiosyncratic risks, and is also informative about sector-wide government guarantees.

A. Δ -Matched Option Price Spreads

To align our comparison between insurance costs, we impose that the moneyness (Δ) of the two schemes are equal, an approach that we refer to as “ Δ -matching.” Δ represents the derivative of an option price with respect to the underlying asset price. This derivative provides an approximate percentage probability that the option expires with a positive payoff. Low values such as 20 indicate an option has a low payoff probability (or is “out-of-the-money”), and high values such as 80 indicate “in-the-money” (ITM) options.^{7,8}

To compare prices across time, sectors, and between puts and calls, we define the *cost per dollar insured* as the price of an option position divided by the dollar amount that it insures. We then define a sector’s *basket-index put spread* as the difference in the per dollar costs of basket and index insurance:

$$Spread_{put,t} = \frac{Put_t^{basket}}{\sum_{j=1}^N K_{j,t} Sh_{j,t}} - \frac{Put_t^{index}}{K_t^{index}}. \quad (1)$$

$K_{j,t}$ and K_t^{index} are the corresponding strike prices of a put on stock j and the sector index, respectively. Call spreads are defined analogously. We build the call and put spread in all sectors for each day in our sample.

The remainder of this section describes the behavior of basket-index option spreads observed in the data. We find that OTM put options on the index were cheap during the financial crisis relative to individual stock options, while OTM index calls were relatively expensive. This pattern is much more pronounced for the financial sector than for non-financial sectors.

⁷While put options have negative Δ , we use the convention of taking the absolute value, so that all reported Δ s are positive. Short-dated at-the-money (ATM) forward options have a Δ of approximately 50.

⁸In the appendix we consider an alternative method for constructing the basket that matches the total dollar amount of insurance protection between the index and individual option basket, an approach we refer to as “strike-matching.” The conclusions from spreads based on either matching scheme are identical. We also compare index and basket put prices using options positions that share the same sensitivity to changes in stock return volatility (the so called option “vega”). With the vega-matched approach, spreads between index and basket put prices widen even more for financials versus non-financials compared to the Δ -matched results reported below. Detailed estimates from our vega-matched put price comparison are available upon request.

B. Data

We use daily options data from January 1, 2003 until June 30, 2009. This includes option prices on the nine S&P 500 sector index exchange-traded funds (ETFs) traded on the Chicago Board of Exchange (CBOE).⁹ As ETFs trade like stocks, options on these products are similar to options on an individual stock. The nine sector ETFs have no overlap and collectively span the entire S&P 500. Appendix A.I contains more details and lists the top 40 holdings in the financial sector ETF.¹⁰ We also use individual option data for all members of the S&P 500. The OptionMetrics Volatility Surface provides daily European put and call option prices that have been interpolated over a grid of time to maturity and option Δ , and that are adjusted to account for the American option feature of the raw option data.¹¹ These constant maturity and constant moneyness options are available at various intervals between 30 and 730 days to maturity and at values of (absolute) Δ ranging from 20 to 80. We focus primarily on options with 365 days to maturity and Δ of 20.

We use CRSP for returns, market equity, and number of shares outstanding for sector ETFs and individual stocks. We calculate the realized volatility of index and individual stock returns, as well as realized correlations among stocks in each sector. Our calculations exactly track the varying composition of the S&P 500 index (as well as the sector indices) to maintain consistency between the composition of the option basket and the index option each day.

C. Main Facts

Panel A in Table 1 provides summary statistics for the basket-index spread, in cents per dollar insured, using the Δ -matched approach where Δ is 20 and time to maturity is 365 days. The first two columns report results for the financial sector. Columns three

⁹We use SPDR ETFs and discuss this sample in detail in Appendix A.I.

¹⁰Our sample length is constrained by the availability of ETF option data. For the financial sector (but not for all non-financial sectors), we are able to go back to January 1999. The properties of our main object of interest, the basket-index put spread for financials, do not materially change if we start in 1999.

¹¹The option price adjustment performed by OptionMetrics converts prices of American options into equivalent European option prices. This allows us to compare them to the European option price formula we later compute in our model. To ensure that our facts regarding basket-index put spreads are not driven by widening bid-ask spreads during the financial crisis, we reconstruct an alternative basket-index spread series using raw option price quotes rather than the interpolated volatility surface provided by OptionMetrics. This also serves as a check that OptionMetrics interpolated prices do not suffer from inaccurate extrapolation or reliance on illiquid contracts. We explore this robustness check in detail in Appendix A.III. To summarize, results from raw options data, combined with accounting for bid-ask spreads and contract liquidity, generates put spreads that are qualitatively identical, and quantitatively very similar, to the results we report above.

Table 1: BASKET-INDEX SPREADS

		Financials		Non-financials		Difference	
		Puts	Calls	Puts	Calls	Puts	Calls
Pre-Crisis	Mean	0.80	0.31	1.39	0.42	-0.59	-0.10
	Std. Dev.	0.19	0.06	0.45	0.06	-0.26	0.00
	Max.	2.27	0.49	3.26	0.53	-0.99	-0.04
Crisis	Mean	3.73	0.06	2.09	0.33	1.64	-0.27
	Std. Dev.	2.31	0.16	0.76	0.09	1.55	0.07
	Max.	12.12	0.37	5.00	0.49	7.13	-0.12

Notes: This table reports summary statistics for the basket-index spread for the financial sector, non-financial sectors and their difference (financials minus non-financials). Non-financial spreads are equity-value-weighted averages of the individual spreads for the eight non-financial sectors. Units are cents per dollar insured. The full sample covers January 2003 to June 2009. The pre-crisis sample covers January 2003 to July 2007. The crisis sample covers August 2007 to June 2009. Δ is 20. Time to maturity is 365 days. Spreads are constructed as described in Section I.A.

and four report results for a value-weighted average of the eight non-financial sectors. The last two columns report the differences in the spread between the financial and non-financial sectors. An increase in the spread between the basket and the index means index options become cheaper relative to the individual options. We report statistics for the January 2003 to July 2007 pre-crisis sample and the August 2007 to June 2009 crisis sample.

Over the pre-crisis sample, the mean spread for OTM puts is 0.80 cents per dollar insured in the financial sector, and 1.39 cents in the non-financial sectors. During the financial crisis, the mean put spread is 3.73 cents per dollar for financials and 2.09 cents for non-financials. While there is an across-the-board increase in the put spread from the pre-crisis to the crisis periods, the increase is much more pronounced for financials (4.7 times versus 1.5 times for non-financials). The largest basket-index put spread for financials is 12.12 cents per dollar, recorded on March 6, 2009. It represents 68% of the cost of the index option on that day. On that same day, the difference between the spread for financials and non-financials peaks at 9.10 cents per dollar insured. Prior to the crisis, the put spread for financials never exceeds 2.3 cents on the dollar, and it never exceeds the non-financial put spread by more than 0.10 cents. Across the entire sample and all sectors, the average basket-index spread for OTM calls is smaller than for puts: 0.24 cents for financials and 0.39 cents for non-financials. Average OTM call spreads fall slightly during the financial crisis, reaching 0.06 cents for financials and 0.33 cents for non-financials.

Panel A of Figure 1 plots financial sector put prices for the entire sample. The green line shows the cost of the basket of put options per dollar insured and the blue line plots the cost of the financial sector put index. Before the financial crisis, the basket-index

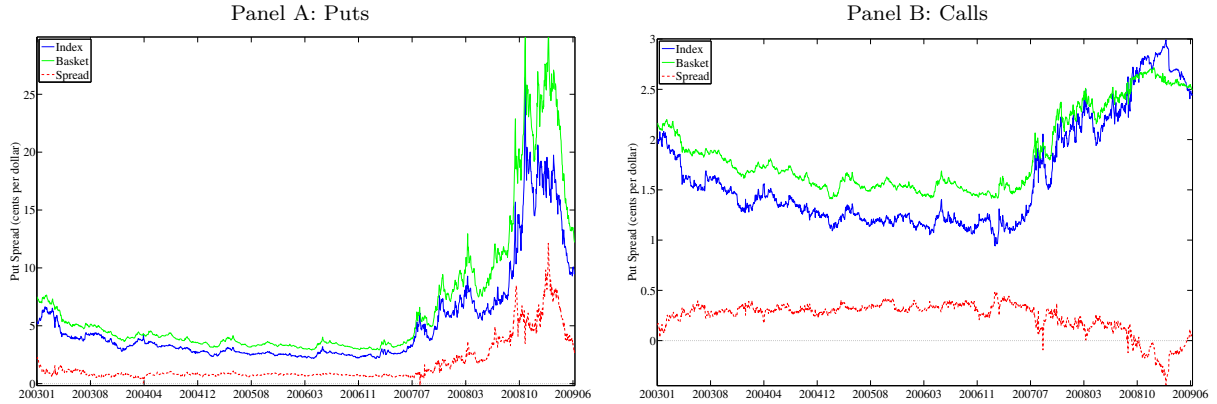


Figure 1: COST OF INSURING FINANCIAL SECTOR EQUITY

Notes: The figure plots the cost of financial sector insurance based on options on the index (blue line) and options on the basket (green line), as well as the basket-index spread (dashed red line). Units are cents per dollar insured. Δ is 20 and time to maturity is 365 days. Panel A uses put options and Panel B uses calls. Spreads are constructed as described in Section I.A.

put spread (red dashed line) is small and essentially constant at around one cent per dollar. During the crisis, it increases as the index option gradually becomes cheaper relative to the basket of puts. The basket cost occasionally exceeds 25 cents per dollar insured while the cost of the index put rarely rises above 20 cents. Panel B of Figure 1 plots call option prices and the call spread. During the crisis, the difference between index calls and the basket of individual calls falls relative to its pre-crisis level. We find similar results for call spreads in all other sectors.

Figure 2 compares the put spread in financial and non-financial sectors. For financials (blue), the put spread starts to widen in August 2007 (the asset-backed commercial paper crisis), spikes in March 2008 (the collapse of Bear Stearns), and then spikes further after the bailouts of Freddie Mac and Fannie Mae and the Lehman Brothers bankruptcy in September 2008. After a decline in November and December of 2008, the basket-index spread peaks a second time with the rescue of AIG in March 2009. For non-financials (green), the basket-index spread remains low until October 2008. The red dashed line plots the difference in put spread between the financial sector and non-financial sectors. This difference is negative pre-crisis, indicating that financial sector index options compared to the cost of the basket were more expensive than their non-financial counterpart. However, the difference in put spreads becomes positive in August 2007 with the onset of the crisis. It increases from the summer of 2007 to October 2008, falls until the end of 2008, and increases dramatically from January to March 2009.

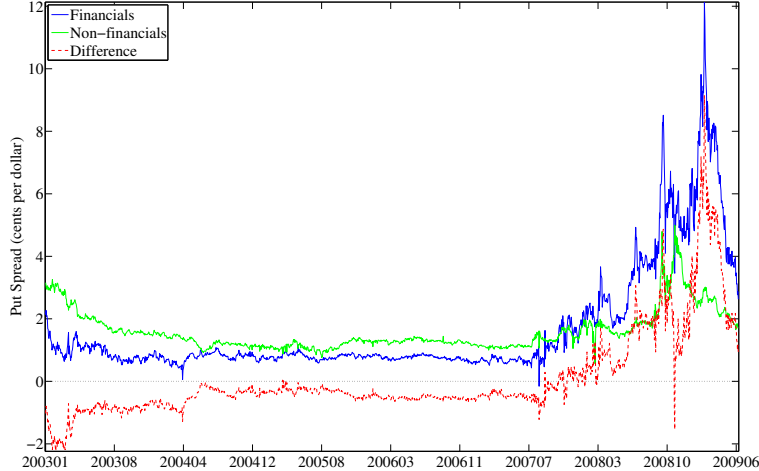


Figure 2: BASKET-INDEX PUT SPREAD ACROSS SECTORS

Notes: The blue line shows the basket-index put option spread for the financial sector. The green line shows equity-value-weighted average spread for non-financial sectors. The difference, financials minus non-financials, is the dashed red line. Units are cents per dollar insured. Δ is 20 and time to maturity is 365 days. Spreads are constructed as described in Section I.A.

D. The Effect of Moneyness

Panels A and B of Table 2 report the cost of insurance for the basket versus the index as a function of moneyness (Δ); these are to be compared with the $\Delta = 20$ results in Table 1. Option prices are typically higher when options are less out-of-the-money, and results show that basket-index spreads also increase in moneyness. However, the proportional increase in the basket-index spread from pre-crisis to crisis is larger for OTM put options than for ATM put options: The put spread increases by a factor of 4.7 for $\Delta = 20$, 3.5 for $\Delta = 30$, 2.9 for $\Delta = 40$. For non-financials, the put spread increase during the crisis is far smaller than for financials across moneyness. The difference between financials and non-financials (reported in the last two columns) during the crisis is larger for OTM puts (1.6 cents per dollar at $\Delta = 20$, 1.3 at $\Delta = 30$, and 1.0 at $\Delta = 40$). As a fraction of the average crisis cost for financial sector index puts, the financials minus non-financials put spreads are larger for deep OTM options (17% for $\Delta = 20$ versus 6% for $\Delta = 40$). Similarly, the difference in maximum put spread (as a fraction of the financials index crisis maximum) falls from 27% to 18% as moneyness increases from $\Delta = 20$ to $\Delta = 40$.

1. Bending the Implied Volatility Skew

The volatility skew refers to the graph of Black-Scholes implied volatilities as a function of the Δ of the option, and is frequently used to summarize the pricing of options by

Table 2: OPTION SPREADS BY MONEYNES AND MATURITY

		Financials		Non-financials		Difference	
		Puts	Calls	Puts	Calls	Puts	Calls
Panel A: Maturity of 1 year, $\Delta = 30$							
Pre-Crisis	Mean	1.18	0.59	1.97	0.80	-0.78	-0.21
	Max.	2.40	0.84	3.89	1.02	-1.49	-0.18
Crisis	Mean	4.17	0.15	2.85	0.66	1.33	-0.52
	Max.	12.98	0.75	6.10	0.98	6.87	-0.23
Panel B: Maturity of 1 year, $\Delta = 40$							
Pre-Crisis	Mean	1.61	0.95	2.61	1.30	-1.00	-0.35
	Max.	2.95	1.41	4.51	1.69	-1.57	-0.29
Crisis	Mean	4.63	0.31	3.61	1.14	1.02	-0.84
	Max.	13.47	1.29	6.92	1.70	6.55	-0.41
Panel C: Maturity of 30 days, $\Delta = 20$							
Pre-Crisis	Mean	0.17	0.15	0.24	0.16	-0.07	-0.01
	Max.	0.38	0.27	0.56	0.32	-0.18	-0.05
Crisis	Mean	0.61	0.09	0.35	0.23	0.26	-0.14
	Max.	2.39	0.27	1.19	0.35	1.20	-0.08

Notes: This table reports summary statistics of put and call basket-index spreads for the financial sector, non-financial sectors and their difference (financials minus non-financials). Non-financial spreads are equity-value-weighted averages of the individual spreads for the eight non-financial sectors. Units are cents per dollar insured. The pre-crisis sample covers January 2003 to July 2007. The crisis sample covers August 2007 to June 2009. Δ is 30 in Panel A, 40 in Panel B, and 20 in Panel C. Time to maturity is 365 days in Panels A and B and 30 days in Panel C. Spreads are constructed as described in Section I.A.

moneyness. Typically, the volatility skew is downward sloping for both index and basket puts, meaning that OTM options are expensive relative to ATM options. Panel A of Figure 3 plots the difference between the put-implied volatility skew for the basket and the index. In normal times, the slope of the volatility skew is roughly the same for the basket and index, so that the difference in their skews is flat across moneyness. Pre-crisis, the basket-index skew spread is flat across moneyness in both the financial sector (squares) and the non-financial sector (diamonds). The same flat shape appears for the basket-index skew spread in non-financial sectors during the crisis (stars), but not in the financial sector during the crisis (circles). The basket-minus-index implied volatility reaches a maximum of 11.5% for $\Delta = 20$ and gradually decreases to 9% for $\Delta = 50$. The guarantee effectively flattens the implied volatility skew for index put options much more than it does for individual options. Intuitively, this downward slope arises because a government guarantee has relatively more impact on index put prices with lower strikes (deeper OTM).

Finally, Panel B of Figure 3 plots the implied volatility skew spread inferred from calls. Here we see the exact opposite pattern. During the crisis, the financial sector

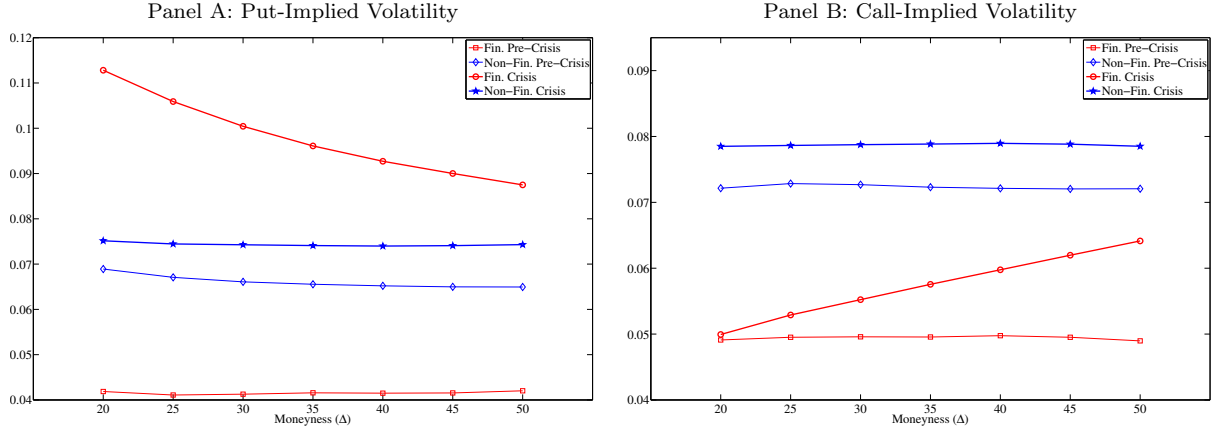


Figure 3: IMPLIED VOLATILITY SKEW

Notes: The figure plots average differences in Black-Scholes implied volatility, basket minus index, across moneyness. Basket volatility is an equity-value-weighted average among stocks in each sector. Volatilities are inferred from puts (Panel A) and calls (Panel B) for financials and non-financials. Non-financial volatility differences are equity-value-weighted averages of the differences for each of the eight non-financial sectors. The pre-crisis sample covers January 2003 to July 2007. The crisis sample covers August 2007 to June 2009. Δ ranges from 20 to 50 and time to maturity is 365 days.

basket-index skew spread for calls has a positive slope (circles). This is because OTM index call options became substantially more expensive relative to the basket of calls. In the absence of a bailout guarantee (which has little effect on OTM calls), this is the picture we would expect to see for puts. This evidence is consistent with the presence of a government guarantee in the financial sector.

E. The Effect of Time-To-Maturity

Panel C of Table 2 reports the cost of insurance for the basket versus the index for one-month options; these are to be compared with the results in Table 1 for one-year options. Basket-index spreads are mechanically smaller for shorter-dated options since option prices increase with maturity. However, the spread patterns are the same as for one-year options. The average put spread for financials is 0.6 cents per dollar in the crisis, up 3.6 times from its pre-crisis level. For non-financials, the put spread increases by a factor of 1.5. The 30-day spread reaches a maximum of 2.4 cents on the dollar, or 51% of the cost of the index option on that day. Call spreads fall slightly for financials and rise slightly for non-financials. Per unit of time (that is, relative to the ratio of the square root of maturities), the put spread increase during the crisis is larger for 30-day options than for 365-day options. Put spreads rise 4.6 times for 12-month options and 3.6 times for one-month options.

Table 3: BASKET-INDEX PUT SPREADS BY SECTOR

	Financials	Materials	Cons. Disc.	Industrials	Technology	Cons. Staples	Health Care	Energy	Utilities
Pre-crisis	0.80	1.19	1.89	1.06	1.72	1.16	1.67	0.59	0.85
Crisis	3.73	2.86	3.17	2.13	2.63	1.85	2.20	0.87	1.10
Difference	2.93	1.67	1.28	1.07	0.91	0.69	0.53	0.28	0.26

Notes: This table reports summary statistics for the basket-index put spread for each sector of the S&P 500. Units are cents per dollar insured. The pre-crisis sample covers January 2003 to July 2007. The crisis sample covers August 2007 to June 2009. Δ is 20 and time to maturity is 365 days. The last column reports the increase in sector put spread from pre-crisis to crisis, and sectors are ordered by crisis spread increase. Spreads are constructed as described in Section I.A.

F. Sector Analysis

Table 3 compares the basket-index spread for all nine sectors of the S&P 500. The only other sectors that experience significant increases in the basket-index spread during the crisis are the consumer discretionary sector and the materials sector. Major components of these sectors are car manufacturers and parts suppliers, as well as retail, home construction, hotels and other businesses with substantial direct and indirect real estate exposure. The auto industry benefited directly from a federal government bailout in the fourth quarter of 2008, and the materials sector ETF has large exposure to businesses benefiting from government guarantees. Examples include U.S. Steel, whose large customers include the automotive and construction industries, and Weyerhaeuser, which produces building materials and operates a large real estate development segment. The basket-index spread peaks at 7.7 and 7.6 cents per dollar insured for these sectors, increasing on average by a factor of 1.7 and 2.4. It is plausible that these sectors benefited more than other non-financial sectors from collective guarantees. Financial sector spreads increased by far more still (a factor of 4.7).

G. Changes in Idiosyncratic Risk

By measuring return correlations among stocks within a sector, we can evaluate the relative importance of aggregate and idiosyncratic risk for the sector, and how it evolved over time. When correlations are high, stock returns are dominated by common risks, and when they are low, returns are more influenced by idiosyncratic fluctuations. If idiosyncratic bank risk disproportionately increased relative to aggregate financial sector risk during the crisis, it might explain the observed increase in the price of individual bank insurance relative to insurance on the financial sector as a whole and relative to other sectors. In this section, we show that facts regarding the importance of idiosyn-

Table 4: REALIZED CORRELATIONS

	Panel A: All			Panel B: Index Below Median		
	Financials	Non-financials	Difference	Financials	Non-financials	Difference
Pre-Crisis	0.49	0.37	0.12	0.28	0.19	0.09
Crisis	0.67	0.53	0.13	0.46	0.34	0.12
Difference	0.18	0.16	0.02	0.18	0.15	0.03
	Panel C: Index Below 25 th Percentile			Panel D: Index Below 10 th Percentile		
	Financials	Non-financials	Difference	Financials	Non-financials	Difference
Pre-Crisis	0.22	0.13	0.09	0.17	0.08	0.09
Crisis	0.38	0.28	0.10	0.31	0.21	0.10
Difference	0.16	0.15	0.01	0.14	0.13	0.01

Notes: This table reports average realized return correlations for the financial sector, non-financial sectors and their difference (financials minus non-financials). We estimate daily correlations using a six-month rolling window, and report averages for the pre-crisis sample (January 2003 to July 2007), the crisis sample (August 2007 to June 2009), and their difference (crisis minus pre-crisis). Panel A reports standard correlations. The remaining panels report downside correlations for days on which the sector index return was below its median (Panel B), 25th percentile (Panel C), or 10th percentile (Panel D) in the rolling window. Estimates for non-financial sectors are equity-value-weighted averages of the eight separate sector correlations.

cratic versus aggregate risk go the wrong way. Rather than explaining the put spread evidence, they exacerbate the puzzle.

1. Realized Correlations

We calculate average correlations in each sector during the pre-crisis and crisis periods. For each day t , we calculate average pairwise correlation within a sector by inverting the definition of index variance, imposing that $\rho_t = \rho_{i,j,t}$ for all stock pairs (i, j) :¹²

$$\rho_t = \frac{\sigma_t^2 - \sum_{j=1}^N w_{j,t}^2 \sigma_{j,t}^2}{\sum_{j,i \neq j} w_{j,t} w_{i,t} \sigma_{j,t} \sigma_{i,t}}, \quad (2)$$

where σ_t^2 is the time t variance of the sector index, $\sigma_{j,t}^2$ is the variance of the j^{th} stock in the sector, N is the number of stocks comprising the sector and $w_{j,t}$ are market value weights. Variances for the sector index and for individual stocks are estimated using a six-month rolling window.

Panel A of Table 4 show that average correlations in the financial sector rose sharply from their pre-crisis level of 49% to 67% during the crisis. This indicates that, while common and idiosyncratic bank risks both increased during the crisis, aggregate risks became relatively more important. Furthermore, correlations rose more in the financial sector than in non-financial sectors. Absent bailout guarantees, this would predict a

¹²Imposing equicorrelation is tantamount to estimating the average pairwise correlation among stocks (Engle and Kelly, 2012).

narrowing of financial sector spreads relative to non-financial spreads, the opposite of what we see in the data.

Calls and puts are similarly influenced by volatility dynamics. Therefore, if observed financial sector put spreads are explainable with a run-up in idiosyncratic risk, it would also imply a large increase in the call spread. This is counterfactual: Table 1 shows that the call spread in fact *fell* from 0.31 cents to 0.06 cents during the crisis.

Because we see such different spread behavior for financial sector put spreads and call spreads, is it possible that banks' idiosyncratic downside risk behaved differently than upside risks? To consider this possibility, we estimate downside correlations. In particular, we calculate ρ_t only using days in which the sector index performed poorly. We look at days on which the sector index return was below its median (Table 4, Panel B), 25th percentile (Panel C), and 10th percentile (Panel D) during the rolling window.¹³ The downside-specific comovement measures paint a similar picture to the results for total correlations. Downside correlations rose during the crisis, and they rose slightly more for financials than for non-financials.¹⁴

In summary, we find that realized aggregate financial sector risk increased disproportionately more than idiosyncratic bank risk, which presents a challenge to any explanation for the large increase in the financial sector basket-index spread during the crisis that relies on large increases in idiosyncratic bank risk.

2. Implied Correlation

Implied correlation is a well-known metric used to compare the cost of index options versus individual stock options (Driessen, Maenhout, and Vilkov, 2009). While it does not measure the value of crash insurance directly, implied correlation may be used to summarize how the market prices tail risk at the sector and firm levels. Much like the average physical-measure correlation in equation (2), $\tilde{\rho}_t$ estimates the average correlation within a sector under the risk-neutral measure. It is based on Black-Scholes

¹³For similar approaches to estimating downside correlation, see Boyer, Gibson, and Loretan (1997) and Ang and Chen (2002).

¹⁴We also consider whether extreme idiosyncratic crash risks changed differentially for the financial sector and individual banks (and relative to non-financials), since this may be missed by standard correlation-based dependence measures. We appeal to extreme value theory and calculate a well known semi-parametric measure of tail risk used in the statistics literature (Sibuya, 1959; Poon, Rockinger, and Tawn, 2004) that captures the likelihood of simultaneous extreme downside moves in the index and the individual stock. We find that lower tail dependence increased for all sectors during the crisis, and that the increase was larger for financials than for non-financials. Results are available upon request.

Table 5: IMPLIED CORRELATIONS

	Financials			Non-financials			Difference		
	Puts	Calls	Diff.	Puts	Calls	Diff.	Puts	Calls	Diff.
Pre-Crisis	0.69	0.55	0.14	0.55	0.45	0.11	0.14	0.10	0.04
Crisis	0.66	0.75	-0.09	0.61	0.52	0.10	0.04	0.23	-0.19
Difference	-0.03	0.20	-0.23	0.06	0.07	-0.01	-0.09	0.13	-0.23

Notes: This table reports average implied correlations for the financial sector, non-financial sectors and their difference (financials minus non-financials). Estimates for non-financial sectors are equity-value-weighted averages of the eight separate sector correlations. We report averages for the pre-crisis sample (January 2003 to July 2007), the crisis sample (August 2007 to June 2009), and their difference (crisis minus pre-crisis). We calculate implied correlations separately based on calls and puts, as well as their difference (puts minus calls). Δ is 20 and time to maturity is 365 days.

implied volatilities of index options ($\tilde{\sigma}_t$) and individual stock options ($\tilde{\sigma}_{j,t}$):

$$\tilde{\rho}_t = \frac{\tilde{\sigma}_t^2 - \sum_{j=1}^N w_{j,t}^2 \tilde{\sigma}_{j,t}^2}{\sum_{j,i \neq j} w_{j,t} w_{i,t} \tilde{\sigma}_{j,t} \tilde{\sigma}_{i,t}}.$$

As the index option becomes cheap relative to individual options (the basket-index spread increases), the implied correlation falls. This is a useful complement to the basket-index spread for two reasons. First, since this metric is a correlation, the numbers are easy to interpret and are bounded by one in absolute value. Second, it uses Black-Scholes implied volatilities as inputs to remove mechanical effects that might be due to differences in underlying prices or other contract-specific features.

We compute implied correlations for each of the nine S&P sectors and report summary statistics in Table 5. We separate results based on OTM ($\Delta = 20$) puts and OTM calls. For financial sector puts, the average implied correlation for financials decreases from 0.69 in the pre-crisis sample to 0.66 in the crisis sample, while call-implied correlations rise 20 percentage points from 0.55 to 0.75. The difference-in-differences (puts minus calls) amounts to a decrease of 23 percentage points for put-implied correlations among financial firms. This drop in implied correlations is unique to the financial sector. For non-financials, both put- and call-implied correlations rise, and the difference-in-differences is only one percentage point. Put- and call-implied correlations in non-financial sectors also behave similarly to realized correlations reported in Table 4. The same is true for call-implied and realized correlations in the financial sector. However, for financial sector puts, there is a sharp divergence between implied and realized correlations. These comparisons reinforce the put spread evidence that financial sector puts became unusually cheap during the crisis.

The averages conceal interesting variation. Figure 4 plots correlations implied by OTM put options prices (Panel A) and OTM calls (Panel B). To emphasize the pre-

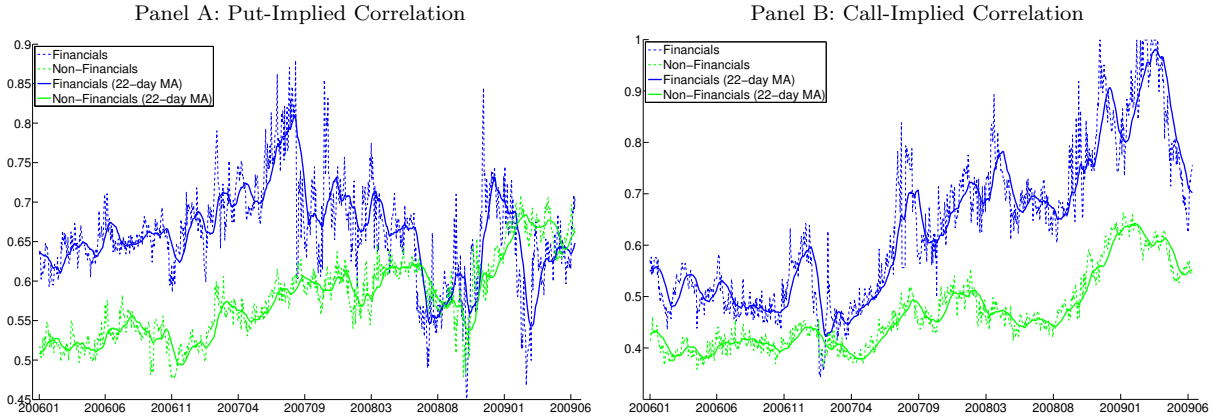


Figure 4: IMPLIED CORRELATIONS

Notes: Panel A plots put-implied correlations for the financial and non-financial sectors, Panel B plot call-implied correlations. Estimates for non-financial sectors are equity-value-weighted averages of the eight separate sector correlations. Dotted lines show daily estimates and solid lines show 22-day moving averages. Δ is 20 and time to maturity is 365 days.

crisis to crisis transition, the figure zooms in on the 2006-2009 period. The dynamics in implied correlations mirror those of the basket-index put spread. Before the crisis, the put-implied correlation is much higher for financials than for non-financials. This pattern reverses during the crisis. The put-implied correlation for financials peaks near 0.9 in the summer of 2007 and then begins a gradual decline. The largest decline (from 0.7 to 0.5) is in the summer of 2008 around the failure of Lehman Brothers. In late 2008, the implied correlation briefly increases again, only to come back down and bottom-out in March 2009. The put-implied correlation for non-financials began a gradual increase at the start of 2007, an increase only briefly interrupted around the failure of Lehman. Panel B shows that call-implied correlations increase during the crisis for both financials and non-financials, in sharp contrast to put-implied correlations. In summary, the dynamics of option-implied correlations are fully consistent with our findings on the dynamics of the basket-index spreads discussed above.

II. Benchmark Models

In this section, we consider the possibility that the dramatic increase in volatilities and correlations during the crisis may differentially affect individual and index options, leading in and of itself to an increase in the basket-index put spread. We develop a state-of-the-art option pricing model to quantify how observed changes in risks would affect the put spread in the absence of a government guarantee. Comparing realized

put spreads against a model-based counterfactual allows us to decompose the data into two parts: the portion of spreads explainable by observed variation in the risks of underlying index and stock prices, and a residual due to effects outside of the model, such as government guarantees.

A. Factor Model for Returns

We develop a continuous-time common-factor model of returns for pricing options. Denote the index price as X_t and the individual stock price as S_t . The instantaneous return on a stock follows:

$$\frac{dS_t}{S_t} = \frac{dX_t}{X_t} + \frac{dI_t}{I_t},$$

where dX_t/X_t is the sector index return and dI_t/I_t is the idiosyncratic stock return. We assume that the stock has a beta of one on the index. This is without loss of generality since we build a representative stock from the complete value-weighted set of sector index constituents.

The index price follows a continuous-time jump diffusion:

$$\begin{aligned} \frac{dX_t}{X_t} &= rdt + \sqrt{v_t}dW_t^X + dJ_t^X \\ dv_t &= (\theta_v - \kappa_v v_t) dt + \sigma_v \sqrt{v_t} dW_t^v, \end{aligned} \quad (3)$$

where W_t^X and W_t^v are Brownian motions with correlation ρ_{Xv} .¹⁵ The index may be subject to stochastic variance, v_t , as in Heston (1993), and may experience price jumps, dJ_t^X , as in Merton (1976).¹⁶

The stock-specific price component takes the same form as the index and may also possess idiosyncratic stochastic variance, z_t , and jumps dJ_t^I :

$$\begin{aligned} \frac{dI_t}{I_t} &= \sqrt{z_t}dW_t^I + dJ_t^I \\ dz_t &= (\theta_z - \kappa_z z_t) dt + \sigma_z \sqrt{z_t} dW_t^z \end{aligned} \quad (4)$$

where W_t^I and W_t^z are Brownians with correlation ρ_{Iz} . Idiosyncratic processes I_t and

¹⁵The parameter ρ_{Xv} governs correlation between returns and shocks to volatility, and is known as a “leverage” effect (Black, 1976; Christie, 1982). The literature typically estimates this parameter at close to -1 . This implies that returns are more volatile on the downside, embedding negative skewness into the returns process. Further skewness is incorporated via price jumps.

¹⁶Jumps are a Poisson-Normal mixture and are defined as $dJ_t^X = ((e^{-q} - 1) dJ(\lambda_q) - \lambda_q \zeta_q dt)$, where $q \sim N(\mu_q, \sigma_q^2)$ and λ_q is the jump intensity. For the idiosyncratic price process, jumps are given by $dJ_t^I = ((e^{-b} - 1) dJ(\lambda_b) - \lambda_b \zeta_b dt)$, where $b \sim N(\mu_b, \sigma_b^2)$ and λ_b is the jump intensity. Aggregate and idiosyncratic jumps are independent.

z_t are uncorrelated with index processes X_t and v_t . We normalize initial prices to $X_0 = I_0 = 1$. Since we will estimate model parameters from options data, we specify this model under the risk neutral measure. This implies that the index has drift equal to the risk-free rate r , and the idiosyncrasy has drift of zero.

This factor structure is ideally suited to our interest in joint pricing of index and individual stock options. It allows for separate dynamics in common and idiosyncratic bank risks, which allows us to evaluate to what extent the basket-index put spread can be explained simply by changes in sector-wide or bank-specific risk. The general model nests well-known models as special cases. By fixing stochastic volatilities at a constant and setting jump risk to zero, we obtain a one-factor version of Black-Scholes. If we allow for stochastic volatility but no jump risk, we obtain a common-factor version of Heston’s (1993) model (Christoffersen, Fournier, and Jacobs, 2013).

The model falls into the affine jump-diffusion class of Duffie, Pan, and Singleton (2000) and we follow these authors to derive analytical expressions for European option prices (up to a Fourier transform). Appendix A.IV provides detailed derivations of index and individual put prices, denoted by $Put_{X,t} = f(v_t, 0, X_t, 0, K_t, r, T; \Theta_X, 0)$ and $Put_{S,t} = f(v_t, z_t, X_t, S_t, K_t, r, T; \Theta_X, \Theta_I)$, respectively, where K_t is the strike price, T is time to maturity, $\Theta_X = (\theta_v, \kappa_v, \sigma_v, \rho_{Xv}, \mu_q, \sigma_q^2, \lambda_q)$ is the vector of index price process parameters (under the risk-neutral measure) and Θ_I is the analogous vector of idiosyncratic process parameters.

To operationalize the model, we require estimates of the model’s two latent state variables v_t and z_t that govern index and basket option prices across all strikes and maturities. For a given set of model parameters, we invert v_t and z_t from ATM index and basket call options assuming that these are priced without error. We then use these implied state variable estimates to compute the price of OTM put options. We construct the model spread in the same way that we construct the empirical spread in equation (1), choosing Δ -matched basket and index puts (corresponding to strike prices $K_{S,t}$ and $K_{X,t}$ for the basket and index).¹⁷ The model put spread (in cost per dollar insured) on day t is denoted

$$\widehat{Spread}_{put,t} = \frac{\widehat{Put}_{S,t}}{K_{S,t}} - \frac{\widehat{Put}_{X,t}}{K_{X,t}}. \quad (5)$$

The analysis for OTM call spreads is conducted analogously. Estimation details are in Appendix A.IV.D.

¹⁷Our latent state estimates and put prices use observed option strike prices and using the maturity-appropriate daily risk-free rate based on the yield curve provided by OptionMetrics.

B. Black-Scholes Benchmark

We begin our model-based analysis of crisis spreads with the well known Black-Scholes option pricing model, then move on to the more sophisticated specifications. Four features make Black-Scholes an attractive starting point. First, it is the simplest model nested within our main specification making it useful for developing intuition behind our empirical findings. Second, it does not require estimating any parameters so we can evaluate fits that are not subject to estimation error. Third, it tracks time-series fluctuations in risk since Black-Scholes option prices are a straightforward function of the underlying index and individual stock volatilities. We view this as an interesting lens for studying basket-index spread dynamics, in the same tradition as using Black-Scholes to study implied volatility dynamics. Fourth, we show how to price options in a Black-Scholes model in the presence of an implicit government guarantee for the financial sector. Characterizing option prices amid a guarantee becomes intractable in the extended versions of our model that include stochastic volatility or jumps.

In the Black-Scholes version of the model, estimates of v_t and z_t are obtained as the Black-Scholes implied volatility of ATM ($\Delta = 50$) calls on the index and basket.¹⁸ From these inputs, equation (5) delivers a model-implied put spread. We follow the same procedure for constructing put option prices in the non-financial sectors.

Table 6 compares the data to Black-Scholes put prices taking into account the dynamics of basket and index volatility estimated from calls. The top panel shows results for financials, the middle panel shows non-financials, and the bottom panel shows their difference. The lower right portion of the table reports differences-in-differences: Financials minus non-financials and actuals minus Black-Scholes. In the pre-crisis period, the financial sector spread is 0.80 cents per dollar, while the Black-Scholes predicted spread is 0.67 cents. Similarly, Black-Scholes generates 1.09 of the 1.39 cent pre-crisis spread for non-financials. In the pre-crisis period, basket-index put spreads in both sectors are well explained by Black-Scholes using volatility estimated from ATM call options.

During the crisis, this unexplained residual in the financial sector increases nine-fold to 1.39 cents. Thus the model fails to match the sharp increase in the financial

¹⁸In the Black-Scholes version of the model, we rely on call-implied volatilities to track the prevailing level of sector-wide and idiosyncratic risk. In the NBER working paper version of this article, we measure return volatilities using a GARCH model and find qualitatively identical results. We use call-implied volatility to conform with our estimation approach in subsequent sections, and to emphasize the disparate price behavior of puts and calls. We have also explored measuring risks using implied volatilities from OTM rather than ATM call options. A bailout guarantee will in principle affect the pricing of all options, but OTM calls should be least sensitive to it. When we use $\Delta = 20$ calls, our results and conclusions are again qualitatively unchanged.

Table 6: MODEL FITS VERSUS DATA: BLACK-SCHOLES

	Index			Basket			Basket-Index		
	Actual	Model	Diff.	Actual	Model	Diff.	Actual	Model	Diff.
Financials									
Pre-crisis	3.14	0.72	2.42	3.94	1.38	2.56	0.80	0.67	0.13
Crisis	9.85	5.36	4.48	13.55	7.67	5.88	3.70	2.31	1.39
Difference	6.71	4.65	2.06	9.61	6.29	3.32	2.90	1.64	1.26
Non-financials									
Pre-crisis	3.09	1.25	1.83	4.48	2.35	2.13	1.39	1.09	0.29
Crisis	5.67	2.52	3.15	7.74	4.37	3.37	2.07	1.85	0.22
Difference	2.58	1.27	1.31	3.26	2.02	1.24	0.69	0.76	-0.07
Difference									
Pre-crisis	0.05	-0.54	0.59	-0.53	-0.96	0.43	-0.59	-0.43	-0.16
Crisis	4.18	2.84	1.34	5.81	3.30	2.51	1.62	0.46	1.17
Difference	4.13	3.38	0.75	6.34	4.26	2.08	2.21	0.88	1.33

Notes: This table reports average basket and index put prices for financials, non-financials, and their difference (financials minus non-financials) compared to the Black-Scholes model. Black-Scholes put price fits are based on ATM call-implied volatilities as described in Section II.B. Units are cents per dollar insured. The pre-crisis sample covers January 2003 to July 2007. The crisis sample covers August 2007 to June 2009. Δ is 20 and time to maturity is 365 days.

sector spread during the crisis. In contrast, the Black-Scholes model explains all of the increase in the basket-index spread for non-financials. The bottom panel shows that Black-Scholes predicts a spread increase of 0.88 cents for financials relative to non-financials, thus capturing only 39% of the 2.21 cent increase in actual spreads. Said differently, Black-Scholes accurately predicts the crisis spread increase for the non-financials sector, but can only explain a portion of the increase for financials. This is despite a sharp increase in average crisis volatility in all sectors (24 percentage points for financials and 10 points for non-financials).

Black-Scholes is well-known to underprice OTM index puts (Rubinstein, 1985; Pan, 2002; Bates, 2000), and a large literature argues that incorporating stochastic volatility and jumps in the underlying stock or index price process can improve model accuracy. The table indeed shows the substantial underpricing of index and basket put price levels. Because the underpricing for the basket and index are approximately equal prior to the crisis, the put spread residual from Black-Scholes is close to zero on average in that sample. We now turn to a state-of-the-art option pricing model that matches option price levels in addition to spreads.

C. Stochastic Volatility and Jumps

Our proposed model in equations (3) and (4) can closely match pre-crisis basket and index price levels in all sectors. The model continues to explain non-financial sector

spreads during the crisis. However, like the Black-Scholes model, it fails to explain the large basket-index spread among financials during the crisis.

Unlike Black-Scholes, this model requires us to estimate parameters. We estimate Θ_X and Θ_I from pre-crisis options prices using non-linear least squares. Given parameter estimates, we then assume ATM basket and index call options are perfectly priced by the model, which allows us to invert our pricing formulas for the latent state processes v_t and z_t . Using the model-implied volatilities and parameter estimates, we calculate the price of OTM ($\Delta = 20$) puts to construct the basket-index put spread. Because parameters are estimated on the pre-crisis sample, model-implied basket-index put spreads during the crisis are calculated on a purely out-of-sample basis. Appendix A.IV provides details for our approach and reports estimated parameter values.¹⁹

Table 7 reports fitted spreads in the stochastic volatility models without jumps (Panel A) and with jumps (Panel B). These richer models do a much better job than Black-Scholes in matching put price *levels* for both the basket and the index prior to the crisis, as evidenced by the columns labeled “Diff.” They also match basket and index option price levels for non-financials during the crisis. However, these models do not change the conclusion that put spreads in the financial sector appear much too large given the risks observed during the crisis. The models slightly overstate the put price of the financial sector index (financial index options appear cheap), and they underprice the basket. The bottom right-hand corner of each panel shows that the model without jumps predicts an increase in the basket-index put spread of financials relative to non-financials of 0.52 cents, while the model with jumps predicts an increase of 0.67 cents. That compares to a 0.88 cent increase of predicted by Black-Scholes (Table 6) and an observed increase of 2.21 cents. The richer models fail to improve on the Black-Scholes model predictions on this key statistic.

Figure 5 plots the daily time series of the difference between actual and model-implied put spreads for financials minus non-financials in each of the three models under consideration. It shows that the inability for observed risk dynamics to account for financial sector spreads in the crisis is *not* an artifact of the Black-Scholes model. More sophisticated models which allow for stochastic volatility and price jumps fail to match spreads in precisely the same manner as Black-Scholes.

¹⁹Parameter estimates suggest that the financial sector index has higher unconditional volatility (θ_V) and higher volatility of volatility (σ_v) than non-financial indices, while parameters of their idiosyncratic volatility processes (θ_z and σ_z) are similar. For the model with jumps, the financial sector index has less downside jump risk than non-financial indices, but individual bank stocks possess more idiosyncratic downside jump risk than non-financial firms. Pre-crisis model fits are somewhat better for the financial sector in terms of root mean squared pricing errors.

Table 7: MODEL FITS VERSUS DATA: STOCHASTIC VOLATILITY AND JUMPS

	Index			Basket			Basket-Index		
	Actual	Model	Diff.	Actual	Model	Diff.	Actual	Model	Diff.
Panel A: Stochastic Volatility, No Jumps									
Financials									
Pre-crisis	3.14	3.12	0.02	3.94	3.93	0.02	0.80	0.80	0.00
Crisis	9.85	10.04	-0.19	13.55	12.28	1.26	3.70	2.25	1.45
Difference	6.71	6.91	-0.21	9.61	8.36	1.25	2.90	1.44	1.45
Non-financials									
Pre-crisis	3.09	3.08	0.01	4.48	4.47	0.00	1.39	1.39	0.00
Crisis	5.67	4.74	0.93	7.74	7.05	0.69	2.07	2.32	-0.24
Difference	2.58	1.66	0.92	3.26	2.58	0.68	0.69	0.92	-0.24
Difference									
Pre-crisis	0.05	0.04	0.01	-0.53	-0.55	0.01	-0.59	-0.59	0.00
Crisis	4.18	5.30	-1.12	5.81	5.23	0.58	1.62	-0.07	1.69
Difference	4.13	5.26	-1.13	6.34	5.78	0.56	2.21	0.52	1.69
Panel B: Stochastic Volatility With Jumps									
Financials									
Pre-crisis	3.14	3.08	0.06	3.94	3.89	0.06	0.80	0.81	-0.01
Crisis	9.85	9.72	0.13	13.55	12.06	1.49	3.70	2.34	1.36
Difference	6.71	6.64	0.07	9.61	8.17	1.44	2.90	1.53	1.37
Non-financials									
Pre-crisis	3.09	3.08	0.01	4.48	4.47	0.00	1.39	1.39	0.00
Crisis	5.67	4.72	0.94	7.74	6.98	0.76	2.07	2.25	-0.18
Difference	2.58	1.64	0.94	3.26	2.50	0.76	0.69	0.86	-0.18
Difference									
Pre-crisis	0.05	-0.01	0.06	-0.53	-0.58	0.05	-0.59	-0.58	-0.01
Crisis	4.18	4.99	-0.81	5.81	5.08	0.73	1.62	0.09	1.54
Difference	4.13	5.00	-0.87	6.34	5.67	0.68	2.21	0.67	1.54

Notes: This table reports average basket and index put prices for financials, non-financials, and their difference (financials minus non-financials) compared to the model of Section II. Model put price fits are based on estimated parameters reported in Appendix A.IV.D and volatility state variables inferred from ATM call prices as described in Section II.C. Panel A reports fits from the model with stochastic volatility, setting jump risk to zero, while Panel B incorporates both stochastic volatility and jumps. Units are cents per dollar insured. The full sample covers January 2003 to June 2009. The pre-crisis sample covers January 2003 to July 2007. The crisis sample covers August 2007 to June 2009. Δ is 20 and time to maturity is 365 days.

D. Black-Scholes with a Government Guarantee

In the previous two sections, we documented a large increase in the basket-index put spread for financials relative to non-financials and showed that this spread was not accounted for by volatility dynamics. In this section, we show that observed basket-index put spread dynamics can be reconciled by a simple model once a collective government guarantee is introduced. Specifically, we extend the Black-Scholes model assuming that the maximum sector-wide loss rate tolerated by the government is fixed and common knowledge. This analysis illustrates how collective bailout guarantees

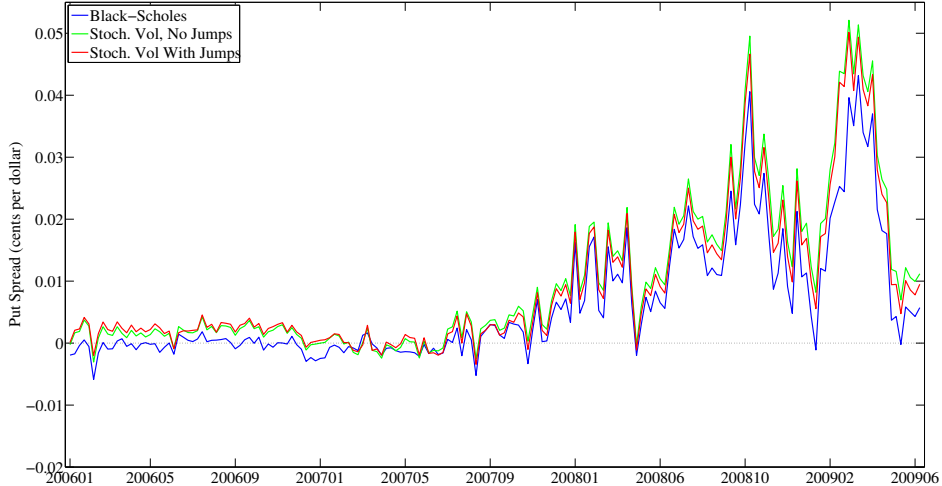


Figure 5: PUT SPREAD FITS ACROSS MODELS: DIFFERENCE-IN-DIFFERENCES

Notes: The figure compares fits from the Black-Scholes (blue), stochastic volatility (green), and stochastic volatility with jumps (red) models. Model put price fits are based on volatility state variables inferred from ATM call prices and estimated parameters reported in Appendix A.IV.D, as described in Sections II.B and Section II.C. Spreads are then plotted as difference-in-differences (actual minus model and financials minus non-financials). Units are cents per dollar insured. Δ is 20 and time to maturity is 365 days.

can produce a large put spread even when correlations among stocks in the sector are rising, and provides indirect evidence for our hypothesis that the government played an important role in generating observed spread patterns.

Prices for the stand-in individual stock follow the same process as in Section II with the following exception: The sector-wide index price is truncated from below by a government guarantee. The truncation point, \underline{X} , defines the government's maximum allowable loss for the sector as a whole. The bailout transforms the index price process into $\tilde{X}_t = \max(X_t, \underline{X})$. This also affects the price of individual stocks in the sector, though without modifying its idiosyncratic price variation. In the no-bailout version of the model, the price of the representative stock (or, equivalently, its gross return through time t) is $S_t = X_t I_t$. Under the bailout, the stock price process becomes $\tilde{S}_t = \tilde{X}_t I_t$.

The bailout embodied by \underline{X} is a stylized way of capturing a broad range of bailout policies, ranging from well-known rescue programs like TARP and TALF to programs providing liquidity to institutions that are fundamentally solvent but are at risk due to market failure or system-wide panic, or even conventional monetary policy.

We derive a closed-form expression for basket and index option prices in the bailout-adjusted Black-Scholes model. The derivation is detailed in Appendix A.V. Bailout-adjusted option prices depend on two new parameters in addition to the standard

Black-Scholes input: (1) \underline{X} and (2) the equity risk premium for the sector μ_t .²⁰ We perform comparative statics with respect to \underline{X} , but require an estimate of μ_t . To obtain a model-free, option-based estimate for the expected return (in levels), we implement the “simple variance swap” idea from Martin (2013).²¹ To compute the basket-index spread in the presence of a bailout, we follow the same procedure that we described in Section A. We extract model-implied index and basket volatilities from ATM call options, and use these to price put options within the model, delivering a daily put price for the basket and the index.

Figure 6 plots the basket-index spread for the financial sector (blue line) along with the predicted spread based on the basic Black-Scholes model (green line) and the Black-Scholes model with a government bailout guarantee (solid red line). The graph sets $\underline{X} = 0.65$, implying a maximum 35% loss rate on the aggregate component of stock prices. The red dashed line shows the difference between the two models with and without bailout. In the pre-crisis period, the models are identical. This is because, prior to the crisis, volatilities are too low for the bailout’s lower tail truncation to affect option prices. When volatilities spike during the crisis, the bailout model produces a spread that matches the data, while spreads in the no-bailout model are too low. Because the bailout truncates aggregate crash risk without alleviating idiosyncratic crash risk, it can account for the cheapness of financial sector index options relative to individual bank options.

Table 8 reports the basket-index put spread for the bailout model for different values of the guarantee threshold \underline{X} , and compares it to the data. A higher value for \underline{X} eliminates more of the aggregate downside risk and hence represents a stronger government guarantee. The put spreads in both the data and the bailout model are differenced against put spreads from the no-bailout Black-Scholes model. Prior to the crisis, the average put spread in deviation from Black-Scholes is 0.13 cents. At pre-crisis risk levels, the bailout model at best generates tiny price differences versus the no-bailout model for most values of \underline{X} . The real test for the bailout mechanism is the crisis sample, at which time Black-Scholes underestimates the spread by 1.39 cents.

²⁰The presence of a bailout guarantee disrupts the Black-Scholes no-arbitrage argument, introducing the need for a risk premium adjustment in option prices.

²¹Martin (2013) derives a model free measure of implied volatility, $SVIX$, from an equally-weighted average of put and call prices at different strikes. He shows that $SVIX$ establishes a lower bound on the expected risk premium under weak conditions. To implement our empirics, we assume the lower bound is satisfied with equality. We compute $SVIX$ for the financial sector index and, since it is based on options data across all strikes, our expected return estimate reflects effects of sector-wide guarantees on stock returns. This makes the empirical quantity directly comparable to the theoretical expected return entering the put price formula. Appendix A.V.C provides the details and shows how expected returns, volatilities, and correlations relate to the structural parameters of the model.

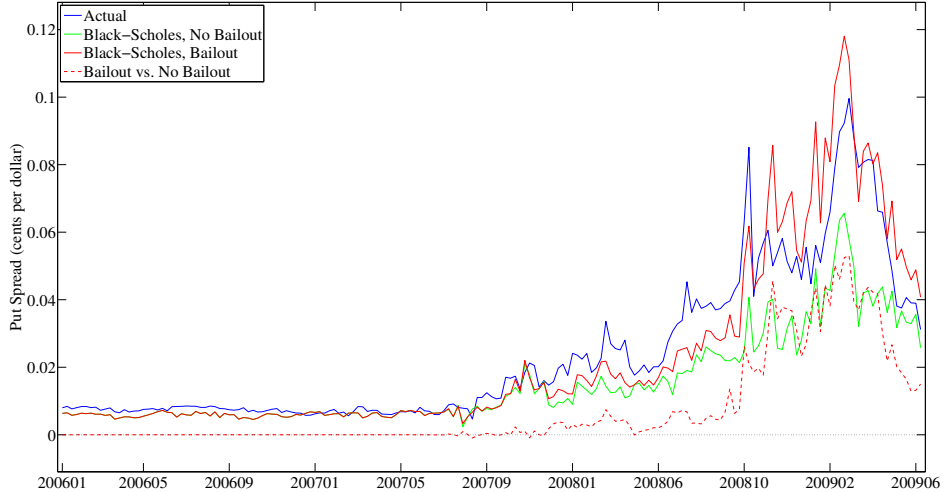


Figure 6: BLACK-SCHOLES PUT SPREADS WITH AND WITHOUT A BAILOUT

Notes: The figure plots the financial sector put spread (blue line) versus fitted values from the standard Black-Scholes model (green line) and Black-Scholes with a bailout guarantee (red line). It also plots the difference in fits between the two models (bailout fit minus no-bailout fit, red dashed line). Bailout model fits use $\underline{X} = 0.65$. Model fits are based on volatility inferred from ATM call prices as described in Sections II.B and Section II.D. Units are cents per dollar insured. Put Δ is 20 and time to maturity is 365 days.

Table 8: BLACK-SCHOLES PUT SPREADS WITH AND WITHOUT A BAILOUT

	Actual vs. No-Bailout	Black-Scholes: Bailout vs. No-Bailout								
		60%	55%	50%	45%	40%	35%	30%	25%	20%
Pre-crisis	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.17
Crisis	1.39	-0.02	0.03	0.16	0.48	1.13	1.40	0.69	0.04	-0.49

Notes: This table reports the average difference in fitted put spreads between the standard Black-Scholes model and Black-Scholes with a bailout guarantee, varying the maximum allowable loss rate ($1-\underline{X}$) for financial sector equity. The first column reports the average difference in put spreads between the data and the standard Black-Scholes model. Units are cents per dollar insured. Put Δ is 20 and time to maturity is 365 days. Fits are based on implied volatilities inferred from ATM call options.

When we choose the maximum loss to be 35% ($\underline{X} = 0.65$, which implies a maximum loss rate of 43% in terms of log returns), the bailout model produces crisis spreads 1.40 cents larger than those of Black-Scholes and thereby matches observed spreads in the data. Contrast this with our findings for non-financials in Table 6: The basic Black-Scholes model successfully matches crisis put spread dynamics without embedding a bailout guarantee.²²

²²When comparing the prices of options in models with and without a bailout (holding all else fixed), there are two effects that arise. The main effect comes from the index truncation, which lowers put prices in the bailout model, and makes puts cheaper for larger bailouts. But there is also a risk premium effect since, in the bailout model, the Black-Scholes risk-free no-arbitrage pricing argument does not hold (see Section II.D and Appendix A.V). This can have a countervailing effect on bailout option prices and produce non-monotonicity in spread differences across varying bailout sizes, as observed in Table 8.

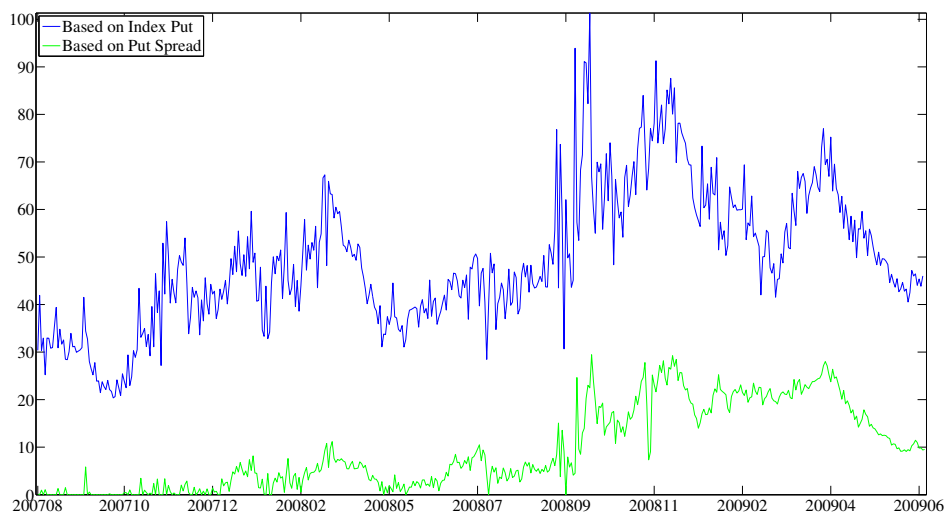
E. The Value of the Guarantee for Equity Holders

To quantify the value of the collective government guarantee to equity holders, we compare the cost of financial sector index put under the Black-Scholes model without bailout guarantee to the cost in the model with guarantee. Because we express put prices in cents per dollar insured and the maturity of the options is one year, the resulting number measures the reduction in the annual insurance premium for protection against catastrophic losses on the financial sector equity index attributable to the government guarantee. Because prices traded far from the bailout trigger pre-crisis, this measure assigns a near-zero value to the government guarantee before the summer of 2007. There is a small 0.03 percentage point reduction in the annual insurance premium due to the guarantee, which amounts to 0.63% of the actual cost of the index put pre-crisis. During the crisis, we find that the annual insurance premium enjoys a much larger subsidy: The annual premium is 5.35 percentage points lower, an average subsidy of 49% of the actual cost of the index put. During the last quarter of 2008 and the first quarter of 2009, the average subsidy represents 60% of the actual put value. These averages hide substantial time variation. The subsidy of the insurance premium reaches a maximum of 13.2 percentage points on March 6, 2009. On that day, the subsidy is nearly 75% of the actual cost of the insurance. On October 8, 2008, the 11.3 percentage point subsidy represents 91% of the cost of the index put.

We obtain a dollar value of the subsidy to equity holders of the financial sector by multiplying the annual insurance premium subsidy by the total dollar amount insured. The amount insured is calculated every day as the market capitalization of the financial sector (all financial firms in the S&P 500) multiplied by the ratio of the index strike price to the index spot price. We find that the daily average value of the government guarantee is \$0.4 billion pre-crisis, \$49.5 billion during the crisis and \$63.1 billion over 2008Q4 and 2009Q1. It breaches \$100 billion on October 8, 2008. The solid line in Figure 7 plots the dynamics of the subsidy during the crisis period.

An alternative approach to calculate the value of the government guarantee uses the difference in the basket-index put spread under Black-Scholes with and without guarantees. This approach is conservative. Even though the bailout only operates on the common component of stock prices, it will still have an effect on the price of the basket because each bank's stock price depends on that common component. Therefore, by subtracting the difference between the basket price without and with bailout from the difference of the index price without and with bailout, we are subtracting a positive amount from the true value of the government guarantee. While this alternative understates the value of the government subsidy, it has the advantage that the

Figure 7: Dollar Value of the Government Guarantee



Notes: The figure reports two measures of the dollar value of the collective bailout guarantee, expressed in billions of dollars. The solid line plots our main estimate, based on the put index price per dollar insured. The dashed line plots an alternative measure, based on the basket-index put spread. Both measures are multiplied by the total dollar amount insured, which is measured as the ratio of the index put to the index spot price multiplied by the total market capitalization of the financial sector component of the S&P 500. The sample covers the crisis period from August 2007 to June 2009.

Black-Scholes model does a better job at accurately fitting put spreads than put index levels, as explained above.

Using this conservative measure, we estimate the dollar value of the government guarantee at \$18.5 billion on average during 2008Q4 and 2009Q1. The insurance premium is three percentage points lower than it otherwise would be over this period, representing an 18% subsidy relative to the actual cost of the put index per dollar insured. The dashed line in Figure 7 plots the dynamics of the alternative dollar subsidy measure. It has a correlation of 77% with our main measure.

These numbers are economically large. The \$63 billion estimate is 6.6% of market capitalization on average during 2008Q4 to 2009Q1. It is also large relative to the size of the government rescue programs during the crisis, such as the \$250 billion equity injection under TARP. Most importantly, the subsidy to equity holders comes on top of the much larger subsidy to bond holders. For example, Veronesi and Zingales (2010) estimate a \$119 billion subsidy just to the bond holders of the 10 largest banks in the days around the TARP announcement.

III. Additional Evidence

A. Government Announcements

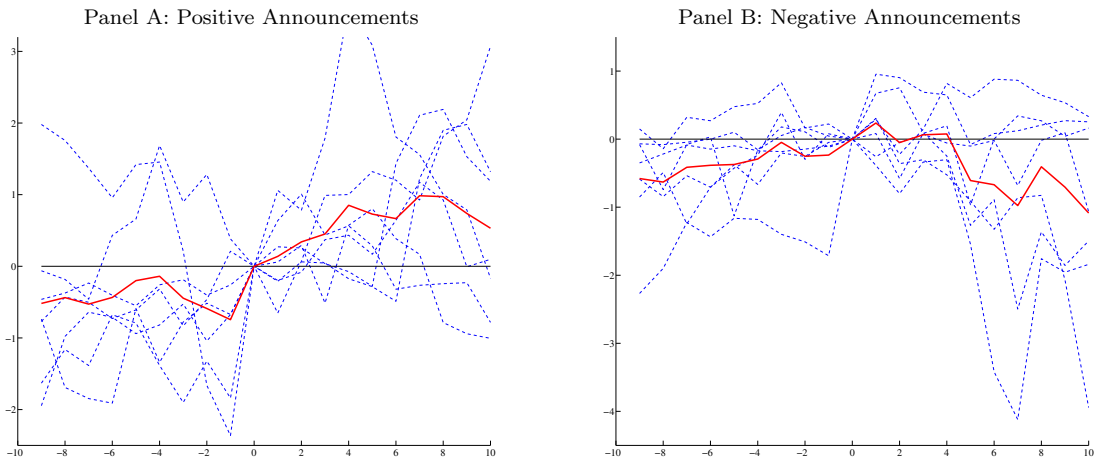
In this section, we provide evidence that the dynamics of the basket-index spread are closely tied to government policy announcements during the financial crisis of 2007-2009. Under the collective bailout hypothesis, an increase in the probability of a financial disaster increases the basket-index put spread. We focus on significant announcements for which we can determine the ex-ante sign of the effect on the likelihood (and size) of a collective bailout. Our evidence suggests that put spreads respond to government announcements in a manner consistent with the collective bailout hypothesis.

We identify seven events that increase the probability of a government bailout for shareholders of the financial sector: (1) July 13, 2008: Paulson requests government funds for Fannie Mae and Freddie Mac, (2) October 3, 2008: Revised bailout plan (TARP) passes the U.S. House of Representatives, (3) October 6, 2008: The Term Auction Facility is increased to \$900bn, (4) November 25, 2008: The Term Asset-Backed Securities Loan Facility (TALF) is announced, (5) January 16, 2009: Treasury, Federal Reserve, and the FDIC provide assistance to Bank of America, (6) February 10, 2009: The Federal Reserve announces it is prepared to increase TALF to \$1 trillion, (7) March 3, 2009: Treasury and Federal Reserve launch TALF. We refer to these as positive announcement dates.

We also identify seven negative announcements that (we expect ex-ante to) decrease the probability of a bailout for shareholders: (1) March 16, 2008: Bear Stearns is bought for \$2 per share, (2) September 7, 2008: Treasury announces plans to place Fannie Mae and Freddie Mac into conservatorship, (3) September 15, 2008: Lehman Brothers files for bankruptcy, (4) September 29, 2008: House votes no on the bailout plan, (6) October 14, 2008: Treasury announces \$250 billion capital injections, (6) November 7, 2008: President Bush warns against too much government intervention in the financial sector, and (7) November 13, 2008: Paulson indicates that TARP will not be used to buy troubled assets from banks.

We study put spread difference-in-differences (data minus Black-Scholes, financials minus non-financials) around announcement dates. By focusing on Black-Scholes-adjusted spreads, we ensure that results are not simply picking up volatility effects. Financial sector spreads rise 0.73 cents per dollar in the five days following a positive announcement, relative to non-financials. This represents a 20% increase relative to

Figure 8: PUT SPREADS AROUND GOVERNMENT ANNOUNCEMENTS



Notes: The figure shows the basket-index spread difference-in-difference (financials minus non-financials and actual minus Black-Scholes) around announcement dates. Panel A shows responses to positive announcements and Panel B shows responses to negative announcements. In each figure, the solid line shows the average spread response over all announcements, and the dotted lines show the responses to each individual announcement. Black-Scholes fits are based on volatilities inferred from ATM call prices as described in Section II.B. Δ is 20 and time to maturity is 365 days.

the average crisis spread for financials. Spreads fall on average by 0.61 cents per dollar in the five days following a negative announcement, or by 16% of the average financial sector crisis spread. The left panel of Figure 8 plots these positive announcements results in event time and the right panel plots negative announcements effects.

The largest positive effect occurred after the government announced the launch of TALF, which was designed to stimulate securitization markets by providing financing to institutions with large exposures to asset-backed securities. The announcement included the date when the first funds would be disbursed, and that interest rates and haircuts would be lower than previously planned. In the five days following the announcement, basket-index spreads in the financial sector widened 3.1 cents per dollar, nearly doubling the average financial sector crisis spread.

The failures of Bear Stearns and Lehman Brothers initially reduce the basket-index put spread. The Lehman failure was then followed by an increase in the spread as the resulting turmoil convinced markets that future bailouts would be more likely.²³ The largest negative effect was registered on October 14, 2008 when the U.S. Treasury announced the TARP would be used as a facility to purchase up to \$250 billion in preferred stock of U.S. financial institutions. The Treasury essentially shifted TARP's focus from purchasing toxic assets to recapitalizing banks. This decision diluted exist-

²³The AIG rescue announcement on the day that followed Lehman is consistent with this.

ing shareholders, driving the put spread down by 1.55 cents per dollar over the next five days. This was the start of a longer decline in the spread that was reinforced by speeches delivered by President Bush and Secretary of the Treasury Henry Paulson in early November. Clearly, there was a fear that bank shareholders would not receive the government bailout they had hoped for.

This decline in the spread was reversed only in early January 2009 when the FDIC, the Fed, and the Treasury provided assistance to Bank of America and explicitly announced programs to purchase toxic assets. The put spread started its largest increase in the beginning of February 2009 and peaked in March 2009 following the implementation of TALF. Our interpretation of the rising basket-index put spread is that markets became gradually reassured that the government was committed to bailing out the financial sector without wiping out existing equity holders.

B. Counterfactual: The Technology Sector Crash

The value of the financial sector ETF peaked in June 2007 and fell by 83.4% by the time it reached its nadir in March 2009. In March 2000, the technology sector crashed in a similarly spectacular fashion, with the Tech/Telecom ETF declining 82.3% from peak to trough. Unlike the financial crisis, we have no reason to believe that prices in the technology sector benefitted from an implicit government bailout guarantee, making this episode a suitable “placebo” event. If standard option pricing models are unable to explain technology sector basket-index spreads in the early 2000s, this calls into question our hypothesis that bailout guarantees are responsible for large financial sector spreads in the 2007 to 2009 crisis.

To mirror our 20-month financial crisis episode, we study the 20-month tech decline from March 2000 to January 2002. For this period, we compare technology and financial sector spreads after accounting for observed risk dynamics via our common-factor Black-Scholes model.²⁴

The basket-index put spread in the technology sector averaged 3.60 cents during the tech crash. This is 1.88 cents higher than its 2003-2007 pre-financial-crisis mean of 1.72 cents. The Black-Scholes model, based on ATM call option implied volatility, accounts for more than 87% of the tech spread run-up. Once we further difference

²⁴State Street only introduced SPDR sector ETFs in 1999. Our main sample begins in 2003 because options on most sectors were illiquid before this time. We are fortunate that there are two exceptions, the technology and financial sector ETFs, whose options were substantially more liquid than other sectors soon after introduction. For this reason, we compare technology and financial sector spreads after accounting for observed risk dynamics via Black-Scholes. We have also explored cross-sector comparisons with the remaining less liquid sectors, and find similar results to those reported here.

with spreads outside the tech sector, the average difference-in-difference tech sector put spread is only 0.23 cents. This same diff-in-diff put spread for financials was 1.33 cents during the financial crisis. Hence, unlike the financial sector spread during the crisis, we find little evidence of a divergence between risk-adjusted basket and index put prices for the technology sector in the early 2000s. The absence of a large put spread for the tech sector amid the tech crash supports our bailout interpretation of financial sector option market behavior during the recent crisis.

C. Individual Firm Evidence

If there is heterogeneity across banks in their likelihood of being bailed out when a crisis occurs, we expect to see different prices of crash insurance across banks. Below we demonstrate that puts on the largest financial institutions appear overpriced relative to puts on smaller banks after controlling for risk, consistent with an implicit “too-big-to-fail” guarantee. We also provide evidence from credit markets that is consistent with this interpretation.

1. Option Market Evidence

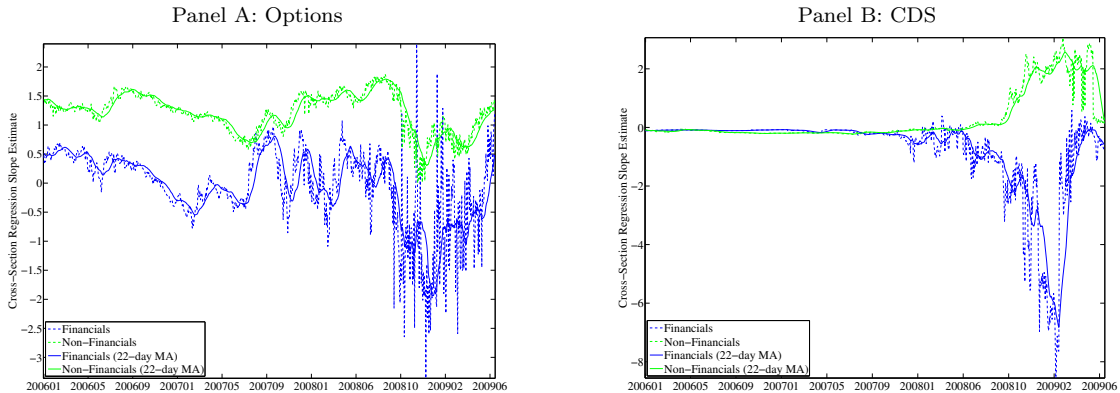
On each day in our sample, we run a cross-sectional regression of OTM put prices for each firm in the financial sector on the firm’s log market size one month earlier:

$$\text{Put/Strike}_{i,t} - \text{Model fit}_{i,t} = a_t + b_t \text{Size}_{i,t-21} + c_t \text{Leverage}_{i,t-21} + e_{i,t}. \quad (6)$$

To adjust for differences in risk across financial firms, we calculate the difference between observed Put/Strike (for $\Delta = 20$ puts), and the Black-Scholes predicted value of Put/Strike based on each firm’s implied volatility extracted from ATM call options. Since differences in leverage mechanically alter the riskiness of equity, we control for this in the put price regression. We measure size as the log of market value of equity plus book value of debt. We define leverage as the log ratio of book value of debt to market value of equity. We lag both size and leverage by one month (21 trading days). If an implicit bailout guarantee benefits large banks more than small banks, we expect a negative slope coefficient (b_t) on size.

Panel A of Figure 9 plots the daily time series of the cross-sectional regression slopes b_t . The solid blue line shows a 22-day moving average of the cross-section slope coefficient using the cross section of stocks in the S&P 500 financial sector index. During the crisis period, the average slope estimate on size is -0.18 . To interpret this estimate, consider that the largest 10% of all S&P 500 banking sector constituents are

Figure 9: PRICE OF CRASH INSURANCE AND FIRM SIZE FROM OPTIONS AND CDS



Notes: Panel A plots size slope coefficient estimates (b_t) from cross section regression equation $\text{Put/Strike}_{i,t} - \text{Model fit}_{i,t} = a_t + b_t \text{Size}_{i,t-21} + c_t \text{Leverage}_{i,t-21} + e_{i,t}$, where the model fit comes from Black-Scholes, size is the log of market value of equity plus book value of debt, and leverage is the log ratio of book value of debt to market value of equity. Panel B reports slope estimates from the same cross section regression replacing the left-hand side with CDS spread $\text{CDS}_{i,t} - \text{Model fit}_{i,t}$, where the model fit is from a Merton (1974) credit model. Regressions are run each day using stocks in the S&P 500 financial sector (blue) and non-financial sectors (green). Dotted lines show daily estimates and solid lines show 22-day moving averages.

on average 9.6 times larger than the remaining 90% of banks in the sector (in levels). This implies that, during the crisis, puts on the largest 10% of banks were cheaper than the remaining 90% of banks by 0.41 cents per dollar insured ($0.18 \times \log(9.6)$), after adjusting for differences in bank leverage and volatility via Black-Scholes.

The figure also shows that this size discount is unique to the financial sector. Non-financial sector estimates of b_t are positive on all days in our sample, indicating that puts on large non-financial firms are always relatively expensive. During the pre-crisis period, the average size slope estimate is positive, at 0.28. However, the slope is smaller for the financial sector than for non-financials, suggesting that large bank equity holders enjoy an insurance discount relative to other sectors even during normal times.

2. Credit Market Evidence

Options prices for the index and the basket are ideally suited for identifying a *systemic* bailout guarantee, our main object of interest. While there is no analogous basket/index comparison that can be made with corporate credit contracts,²⁵ individ-

²⁵The natural object to study would be CDS on individual banks versus CDS on the financial sector index. There is a widely-traded Credit Default Index (CDX) contract which is a basket of CDS contracts. Unfortunately, there is no CDX index for the US financial sector. But the problem goes beyond data availability. Conceptually, the CDX is not a CDS on a portfolio in the same way an index option is. Instead, it is simply the weighted average of the individual CDS contracts of the firms in the index. CDX index tranches, which allow investors to take bets on a slice of the default

ual bank credit default swap (CDS) spreads are useful to determine if bank-level crash insurance prices are influenced by sector-wide government guarantees. In particular, we show that bank size is a key driver of differences in individual bank CDS spreads, even after accounting for default probabilities estimated from a Merton (1974) model.

We collect daily 5-year CDS rates from Markit.²⁶ To adjust for differences in risk across financial firms, we calculate a model-implied CDS rate from a Merton model, which takes as inputs the current stock price, the book value of debt, and the stock’s volatility (we use implied volatility from ATM call options). As in the previous section, we run cross-sectional regression equation (6) each day, but now use as the dependent variable the observed CDS spread in excess of the model-predicted CDS rate (left-hand side variables are unchanged). The solid blue line in Panel B of Figure 9 shows that risk-adjusted CDS rates are lower for larger firms in the financial sector, and that this relationship steepens strongly during the financial crisis. There is no evidence of a CDS discount for large non-financial firms during the crisis (green line). Thus the price of crash insurance, measured from debt markets and taking into account the effects of leverage and volatility, is lower for large banks than for small banks, consistent with our evidence from the options markets.²⁷

IV. Alternative Explanations

This section consider alternatives to the collective bailout explanation for the behavior of crisis put spreads, including counter-party risk, mispricing, short sale restrictions, hedging costs, and liquidity. We conclude that none are consistent with the patterns in the data.

A. Counterparty Credit Risk

The most obvious alternative explanation is counterparty risk. OTM financial index put options pay off when the financial system is potentially in a meltdown. If option contracts are not honored in these states of the world, it could generate a basket-index spread increase for put options on financial firms, more so than for other firms.

distribution, could be more useful for a systemic risk comparison. But due to the absence of a finance sector-specific CDX tranches, the data are not available to infer a systemic bailout guarantee from credit derivatives.

²⁶We are able to collect CDS data for 81 financial firms and 411 non-financial firms that were part of the S&P 500 index over our sample.

²⁷We find qualitatively identical results in a range of alternative specifications, for example using raw put prices and CDS spreads in place of model residuals, using different measures of size such as equity value, or controlling for additional bank characteristics.

All of the options traded on the CBOE are cleared by the Options Clearing Corporation (OCC), which also is the ultimate guarantor of these contracts. The writer of an option is subject to margin requirements that exceed the current market value of the contract. Positions are marked-to-market on a daily basis, mechanically increasing margin requirements in volatile markets, and margins are exempt from bankruptcy clawbacks. In addition, the OCC has a clearing fund. The size of the clearing fund is directly tied to the volume of transactions. This clearing fund was only tapped once after the stock market crash of 1987, and the amount was small. The clearing fund was not used during the recent financial crisis, even though the volume of transactions set a new record. S&P has consistently given the OCC a AAA rating since 1993. So, counterparty risk seems limited.

Moreover, if counter-party credit risk were the driver of the basket-index spread, then the percentage effects should be much larger for shorted-dated options. Given that these contracts are marked-to-market every day, the effect of counter-party credit risk on a one-year option is of order $\sigma/\sqrt{250}$ rather than σ , because the contract is re-collateralized each day as needed. However, we find that the basket-index spreads roughly increase with the square root of the maturity of the contract (see Section I.D).

Finally, the dynamics of the basket-index spread around government announcements are inconsistent with a counter-party credit risk explanation. Announcements that increase the likelihood of a bailout increased the basket-index spread, while negative announcements decreased the spread. The counter-party credit risk explanation would predict the opposite effect.

B. Mispricing, Cost of Hedging and Short-Sale Restrictions

Recent research has documented violations of the law of one price in several segments of financial markets during the crisis.²⁸ A few factors make the mispricing explanation a less plausible candidate for our basket-index put spread findings. First, trading on the difference between the cost of index options and the cost of the basket requires substantially less capital than some other trades (CDS basis trade, TIPS/Treasury trade) due to the implicit leverage in options. Hence, instances of mispricing in the basket-index spread due to capital shortages are less likely to persist (Mitchell, Pedersen, and Pulvino, 2007; Duffie, 2010). Second, if we attribute our basket-index spread findings

²⁸In currency markets, violations of covered interest rate parity have been documented (Garleanu and Pedersen, 2011). In government bond markets, there was mispricing between TIPS, nominal Treasuries and inflation swaps (Fleckenstein, Longstaff, and Lustig, 2010). Finally, in corporate bond markets, large arbitrage opportunities opened up between CDS spreads and the CDX index and between corporate bond yields and CDS (Mitchell and Pulvino, 2009).

to mispricing, we need to explain the divergence between put and call spreads. This asymmetry rules out most alternative explanations except perhaps counter-party risk (addressed above) and the cost of hedging.

Single-name options and index options have different costs of hedging. Single-name options are hedged with cash market transactions while index options are hedged using futures since the latter are more liquid. Hedging using cash transactions is more expensive than using futures. This affects put options more than call options since shorting a stock accrues additional costs, and these costs can be larger in times of crisis. In fact, there were explicit short sale restrictions on financial sector stocks. A short-sale ban could push investors to express their bearish view by buying put options instead of shorting stocks. Market makers or other investors may find writing put options more costly when such positions cannot be hedged by shorting stock. The SEC imposed a short sale ban from September 19, 2008 until October 8, 2008, which affected 800 financial stocks. From July 21, 2008 onwards, there was a ban on *naked* short-selling for Freddie Mac, Fannie Mae, and 17 large banks.

However, exchange and over-the-counter option market makers were exempted from short-sales restrictions so that they could continue to provide liquidity and hedge their positions during the ban. Both the short window of the short sales ban compared to the period over which the put spread increased and the exemption for market makers make the short sale ban an unlikely explanation for our findings. Second, the changes in the cost of shorting do not line up with the basket-index spread dynamics. To measure short sales costs, we use securities lending fee data from the SEC for each stock in the S&P 500, and calculate value-weighted average lending fees by sector. We find little association between the put spreads and short sale costs. In the financial sector, changes in lending fees have a 3.7% correlation with changes in spreads, versus a correlation of -4.1% for non-financials. The correlation is insignificant in both cases with p -values over 0.25. Similarly, we find no association between put spreads and short sale quantities, both for shares on loan and for shares available to lend.

C. Liquidity

Another potential alternative explanation of our findings is that index put options are more liquid than individual options, and that their relative liquidity rose during the financial crisis. The same explanation must also apply to call options. Illiquidity is an unlikely explanation for our findings, often pointing in the opposite direction. Appendix A.VI contains details, while here we summarize the main findings. These findings corroborate our bid-ask spread analysis in Appendix A.III

While one-year OTM put options have substantial bid-ask spread and limited volume, financial sector index options are more liquid than other sector index options. The liquidity difference between index and individual put options is smaller for the financial sector than for the average sector. Furthermore, during the financial crisis, the liquidity of the options increases, and it increases more for index puts than for individual puts and more in the financial sector than elsewhere. The absolute increase in liquidity of financial sector index puts during the financial crisis and its relative increase versus individual put options suggest that financial sector index options should have become more expensive, not cheaper during the crisis. Short-dated put options are more liquid than long-dated options, and we verified above that our results are robust across option maturities. Finally, we also find that calls and puts are similarly liquid, yet they display very different basket-index spread behavior. All these facts suggest that illiquidity is an unlikely explanation for our findings.

V. Conclusion

We uncover new evidence from option prices that suggests the government absorbed aggregate tail risk during the 2007-2009 financial crisis by providing a sector-wide bailout guarantee to the financial sector. Indirect evidence comes from the failure of standard asset pricing models to simultaneously explain (a) the relative price dynamics of financial sector index put options and puts on the basket of individual banks and (b) return correlations among banks. A modified version of the standard model that truncates downside risk in the financial sector does a much better job explaining put spread behavior. Direct evidence comes from studying the basket-index put spread around government announcements.

Our evidence implies that the government subsidized private insurance against financial sector systemic risk. Government financial crisis policy typically aims to protect debt holders at the expense of equity holders. Our analysis shows that financial sector equity benefited during the 2007-09 crisis alongside debt holders. We estimate that equity holders of the 90 largest financial institutions in the U.S. enjoyed a crash insurance subsidy of on average \$50 billion during the financial crisis. The value of the bailout guarantee peaked at \$100 billion at the height of the crisis.

This finding has implications for the measurement of systemic risk, which often uses equity (or equity option) prices, because these prices are contaminated by the government guarantee. Our results show that this contamination can be dramatic: The basket-index put spread increased in the crisis rather than decreased, as it likely

would have in the absence of a government guarantee.

Future work could extend our analysis to jointly model the dynamics of banks' option, stock, and bond prices to get at the total value of government guarantees. Applying our model to the recent European crisis also strikes us as a promising endeavor.

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Separate Appendix for Online Publication

A.I. Sample Detail

Our sample uses exchange traded funds (ETFs) belonging to the Select Sector SPDR. SPDRs are a large ETF family traded in the U.S., Europe, and Asia-Pacific and managed by State Street Global Advisors. These sector funds represent nine separate portfolios based on the

Table A.1: TOP 40 HOLDINGS OF THE FINANCIAL SECTOR INDEX XLF

	12/30/2010		07/30/2007	
	Name	Weighting	Name	Weighting
1	JPMorgan Chase	9.01	Citigroup	11.1
2	Wells Fargo	8.86	Bank of America	10.14
3	Citigroup	7.54	AIG	8.02
4	Berkshire Hathaway	7.52	JPMorgan Chase	7.25
5	Bank of America	7.30	Wells Fargo	5.44
6	Goldman Sachs	4.66	Wachovia	4.35
7	U.S. Bancorp	2.82	Goldman Sachs	3.71
8	American Express	2.44	American Express	3.35
9	Morgan Stanley	2.25	Morgan Stanley & C	3.25
10	MetLife	2.21	Merrill Lynch	3.11
11	Bank of New York Mellon	2.04	Federal National Mortgage	2.81
12	PNC Financial Services	1.75	US Bancopr	2.51
13	Simon Property	1.60	Bank of New York Mellon	2.32
14	Prudential	1.56	Metlife	2.15
15	AFLAC	1.45	Prudential	2.00
16	Travelers	1.39	Federal Home Loan Mortgage	1.83
17	State Street	1.27	Travelers	1.63
18	CME Group	1.18	Washington Mutual	1.61
19	ACE Ltd.	1.15	Lehman Brothers	1.59
20	Capital One Financial	1.06	Allstate	1.56
21	BB&T	1.00	CME Group	1.46
22	Chubb	0.99	Capital One Financial	1.41
23	Allstate .	0.93	Hartford Financial	1.40
24	Charles Schwab	0.93	Suntrust Banks	1.35
25	T. Rowe Price	0.89	State Street	1.28
26	Franklin Resources	0.87	AFLAC	1.23
27	AON	0.82	PNC	1.11
28	Equity Residential	0.81	Regions Financial	1.02
29	Marsh & McLennan	0.81	Loews	1.02
30	SunTrust Banks	0.80	Franklin Resources	1.01
31	Ameriprise Financial	0.78	Charles Schwab	0.98
32	Public Storage	0.77	BB&T	0.98
33	Vornado Realty Trust	0.74	Fifth Third Bancorp	0.98
34	Northern Trust	0.73	Chubb	0.97
35	HCP	0.73	SLM	0.97
36	Progressive	0.71	Simon Property	0.93
37	Loews	0.67	ACE Ltd.	0.91
38	Boston Properties	0.66	National City	0.82
39	Host Hotels & Resorts	0.64	Countrywide Financial	0.81
40	Fifth Third Bancorp	0.64	Lincoln National	0.79

Notes: This table reports the XLF weights on 12/30/2010 and 07/30/2007. On 12/30/2010, there were 81 companies in XLF; on 07/30/2007, there were 96 companies. This table reports the relative market capitalizations of the top 40 holdings of the index.

industry sectors comprising stocks in the S&P 500 index. The S&P 500 is classified into ten sectors but, due to the small number of telecommunications firms in the index, technology and telecommunications are combined in a single ETF. The investment objective of each fund is to provide investment results that, before expenses, correspond generally to the return performance of the stocks represented in each specified sector index. The financial sector index ticker is XLF, and Table A.1 reports the XLF holdings before and after the crisis. Options on SPDR sector ETFs are physically settled and have an American-style exercise feature. Further detail regarding SPDR S&P 500 sector ETFs is available at <https://www.spdrs.com/>.

A.II. Strike-Matched Spreads

An alternative to Δ -matching is to construct the option basket to ensure that the total dollar amount of protection for the two insurance schemes are equal. In this appendix we discuss this approach, and refer to it as “strike-matching.”

To align our comparison between insurance costs, we impose that the total strike price of the two schemes are equal. We first choose index strike price K_t^{index} to match a given Δ . Second, we search for options on individual stocks in the index (all of which must share the same Δ , though this may be different from the index Δ) such that their strike prices $K_{j,t}$ ($j = 1, 2, \dots, N$) satisfy

$$scale_t K_t^{index} = \sum_{j=1}^N Sh_{j,t} K_{j,t} \quad (\text{A.1})$$

where *scale* refers to the ratio of total index market equity to the reported index level. That is, strike price of the index (in dollars) equals the share-weighted sum of the individual strike prices.

With strike-matching, the cost of the basket of put options has to exceed the cost of the index option by no arbitrage (Merton, 1973), which bounds the basket-index spread below from zero. The payoffs at maturity satisfy the following inequality:

$$\sum_{j=1}^N Sh_{j,t} \max(K_{j,t} - S_{j,T}, 0) \geq \max \left(scale_t K_t^{index} - \sum_{j=1}^N Sh_{j,t} S_{j,T}, 0 \right). \quad (\text{A.2})$$

To see why, first note that, for each j , $Sh_{j,t} \max(K_{j,t} - S_{j,t}, 0) \geq Sh_{j,t} (K_{j,t} - S_{j,t})$. This implies that $\sum_{j=1}^N Sh_{j,t} \max(K_{j,t} - S_{j,T}, 0) \geq scale_t K_t^{index} - \sum_{j=1}^N Sh_{j,t} S_{j,T}$. This also means that $\sum_{j=1}^N Sh_{j,t} \max(K_{j,t} - S_{j,T}, 0) \geq \max(scale_t K_t^{index} - \sum_{j=1}^N Sh_{j,t} S_{j,T}, 0)$, because the right hand side is non-negative for out-of-the-money put options. Since the payoff from the option basket exceeds that of the index option, its cost must be weakly higher as well.

Table A.2 reports results for our the strike-matching approach to constructing the basket-index spread. Results are qualitatively and quantitatively similar to Δ -matched results reported in the main text. The time series correlation between spreads for the two approaches is over 99%. Basket-index spreads are somewhat larger when we match the share-weighted strike price, because strike-matching requires individual options that have slightly higher Δ than index options used, which increases spreads. However, the change in spreads from pre-crisis to crisis is nearly identical in the two approaches.

We verify that the basket-index spread is similar if we define put option prices relative

Table A.2: STRIKE-MATCHED BASKET-INDEX SPREADS

		Financials		Non-financials		Difference	
		Puts	Calls	Puts	Calls	Puts	Calls
Full Sample	Mean	2.88	0.99	2.79	1.15	0.09	-0.16
	Std. Dev.	2.38	0.10	0.98	0.07	1.40	0.03
	Max.	15.26	1.27	7.57	1.41	7.69	-0.14
Pre-Crisis	Mean	1.70	0.95	2.42	1.11	-0.72	-0.16
	Std. Dev.	0.33	0.07	0.63	0.05	-0.29	0.02
	Max.	3.76	1.17	4.89	1.24	-1.13	-0.07
Crisis	Mean	5.69	1.09	3.66	1.23	2.03	-0.14
	Std. Dev.	2.78	0.10	1.10	0.06	1.68	0.03
	Max.	15.26	1.27	7.57	1.41	7.69	-0.14

Notes: This table reports summary statistics for the basket-index spread for the financial sector, non-financial sectors and their difference (financials minus non-financials). Units are cents per dollar insured. The full sample covers January 2003 to June 2009. The pre-crisis sample covers January 2003 to July 2007. The crisis sample covers August 2007 to June 2009. Δ is 20. Time to maturity is 365 days in Panel A and 30 days in Panel B. Spreads are constructed using strike matching as described in Appendix A.II.

to stock prices, rather than relative to strike prices. We also compare index and basket put prices using options positions that share the same sensitivity to changes in stock return volatility, the so called option “vega”. With the vega-matched approach, spreads between index and basket put prices widen even more for financials versus non-financials compared to the strike-matched results reported below. Detailed estimates from our vega-matched put price comparison are available upon request.

A.III. Bid-Ask Spread Adjustment

To ensure that the increase in the basket-index put spread is not solely due to wider bid-ask spreads during the financial crisis, we reconstruct an alternative basket-index spread series using raw option price quotes rather than the interpolated volatility surface provided by OptionMetrics. This also serves as a check that OptionMetrics interpolated prices do not suffer from inaccurate extrapolation or reliance on illiquid contracts. To summarize, results from raw options data combined with accounting for bid-ask spreads and contract liquidity generates put spreads that are qualitatively identical, and quantitatively very similar, to the results we report in the main text.

For this analysis, we construct synthetic options with constant maturity (365 days) and constant Δ of 30 by interpolating raw option prices in a similar vein as OptionMetrics. There are two key differences with the OptionMetrics methodology that makes our approach robust. First, we restrict the universe of raw options to those with positive open interest to ensure a minimum degree of liquidity. Results are similar if we instead require that contracts have positive volume. Second, when constructing synthetic options with constant maturity and constant Δ , we *strictly interpolate* and never extrapolate. In particular, we require at least one option with Δ above 30 and one with Δ below 30, and similarly require one option with maturity greater than 365 and one with maturity less than 365. Often a stock has only one option near $\Delta = 20$, which is why we construct synthetic options with $\Delta = 30$. Finally, to account for bid-ask spreads, all individual option prices are set equal to the bid

price, and all index option prices are set equal to their ask price. This results in the most conservative spread in prices of index puts versus the basket of individual puts, so that the bid-ask-adjusted put spread is always narrower than the spread calculated from midquotes.

The resulting “net of transaction costs” basket-index put spread has very similar behavior to the $\Delta = 20$, 365-day spread series documented above. Their correlation is 96% (0.93%) over the entire (crisis) sample. The “net of transaction costs” put spread for financials is 1.5 cents per dollar before the crisis, rising to 4.3 cents during the crisis. For the non-financials, the spread goes from 2.4 to 3.4 cents. The result is an additional increase of 1.8 cents per dollar for financials relative to non-financials, quantitatively consistent with the 2.0 cents estimate presented earlier.

A.IV. Option Pricing Without Bailout

In this section, we derive option prices for the model of Section II. First, we consider the case with only stochastic volatility but no jumps. Then, we reevaluate prices in the presence of jumps.

A.IV.A. Stochastic Volatility, No Jumps

We begin with a continuous time common-factor model for returns that incorporate separate stochastic volatility processes for the common and idiosyncratic components of returns. Stock prices are comprised of a common (index) component X_t and an idiosyncratic component I_t , and are given by

$$S_t = X_t I_t \tag{A.3}$$

where

$$\begin{aligned} \frac{dX_t}{X_t} &= r dt + \sqrt{v_t} dW_t^X \\ dv_t &= (\theta_v - \kappa_v v_t) dt + \sigma_v \sqrt{v_t} dW_t^v \end{aligned} \tag{A.4}$$

with $E [dW_t^X dW_t^v] / dt = \rho_{Xv}$, and

$$\begin{aligned} \frac{dI_t}{I_t} &= \sqrt{z_t} dW_t^I \\ dz_t &= (\theta_z - \kappa_z z_t) dt + \sigma_z \sqrt{z_t} dW_t^z \end{aligned} \tag{A.5}$$

with $E [dW_t^I dW_t^z] / dt = \rho_{Iz}$. Idiosyncratic processes I_t and z_t are independent of index processes X_t and v_t . Throughout, we take these processes to describe price dynamics under the risk-neutral measure. We normalize all time 0 prices as $X_0 = I_0 = 1$.

A.IV.B. Pricing European Options

Consider a European call option written on the underlying S_t with maturity date T and strike price K . Assuming a constant interest rate (it is straightforward to generalize to a diffusive

interest rate), the call option price at date $t < T$ is

$$\begin{aligned} C(X, I, v, z, T) &= \mathbb{E}^{\mathbb{Q}} \left[e^{-\int_t^T r(s) ds} \max \{S(t, T) - K, 0\} \right] \\ &= PV(s, t) \mathbb{E}^{\mathbb{Q}} [(S(t, T) - K)^+] \end{aligned} \quad (\text{A.6})$$

where $PV(s, t)$ is the risk-free discounting term.

Our model falls into the affine class of Duffie, Pan and Singleton (2000), and our derivation follows from that paper and uses the Fourier transform method. Let Ω be a sample space and let A be the set $A = \{\omega \in \Omega : S(\omega, t) \geq K\}$, then the pricing function in equation (A.6) can be rewritten as follows:

$$\begin{aligned} C(T) &= PV(t, T) \mathbb{E}^{\mathbb{Q}} [S(t, T) 1_A - K 1_A] \\ &= PV(t, T) [S(t, T) \Pi_1 - K \Pi_2] \end{aligned}$$

where Π_1 and Π_2 are the risk neutral probabilities of finishing in-the-money,

$$\begin{aligned} \Pi_1 &= E[e^S 1_{S_T > K}] / E[e^S] = \frac{1}{2} + \frac{1}{\pi} \int_0^\infty \text{Re} \left[\frac{e^{-iu \ln(K)} \varphi(u - i, t, T)}{iu \varphi(-i, t, T)} \right] du \\ \Pi_2 &= \Pr\{S_T > K\} = \frac{1}{2} + \frac{1}{\pi} \int_0^\infty \text{Re} \left[\frac{e^{-iu \ln(K)} \varphi(u, t, T)}{iu} \right] du \end{aligned}$$

and $\varphi(u, t)$ represents the characteristic function of log-return, $\ln(S_T/S_t)$. Π_1 and Π_2 can be found via Fourier inversion of the following characteristic function:

$$\varphi(u, t, T) \equiv \mathbb{E}_t^{\mathbb{Q}} \left[e^{iu \ln(S(T)/S(t))} \right], \quad u \in \mathbb{C}. \quad (\text{A.7})$$

The PDE solving the expectation in equation (A.7) is obtained from the Feynman-Kac theorem which gives the underlying dynamics of $\varphi(u, t, T)$. The PDE emerges by setting the drift equal to zero,

$$\begin{aligned} \mathbb{E}[d\varphi(t)] &= \frac{\partial \varphi}{\partial t} + \frac{\partial \varphi}{\partial S} r S_t + \frac{\partial \varphi}{\partial v} (\theta_v - \kappa_v v_t) + \frac{\partial \varphi}{\partial z} (\theta_z - \kappa_z z_t) + \\ &+ \frac{1}{2} [v_t + z_t] \frac{\partial^2 \varphi}{\partial^2 S} + \frac{1}{2} \sigma_v^2 v_t \frac{\partial^2 \varphi}{\partial^2 v} + \frac{1}{2} \sigma_z^2 z_t \frac{\partial^2 \varphi}{\partial^2 z} + \\ &+ \sigma_v \rho_{Xv} v_t S_t \frac{\partial^2 \varphi}{\partial S \partial v} + \sigma_z \rho_{Iv} z_t S_t \frac{\partial^2 \varphi}{\partial S \partial z} \end{aligned}$$

To solve the PDE, we posit that $\varphi(\cdot)$ is an affine function of the state variables,

$$\varphi(u, t, T) = e^{A(T-t) + B(T-t) \cdot \Gamma + u i S} \quad (\text{A.8})$$

where $\Gamma = [v_t, z_t]$ is the vector of states and $A(T-t)$ and $B(T-t)$ are the solutions of the following ordinary differential equations:

$$\begin{aligned} \dot{\mathbf{A}}(\tau) + i u r &= \mathbf{B}(\tau)^\top \boldsymbol{\theta} \\ \dot{\mathbf{B}}(\tau) &= -\frac{1}{2} \mathbf{U} - \mathbb{k}^\top \mathbf{B}(\tau) + \frac{1}{2} \boldsymbol{\Sigma} \mathbf{B}(\tau) \odot \mathbf{B}(\tau) \end{aligned}$$

with $\tau = T - t$, initial conditions $\mathbf{A}(0) = 0$ and $\mathbf{B}(0) = 0$, $\dot{\mathbf{A}}(\tau)$ and $\dot{\mathbf{B}}(\tau)$ are the derivatives

of $\varphi(\cdot)$ with respect to time, and

$$\theta = \begin{bmatrix} \theta_v \\ \theta_z \end{bmatrix} \quad \mathbf{U} = \begin{bmatrix} iu + u^2 \\ iu + u^2 \end{bmatrix}$$

$$\mathbb{k}^\top = \begin{bmatrix} \kappa_v - iu\rho_{Xv}\sigma_v & 0 \\ 0 & \kappa_z - iu\rho_{Iz}\sigma_z \end{bmatrix} \quad \mathbf{\Sigma} = \begin{bmatrix} \sigma_v^2 & 0 \\ 0 & \sigma_z^2 \end{bmatrix}.$$

Given that the processes X_t and I_t are independent, the solutions to the PDEs apply symmetrically to both rows in the vectors $\dot{\mathbf{A}}(\tau)$ and $\dot{\mathbf{B}}(\tau)$. Hereafter, we report the solution for the first row, that is,

$$B(\tau) = \frac{c-d}{\sigma_v^2} \frac{e^{-d\tau} - 1}{fe^{-d\tau} - 1}$$

$$A(\tau) = \frac{\theta_v(c-d)}{\sigma_v^2} \int_0^\tau \frac{e^{-ds} - 1}{fe^{-ds} - 1} ds$$

$$= \frac{\theta_v}{\sigma_v^2} \left[(c-d)\tau - 2 \ln \left\{ \frac{\psi(\tau) - 1}{\psi(0) - 1} \right\} \right]$$

where

$$c = \kappa_v - iu\rho_{Xv}\sigma_v, \alpha = -\frac{1}{2}(u^2 + iu), d = \sqrt{c^2 + \sigma_v^2(u^2 + iu)}, f = \frac{c-d}{c+d}, \psi(\tau) = fe^{-d\tau}.$$

Finally, the closed-form characteristic function in equation (A.8) takes the form:

$$\varphi(u, t, T) = e^{iur(T-t) + \mathbf{A}(T-t) + \mathbf{B}(T-t) \cdot \Gamma + iu \ln(S_t)},$$

with $\Gamma = [v_t, z_t]$. Carr and Madan (1999) show that the option's value can be obtained by "fast Fourier transform." We use this to numerically evaluate the above pricing formulas.

A.IV.C. Adding Jumps

To incorporate price jumps, we allow both the index and idiosyncratic price components to change by discretely by q and b , respectively, such that the post-jump value is $X(t) = X(t-)e^{-q}$ and $I(t) = I(t-)e^{-b}$, respectively.

Under the risk-neutral probability measure, the processes dX_t and dI_t have the following jump-diffusion representations:

$$\frac{dX_t}{X_t} = rdt + \sqrt{v_t}dW_t^X + ((e^{-q} - 1)dJ(\lambda_q) - \lambda_q\zeta_q dt)$$

$$\frac{dI_t}{I_t} = \sqrt{z_t}dW_t^I + ((e^{-b} - 1)dJ(\lambda_b) - \lambda_b\zeta_b dt).$$

The diffusive components are identical to those in Section A.IV.A. The jump terms are compound Poisson processes with $(e^{-q} - 1)dJ(\lambda_q)$ and $(e^{-b} - 1)dJ(\lambda_b)$ denoting the increments of the Poisson process with constant arrival rates λ_q and λ_b and random jump sizes $(e^{-q} - 1)$ and $(e^{-b} - 1)$. Conditionally on the jump occurring, we assume that $q \sim N(\mu_q, v_q)$, $b \sim N(\mu_b, v_b)$ such that the mean percentage size is $\zeta_q = e^{-\mu_q + v_q/2} - 1$ and $\zeta_b = e^{-\mu_b + v_b/2} - 1$.

The characteristic function now is obtained by solving the following PDE:

$$\begin{aligned}\mathbb{E}[d\varphi(t)] &= \frac{\partial\varphi}{\partial t} + \frac{\partial\varphi}{\partial S}(r - \lambda_q\zeta - \lambda_b\zeta_b)S_t + \frac{\partial\varphi}{\partial v}(\theta_v - \kappa_v v_t) + \frac{\partial\varphi}{\partial z}(\theta_z - \kappa_z z_t) + \\ &+ \frac{1}{2}[v_t + z_t]\frac{\partial^2\varphi}{\partial^2 S} + \frac{1}{2}\sigma_v^2 v_t \frac{\partial^2\varphi}{\partial^2 v} + \frac{1}{2}\sigma_z^2 z_t \frac{\partial^2\varphi}{\partial^2 z} + \\ &+ \sigma_v \rho_{X,v} v_t S_t \frac{\partial^2\varphi}{\partial S \partial v} + \sigma_z \rho_{I,v} z_t S_t \frac{\partial^2\varphi}{\partial S \partial z} \\ &- \int_{\mathbb{R}_0} [\varphi(x) - \varphi(x+q)] d\mu(dq) - \int_{\mathbb{R}_0} [\varphi(x) - \varphi(x+q)] d\mu(dq)\end{aligned}$$

The characteristic function for the jump-diffusion version of the model becomes

$$\varphi(u, t, T) = e^{R(T-t) + \mathbf{A}(T-t) + \mathbf{B}(T-t) \cdot \Gamma + iu \ln(S_t)}$$

where $\mathbf{A}(T-t)$ and $\mathbf{B}(T-t)$ have the same solutions as before and

$$R = (iur + (\psi_q(u) - iu\zeta)\lambda_q + (\psi_b(u) - iu\zeta)\lambda_b).$$

A.IV.D. Model Estimation

The objective is to estimate parameters (Θ_X, Θ_I) . Since sector index option prices depend only on Θ_X , we first estimate Θ_X only using index option data. Then, given Θ_X , we estimate the remaining Θ_I parameters.

Our estimation approach uses an interactive non-linear least squares procedure, exemplified by Christoffersen, Fournier, and Jacobs (2013). The approach is related to Pan (2002), Broadie, Chernov, and Johannes (2007), and Andersen, Fusari, and Todorov (2012). We outline the procedure for index options; estimation of idiosyncratic return parameters follows analogously.

First, guess parameter values Θ_X . We assume ATM ($\Delta = 50$) basket and index call options are perfectly priced by the model. Given the parameter guess, we invert the pricing formulas derived in the previous section to obtain the latent state processes v_t and z_t from observed ATM calls. Then, using the parameter guess and the model-implied volatilities, we calculate the price of OTM ($\Delta = 20$) puts. OTM puts are fitted with error, and our objective is to minimize the sum of squared pricing errors

$$\mathcal{L}\left(\{Put_t^{index}\}_{t=1}^T; \Theta_X\right) = \sum_{t=1}^T \left(Put_t^{index} - Put_{X,t}\right)^2$$

where Put_t^{index} is the observed price, $Put_{X,t} = f(v_t, 0, X_t, 0, K_t, r_t, T; \Theta_X, 0)$ is the predicted price given parameter guess Θ_X and call-option-implied state variable v_t . The estimation sample over which we fit put prices is the pre-crisis sample.

We use the pricing errors and the objective function $\mathcal{L}(\cdot)$ to advance to the next parameter guess via Nelder-Mead simplex search. We iterate on this procedure until the simplex search converges. To mitigate local optima concerns, we randomly generate 100 initial guesses for the parameter vector. The optimization is computationally intensive and, to reduce the parameterization, we fix the parameters governing volatility's speed of mean reversion (κ_v and κ_z) to unity, and the leverage effect parameters ($\rho_{X,v}$ and $\rho_{I,z}$) to -0.95 . This restriction is based on the findings of Cristoffersen et al. (2013), who show that these parameters show

Table A.3: STOCHASTIC VOLATILITY AND JUMP PARAMETER ESTIMATES

Parameters	Stochastic Vol., No Jumps		Stochastic Vol. With Jumps	
	Financials	Non-financials	Financials	Non-financials
θ_V	0.101	0.052	0.098	0.053
σ_V	1.236	0.851	1.102	0.880
θ_Z	0.030	0.034	0.021	0.015
σ_Z	0.714	0.723	0.747	0.639
$\mu_{J,X}$			0.034	0.181
$\lambda_{J,X}$			0.000	0.020
$\sigma_{J,X}$			0.000	0.396
$\mu_{J,I}$			0.346	0.152
$\lambda_{J,I}$			0.016	0.002
$\sigma_{J,I}$			0.048	0.034
Pre-crisis RMSE Index	0.237	0.346	0.150	0.175
Pre-crisis RMSE Basket	0.213	0.205	0.199	0.208
Crisis RMSE Index	0.848	1.268	0.856	1.286
Crisis RMSE Basket	1.899	1.207	2.118	1.293

Notes: The table reports model parameter estimates and root mean squared option pricing errors (in cents per dollar insured). Parameters are estimated in the pre-crisis sample (January 2003 to July 2007), thus pricing errors during the crisis sample (August 2007 to June 2009) are evaluated on a purely out-of-sample basis. Models are estimated separately for each sector, and reported parameters are averaged across the eight non-financial sectors.

little variation across stocks. Our conclusions are insensitive to this restriction, it merely allows us to perform a more thorough search of the remaining parameter space. This includes the mean-reverting level of volatility, the volatility of volatility, and jump risk parameters. Robustness tests verify that these are the parameters that display much more meaningful heterogeneity in the cross section.

The model is parameterized so that jumps are negative shocks. That is, discontinuous index and idiosyncratic price moves dJ_t^X and dJ_t^I tend to be more negative when $\mu_{J,X}$ and $\mu_{J,I}$ are larger. Higher $\sigma_{J,\cdot}$ means that jumps are more variable and higher $\lambda_{J,\cdot}$ means that jumps occur more frequently.

We repeat this estimation for the financial sector and for each of the eight non-financial sectors. Table A.3 shows the resulting parameter estimates; the estimates for non-financials are averages over the 8 non-financial sectors. Estimates from the stochastic volatility model suggest that the annualized long term mean of the volatility process is 31.8% for the financial sector index and 17.3% for idiosyncratic bank volatility. This compares to 22.8% for non-financial sector indices and 18.4% for non-financial idiosyncratic volatility. The volatility of the stochastic variance process is 1.2 for the financial index and 0.9 for non-financial indices. Volatility estimates are similar for the model that includes jumps. Our estimates suggest jump risk is lower for all sectors relative to estimates in prior literature. This occurs for two reasons. First, we use options with one year to maturity while the empirical options literature typically focuses on shorter maturity options. Jump risk has a relatively larger impact on the prices of short maturity options. Second, our estimation sample covers the especially tranquil markets experienced from 2003 to 2007. We run robustness checks to ensure that jump parameter estimates are not driving our results. In particular, we fix the jump process

parameters to equal those estimated in Eraker’s (2004) SVJ (stochastic volatility with jumps) specification for S&P 500 index options. He finds an annualized jump intensity of 0.5, with mean risk-neutral jump size of -2.0% and jump size standard deviation of 6.6% . Combining this jump process for both aggregate and idiosyncratic jump components with our estimated stochastic volatility process yields a fitted basket-index spread for the financial sector of 2.20 cents per dollar during the crisis, compared to 2.25 cents per dollar based on the estimated jump parameters in Table A.3. Therefore, further increases in jump risk fare no better at matching observed basket-index crisis spreads and fare far worse in terms of pre-crisis fits.

A.V. Option Pricing With Bailout

In this section, we begin from a special case of the model A.IV.A where volatility is constant. This is common-factor version of the Black-Scholes model, and in this simplified setting we are able to derive closed-form option prices in the presence of a bailout guarantee. Under the constant volatility assumption, it is convenient to represent the model in terms of log returns rather than prices. This is without loss of generality since log returns and log prices are equivalent when initial prices are set to one, as we assumed in the previous section. We also treat this version of the model in discrete time. This is also without loss of generality since our discretized Gaussian shocks arise directly from the previously presented continuous-time model.

A.V.A. Stock Return Dynamics

Let $r_S = \log(S_T/S_0)$ be an individual firm’s equity return under the physical measure, $r_X = \log(X_T/X_0)$ the aggregate component, and $r_I = \log(I_T/I_0)$ the idiosyncratic component. An individual bank’s stock return is given by:

$$\begin{aligned} r_S &= \mu + \tilde{r}_X + r_I = \mu - J^a + \sigma\epsilon, \\ J^a &= \min(J^r, \underline{J}), \quad J^r \sim \mathcal{N}(\theta_r, \delta_r^2) \end{aligned}$$

where the shock ϵ is an idiosyncratic shock which is standard normally distributed and i.i.d. over time and across firms. In contrast, the shock J^a is an aggregate shock, also i.i.d. over time. The common shock is truncated by a government bailout for $\underline{J} < \infty$. Absent a bailout ($\underline{J} = \infty$), $J^a = J^r = -r_X$, the negative of the common return component. The truncation of the log return component r_X is equivalent to a truncation of the common price component X at \underline{X} : if the price at option expiry X_T were to fall below this level, then it would be capped at \underline{X} . Thus, $\underline{J} = -\log(\underline{X}/X_0)$ is the maximal return decrease or price drop the government will tolerate (in absolute value).

It is convenient to price options in this setting assuming the existence of log stochastic discount factor (SDF), m , that is normally distributed, and assuming that m and the idiosyncratic return r_I are uncorrelated. The shocks J^r and ϵ are orthogonal; ϵ is uncorrelated with the SDF. The process J^r is correlated with the SDF; define $\sigma_{m,J} = Cov(m, J^r)$ and

$$\beta_J = \frac{Cov(m, J^r)}{Var(J^r)} = \frac{\sigma_{m,J}}{\delta_r^2}.$$

The bivariate normality of m and J^r implies (see Lemma 4 at the end of this appendix):

$$E[m|J^r] = E[m] + \beta_J(J^r - \theta_r), \text{ and } V[m|J^r] = V[m] - \beta_J\sigma_{m,J}.$$

We are interested in computing the variance of returns and the covariance between a pair of returns. This will allow us to compute the volatility of returns and the correlation of returns. Two auxiliary results turn out to be useful:

$$\begin{aligned} E[J^a] &= E[\min(J^r, \underline{J})] = E[J^r 1_{(J^r < \underline{J})}] + \underline{J} E[1_{(J^r \geq \underline{J})}] \\ &= \theta_r \Phi\left(\frac{\underline{J} - \theta_r}{\delta_r}\right) - \delta_r \phi\left(\frac{\underline{J} - \theta_r}{\delta_r}\right) + \underline{J} \Phi\left(\frac{\theta_r - \underline{J}}{\delta_{ri}}\right) \equiv \theta_a \end{aligned}$$

and

$$\begin{aligned} E[J^{a2}] &= E[\min(J^r, \underline{J})^2] = E[J^{r2} 1_{(J^r < \underline{J})}] + \underline{J}^2 E[1_{(J^r \geq \underline{J})}] \\ &= (\delta_r^2 + \theta_r^2) \Phi\left(\frac{\underline{J} - \theta_r}{\delta_r}\right) - \delta_r(\underline{J} + \theta_r) \phi\left(\frac{\underline{J} - \theta_r}{\delta_r}\right) + \underline{J}^2 \Phi\left(\frac{\theta_r - \underline{J}}{\delta_r}\right), \\ &\equiv \sigma_a^2 + \theta_a^2, \end{aligned}$$

where $\phi(\cdot)$ is the standard normal pdf and $\Phi(\cdot)$ is the standard normal cdf. The variance of returns is:

$$Var[r_S] = E[(r_S)^2] - (E[r_S])^2 = \sigma^2 + \sigma_a^2$$

Similarly, mean returns are given by:

$$E[r_S] = \mu - \theta_a.$$

Note that absent a bailout guarantee, $\theta_a = \theta_r$ and $\sigma_a^2 = \delta_r^2$, so that

$$Var[r_S] \equiv \sigma_{nb}^2 = \sigma^2 + \delta_r^2 \quad E[r_S] = \mu - \theta_r$$

The covariance of a pair of different firms' returns (r^1, r^2) is:

$$Cov[r_S^1, r_S^2] = E[r_S^1 r_S^2] - E[r_S^1] E[r_S^2] = \sigma_a^2,$$

Define

$$\chi = \theta_r + \sigma_{m,J}.$$

In order to get the equity risk premium for an individual stock, start from the Euler equation:

$$\begin{aligned} 1 &= E[\exp(m + \mu - J^a + \sigma\epsilon)] \\ &= \exp(\mu + .5\sigma^2) E[\exp(m - J^a)] \\ &= \exp(\mu^j) \{ E[\exp(m - J^r) 1_{(J^r < \underline{J})}] + E[\exp(m - \underline{J}) 1_{(J^r \geq \underline{J})}] \} \\ &= \exp(\mu + .5\sigma^2) \left\{ \Psi(1, -1; m, J^r) \Phi\left(\frac{\underline{J} - \chi + \delta_r^2}{\delta_r}\right) + \exp(-r^f - \underline{J}) \Phi\left(\frac{\theta_r - \underline{J}}{\delta_r}\right) \right\} \text{ by Lemma 1} \\ &= \exp(\mu - r^f + .5\sigma^2) \\ &\quad \times \left\{ \exp(-\chi + .5\delta_r^2) \Phi\left(\frac{\underline{J} - \chi + \delta_r^2}{\delta_r}\right) + \exp(-\underline{J}) \Phi\left(\frac{\theta_r - \underline{J}}{\delta_r}\right) \right\} \end{aligned}$$

which implies that the expected return equals:

$$\mu = r^f - .5\sigma^2 - \log \left\{ \exp(-\chi + .5\delta_r^2) \Phi \left(\frac{\underline{J} - \chi + \delta_r^2}{\delta_r} \right) + \exp(-\underline{J}) \Phi \left(\frac{-\underline{J}}{\delta_r} \right) \right\}. \quad (\text{A.9})$$

In the no-bailout case, $\underline{J} \rightarrow +\infty$, and the equity risk premium (including Jensen term) becomes $\mu_{nb}^j - r^f + .5\sigma_{nb}^2 = \chi$. Therefore, χ is the risk premium in the absence of a bailout.

A.V.B. Valuing Options

The main technical contribution of the paper is to price options in the presence of a bailout guarantee. Details regarding intermediate steps of this derivation are available from the authors upon request.

We are interested in the price per dollar invested in a put option (cost per dollar insured) on a bank stock. For simplicity, we assume that the option has a one-period maturity and is of the European type. We denote the put price by

$$Put_t = E_t [M_{t+1} (K - R_{t+1})^+],$$

where the strike price K is expressed as a fraction of a dollar (that is, $K = 1$ is the ATM option). The value of an option on stock j is:

$$Put^j = E [M(K - R^j)^+] = -E [\exp(m + r^j) 1_{k > r^j}] + KE [\exp(m) 1_{k > r^j}] = -V_1 + V_2$$

We now compute this in terms of the underlying structural parameters. Define $\tilde{r} = \mu + \sigma\epsilon$ and $r_S = \tilde{r} - \min(J^r, \underline{J})$, where we omit the dependence on j for ease of notation. Our derivation below exploits the normality of m and \tilde{r} , which are conditionally uncorrelated.

First term V_1

$$\begin{aligned} V_1 &= E [\exp(m + r_S) 1_{k > r} 1_{J^r < \underline{J}}] + E [\exp(m + r_S) 1_{k > r_S} 1_{J^r > \underline{J}}] \\ &= E [\exp(m + \tilde{r} - J^r) 1_{k > r} 1_{J^r < \underline{J}}] + E [\exp(m + \tilde{r} - \underline{J}) 1_{k > r_S} 1_{J^r > \underline{J}}] \\ &= V_{11} + V_{12} \end{aligned}$$

The first term V_{11} may be written as:

$$V_{11} = \Psi(1; m) \Psi(1; \tilde{r}) \exp(.5\delta_r^2 - [\sigma_{m,J} + \theta_r]) \tilde{\Phi} \left(\frac{\phi_0 - t_1}{\sqrt{1 + \phi_1^2 \delta_r^2}}, \frac{\underline{J} - t_2}{\delta_r}; \rho \right)$$

where $\phi_1 = \frac{1}{\sigma}$, $\phi_0 = \phi_1 (k - \mu - \sigma^2)$, $t_2 = \theta_r + \sigma_{m,J} - \delta_r^2$, $t_1 = -\phi_1 t_2$, $\rho = \frac{-\phi_1 \delta_r}{\sqrt{1 + \phi_1^2 \delta_r^2}}$, and $\tilde{\Phi}(\cdot, \cdot)$ is the bivariate normal cdf. We have used fact that m and J^r are jointly normal to calculate the conditional moments $E[m|J^r]$ and $V[m|J^r]$, as discussed above.

Next, we turn to V_{12} :

$$\begin{aligned} V_{12} &= \exp(-\underline{J}) \Psi(1; m) \Psi(1; \tilde{r}) \Phi \left(\frac{\underline{J} + k - \mu - \sigma^2}{\sigma} \right) \left[1 - \Phi \left(\frac{\underline{J} - \theta_r - \sigma_{m,J}}{\delta_r} \right) \right] \text{ by Lemma 1} \\ &= \exp(-\underline{J}) \Psi(1; m) \Psi(1; \tilde{r}) \Phi \left(\frac{\underline{J} + k - \mu - \sigma^2}{\sigma} \right) \Phi \left(\frac{-\underline{J} + \theta_r + \sigma_{m,J}}{\delta_r} \right). \end{aligned}$$

Second term V_2

$$\begin{aligned}
V_2 &= KE [\exp(m) 1_{k>r_S}] \\
&= KE [\exp(m) 1_{k>r_S} 1_{J^r < \underline{J}}] + KE [\exp(m) 1_{k>r_S} 1_{J^r > \underline{J}}] \\
&= V_{21} + V_{22}.
\end{aligned}$$

The first term V_{21} can be solved as follows:

$$V_{21} = K\Psi(1; m)\tilde{\Phi}\left(\frac{\phi_0 - t_1}{\sqrt{1 + \phi_1^2\delta_r^2}}, \frac{\underline{J} - t_2}{\delta_r}; \rho\right) \text{ by Lemma 2}$$

where $\phi_1 = \frac{1}{\sigma_d}$, $\phi_0 = \phi_1(k - \mu)$, $t_2 = \theta_r + \sigma_{m,J}$, $t_1 = -\phi_1 t_2$, $\rho = \frac{-\phi_1\delta_r}{\sqrt{1 + \phi_1^2\delta_r^2}}$.

Finally, we turn to V_{22} :

$$V_{22} = K\Psi(1; m)\Phi\left(\frac{\underline{J} + k - \mu}{\sigma}\right)\Phi\left(\frac{-\underline{J} + \theta_r + \sigma_{m,J}}{\delta_r}\right).$$

Combining Terms Note that $\Psi(1; m) = \exp(-r_t^f)$ and that $\Psi(1; \tilde{r}) = \exp(\mu_r + .5\sigma^2)$ which is the expected log stock return adjusted for a Jensen term. Note that the Jensen term only involves the idiosyncratic risk. The correlation coefficient is $\rho = \frac{-\delta_r}{\sqrt{\sigma^2 + \delta_r^2}}$. Recall the definitions:

$$\chi = \theta_r + \sigma_{m,J} \quad \text{and} \quad \sigma_{nb}^2 = \sigma^2 + \delta_r^2.$$

Combining the four terms, we get that the put price on an individual stock is given by (dependence on j suppressed):

$$\begin{aligned}
Put &= -\exp(\mu - r^f + .5\sigma^2) \left\{ \exp(-\chi + .5\delta_r^2) \tilde{\Phi}\left(\frac{k - \mu + \chi - \sigma_{nb}^2}{\sigma_{nb}}, \frac{\underline{J} - \chi + \delta_r^2}{\delta_r}; \rho\right) \right. \\
&\quad \left. + \exp(-\underline{J}) \Phi\left(\frac{k - \mu - \sigma^2 + \underline{J}}{\sigma}\right) \Phi\left(\frac{-\underline{J} + \chi}{\delta_r}\right) \right\} \\
&\quad + K \exp(-r_t^f) \left\{ \tilde{\Phi}\left(\frac{k - \mu + \chi}{\sigma_{nb}}, \frac{\underline{J} - \chi}{\delta_r}; \rho\right) + \Phi\left(\frac{k - \mu + \underline{J}}{\sigma}\right) \Phi\left(\frac{-\underline{J} + \chi}{\delta_r}\right) \right\}.
\end{aligned} \tag{A.10}$$

Comparison with Black-Scholes To compare with Black-Scholes, set $\underline{J} = +\infty$. This implies, along with $\mu_{nb}^j - r^f + .5\sigma_{nb}^2 = \chi$, that

$$Put = -\Phi\left(\frac{k - r^f - .5\sigma_{nb}^2}{\sigma_{nb}}\right) + K \exp(-r_t^f) \Phi\left(\frac{k - r^f + .5\sigma_{nb}^2}{\sigma_{nb}}\right).$$

Hence, our expression collapses to the standard Black-Scholes price for a put option in the absence of a bailout guarantee.

The Index The index has no idiosyncratic risk. Its equilibrium expected return (by analogy with the individual expected return) is given by:

$$\mu^{index} = r^f - \log \left\{ \exp \left(-\chi + \frac{\delta_r^2}{2} \right) \Phi \left(\frac{\underline{J} - \chi + \delta_r^2}{\delta_r} \right) + \exp(-\underline{J}) \Phi \left(\frac{\theta_r - \underline{J}}{\delta_r} \right) \right\}. \quad (\text{A.11})$$

The index option price is a simple case of the general option pricing formula with $\mu = \mu^{index}$ and with $\sigma = 0$. Because the variable \tilde{r} is no longer a random variable, but a constant, the derivation becomes easier. The four terms of the put option formula become:

$$\begin{aligned} V_{11}^{index} &= \exp \left(\mu^{index} - r^f + .5\delta_r^2 - \chi \right) \left\{ \Phi \left(\frac{\underline{J} - \chi + \delta_r^2}{\delta_r} \right) - \Phi \left(\frac{\mu^{index} - k - \chi + \delta_r^2}{\delta_r} \right) \right\} \\ V_{12}^{index} &= \exp(\mu^{index} - r^f - \underline{J}) \Phi \left(\frac{-\underline{J} + \chi}{\delta_r} \right) \\ V_{21}^{index} &= K \exp(-r^f) \left\{ \Phi \left(\frac{\underline{J} - \chi}{\delta_r} \right) - \Phi \left(\frac{\mu^{index} - k - \chi}{\delta_r} \right) \right\} \\ V_{22}^{index} &= K \exp(-r^f) \Phi \left(\frac{-\underline{J} + \chi}{\delta_r} \right) \end{aligned}$$

Combining terms,

$$\begin{aligned} Put^{index} &= -\exp \left(\mu^{index} - r^f \right) \left\{ \exp \left(.5\delta_r^2 - \chi \right) \left[\Phi \left(\frac{\underline{J} - \chi + \delta_r^2}{\delta_r} \right) - \Phi \left(\frac{\mu^{index} - k - \chi + \delta_r^2}{\delta_r} \right) \right] \right. \\ &\quad \left. + \exp(-\underline{J}) \Phi \left(\frac{-\underline{J} + \chi}{\delta_r} \right) \right\} + K \exp(-r^f) \Phi \left(\frac{k - \mu_r^{index} + \chi}{\delta_r} \right). \end{aligned}$$

Note that this formula only holds if $\mu^{index} < k + \underline{J}$. If instead $\mu^{index} > k + \underline{J}$, then $Put^{index} = 0$.

A.V.C. How to Operationalize

We need each of the inputs to formula (A.10). The six-step procedure below is for a given bailout level \underline{J} .

First, and without loss of generality, we set $\theta_r = 0$, which makes J^r a mean-zero shock. Then, $\chi = \sigma_{m,J}$. The formula requires a zero-coupon risk-free rate r^f which is readily available in the OptionMetrics data at daily frequency.

Second, we can recover estimates for σ^a and σ_a^2 from the variance of an individual stock return,

$$Var[r_S] = \sigma_a^2 + \sigma^2,$$

and from the variance of the index return,

$$(\sigma^{index})^2 = \sigma_a^2.$$

These two variances can be estimated at a daily frequency.

Third, the moments of the aggregate truncated shock derived above imply the following non-linear equation, which we can solve based on observables to arrive at an estimate for the

jump variance δ_r^2 :

$$\sigma_a^2 = \delta_r^2 \Phi\left(\frac{J}{\delta_r}\right) - \delta_r \underline{J} \phi\left(\frac{J}{\delta_r}\right) + \underline{J}^2 \Phi\left(\frac{-J}{\delta_r}\right) - \delta_r^2 \phi\left(\frac{J}{\delta_r}\right)^2 - \underline{J}^2 \Phi\left(\frac{-J}{\delta_r}\right)^2 + 2\delta_r \underline{J} \phi\left(\frac{J}{\delta_r}\right) \Phi\left(\frac{-J}{\delta_r}\right).$$

Finally, we must estimate the expected log index return. To do so, we rely on the equity risk premium lower bound derived in Martin's (2013) simple variance swap framework. He shows that the following bound obtains under weak assumptions:

$$\exp(r^f) E[\exp(r^{index}) - \exp(r^f)] \geq SVIX^2.$$

For our estimate, we assume that this bound holds with equality. Next, we make the Jensen inequality adjustment

$$\log E[\exp(r^{index})] = \mu^{index} + .5\sigma_a^2. \quad (\text{A.12})$$

This relationship is exact in the absence of a bailout ($\underline{J} = \infty$). When J^a is truncated, normality is violated and the equality in (A.12) is an approximation. The expected return based on *SVIX* and the previously discussed inputs is then calculated as

$$\mu^{index} = \log\left(\frac{SVIX^2}{\exp(r^f)} + \exp(r^f)\right) - \frac{\sigma_a^2}{2}.$$

Our calculation of *SVIX* for this step uses financial sector index options with $TTM = 30$. Our construction follows Martin (2013), which effectively forms an equally weighted portfolio of index calls and puts with varying strikes.

A.V.D. Auxiliary Lemmas

Below we present various intermediate results used in the previous derivation. Additional detail for these proofs are available upon request.

Lemma 1. *Let $x \sim N(\mu_x, \sigma_x^2)$ and $y \sim N(\mu_y, \sigma_y^2)$ with $\text{Corr}(x, y) = \rho_{xy}$. Then*

$$E[\exp(ax+by)1_{d < y < c}] = \Psi(a, b; x, y) \left\{ \Phi\left(\frac{c - \mu_y - b\sigma_y^2 - a\rho_{xy}\sigma_x\sigma_y}{\sigma_y}\right) - \Phi\left(\frac{d - \mu_y - b\sigma_y^2 - a\rho_{xy}\sigma_x\sigma_y}{\sigma_y}\right) \right\}$$

where $\Psi(a, b; x, y) = \exp\left(a\mu_x + b\mu_y + \frac{a^2\sigma_x^2}{2} + \frac{b^2\sigma_y^2}{2} + ab\rho_{xy}\sigma_x\sigma_y\right)$ is the bivariate normal moment-generating function of x and y evaluated at (a, b) .

Proof. Lemma 1 First, note that $x|y \sim N\left(\mu_x + \frac{\rho_{xy}\sigma_x}{\sigma_y}[y - \mu_y], \sigma_x^2(1 - \rho_{xy}^2)\right)$, therefore

$$E[\exp(ax)|y] = Q \exp\left(\frac{a\rho_{xy}\sigma_x}{\sigma_y}y\right)$$

where $Q = \exp\left(a\mu_x - \frac{a\rho_{xy}\sigma_x\mu_y}{\sigma_y} + \frac{a^2\sigma_x^2(1-\rho_{xy}^2)}{2}\right)$. Denote $\Gamma = E[\exp(ax + by)1_{d < y < c}]$, then:

$$\begin{aligned}
\Gamma &= E[E\{\exp(ax)|y\} \exp(by)1_{d < y < c}] \\
&= Q \int_d^c \exp\left(y \left\{ \frac{a\rho_{xy}\sigma_x}{\sigma_y} + b + \frac{\mu_y}{\sigma_y^2} \right\} - \frac{y^2}{2\sigma_y^2} - \frac{\mu_y^2}{2\sigma_y^2}\right) \frac{dy}{\sigma_y\sqrt{2\pi}} \\
&\quad \text{Complete the square and substitute } u = \frac{y - \sigma_y^2 \left\{ \frac{a\rho_{xy}\sigma_x}{\sigma_y} + b + \frac{\mu_y}{\sigma_y^2} \right\}}{\sigma_y}, \quad du\sigma_y = dy \\
&= \exp\left(a\mu_x + \frac{a^2\sigma_x^2(1-\rho_{xy}^2)}{2} + \frac{\sigma_y^2}{2} \left\{ \frac{a\rho_{xy}\sigma_x}{\sigma_y} + b \right\}^2 + b\mu_y\right) \\
&\quad \times \left\{ \Phi\left(\frac{c - \mu_y - b\sigma_y^2 - a\rho_{xy}\sigma_x\sigma_y}{\sigma_y}\right) - \Phi\left(\frac{d - \mu_y - b\sigma_y^2 - a\rho_{xy}\sigma_x\sigma_y}{\sigma_y}\right) \right\}.
\end{aligned}$$

□

Lemma 2. Let $x \sim N(\mu_x, \sigma_x^2)$, then

$$E[\Phi(b_0 + b_1x) \exp(ax) 1_{x < c}] = \tilde{\Phi}\left(\frac{b_0 - t_1}{\sqrt{1 + b_1^2\sigma_x^2}}, \frac{c - t_2}{\sigma_x}; \rho\right) \exp(z_1) \quad (\text{A.13})$$

where $t_1 = -b_1t_2$, $t_2 = a\sigma_x^2 + \mu_x$, $z_1 = \frac{a^2\sigma_x^2}{2} + a\mu_x$, $\rho = \frac{-b_1\sigma_x}{\sqrt{1 + b_1^2\sigma_x^2}}$, and $\tilde{\Phi}(\cdot, \cdot; \rho)$ is the cumulative density function (cdf) of a bivariate standard normal with correlation parameter ρ .

Proof. Lemma 2 Denote $\Omega = E[\Phi(b_0 + b_1x) \exp(ax) 1_{x < c}]$, then:

$$\begin{aligned}
\Omega &= \int_{-\infty}^c \int_{-\infty}^{b_0 + b_1x} \exp(ax) dF(v) dF(x) \\
&= \int_{-\infty}^c \int_{-\infty}^{b_0 + b_1x} \exp\left(ax - \frac{v^2}{2} - \frac{[x - \mu_x]^2}{2\sigma_x^2}\right) \frac{dv dx}{\sigma_x 2\pi} \\
&\quad \text{Substitute } v = u + b_1x, \quad dv = du \\
&= \int_{-\infty}^c \int_{-\infty}^{b_0} \exp\left(ax - \frac{(u + b_1x)^2}{2} - \frac{[x - \mu_x]^2}{2\sigma_x^2}\right) \frac{du dx}{\sigma_x 2\pi} \\
&= \int_{-\infty}^c \int_{-\infty}^{b_0} \exp\left(-\frac{u^2}{2} - x^2 \left(\frac{1}{2\sigma_x^2} + \frac{b_1^2}{2}\right) - b_1ux + 0u + x \left(a + \frac{\mu_x}{\sigma_x^2}\right) - \frac{\mu_x^2}{2\sigma_x^2}\right) \frac{du dx}{\sigma_x 2\pi} \\
&\quad \text{Complete the square in two variables using Lemma 3} \\
&= \int_{-\infty}^c \int_{-\infty}^{b_0} \exp\left\{\left(\begin{array}{c} u - t_1 \\ x - t_2 \end{array}\right)' \begin{pmatrix} s1 & s2 \\ s2 & s3 \end{pmatrix} \begin{pmatrix} u - t_1 \\ x - t_2 \end{pmatrix} + z_1\right\} \frac{du dx}{\sigma_x 2\pi} \\
&= \int_{-\infty}^c \int_{-\infty}^{b_0} \exp\left(-\frac{1}{2}(U - T)'(-2S)(U - T) + z_1\right) \frac{du dx}{\sigma_x 2\pi}
\end{aligned}$$

where $U = (u, x), T = (t_1, t_2), -2S = \begin{pmatrix} 1 & b_1 \\ b_1 & b_1^2 + \frac{1}{\sigma_x^2} \end{pmatrix}, (-2S)^{-1} = \begin{pmatrix} 1 + b_1^2 \sigma_x^2 & -b_1 \sigma_x^2 \\ -b_1 \sigma_x^2 & \sigma_x^2 \end{pmatrix}$.

This is the CDF for $U \sim N(T, (-2S)^{-1})$. Let $w_1 = \frac{u-t_1}{\sqrt{1+b_1^2\sigma_x^2}}, w_2 = \frac{x-t_2}{\sigma_x}$, and $\Sigma = \begin{pmatrix} 1 & \rho \\ \rho & 1 \end{pmatrix}$ with $\rho = \frac{-b_1\sigma_x}{\sqrt{1+b_1^2\sigma_x^2}}$. We have that $W' = (w_1, w_2) \sim N(0, \Sigma)$. Also, $du = dw_1\sqrt{1+b_1^2\sigma_x^2}$ and $dx = dw_2\sigma_x$.

$$\begin{aligned} \Omega &= \exp(z_1) \left\{ \int_{-\infty}^{\frac{c-t_2}{\sigma_x}} \int_{-\infty}^{\frac{b_0-t_1}{\sqrt{1+b_1^2\sigma_x^2}}} \exp\left(-\frac{1}{2}W'\Sigma^{-1}W\right) \frac{dw_1 dw_2}{2\pi\sqrt{1-\rho^2}} \right\} \sqrt{1+b_1^2\sigma_x^2}\sqrt{1-\rho^2} \\ &= \tilde{\Phi}\left(\frac{b_0-t_1}{\sqrt{1+b_1^2\sigma_x^2}}, \frac{c-t_2}{\sigma_x}; \rho\right) \exp(z_1) \end{aligned}$$

where we used that $\sqrt{1+b_1^2\sigma_x^2}\sqrt{1-\rho^2} = 1$, and where completing the square implies $t_1 = -b_1 t_2, t_2 = a\sigma_x^2 + \mu_x, s_1 = -.5, s_2 = -.5b_1, s_3 = -.5b_1^2 - \frac{1}{2\sigma_x^2}$, and $z_1 = \frac{a^2\sigma_x^2}{2} + a\mu_x$ by application of Lemma 3. \square

Lemma 3. *Bivariate Complete Square*

$$Ax^2 + By^2 + Cxy + Dx + Ey + F = \begin{pmatrix} x - t_1 \\ y - t_2 \end{pmatrix}' \begin{pmatrix} s_1 & s_2 \\ s_2 & s_3 \end{pmatrix} \begin{pmatrix} x - t_1 \\ y - t_2 \end{pmatrix} + z_1$$

where

$$\begin{aligned} t_1 &= -(2BD - CE)/(4AB - C^2) & s_1 &= A \\ t_2 &= -(2AE - CD)/(4AB - C^2) & s_2 &= C/2 \\ z_1 &= F - \frac{BD^2 - CDE + AE^2}{4AB - C^2} & s_3 &= B. \end{aligned}$$

Lemma 4. *Let $Z \sim N(\mu, \sigma^2)$ and define $\phi = \phi\left(\frac{b-\mu}{\sigma}\right)$ and $\Phi = \Phi\left(\frac{b-\mu}{\sigma}\right)$. Then*

$$E[Z1_{Z < b}] = \mu\Phi - \sigma\phi, \tag{A.14}$$

$$E[Z^2 1_{Z < b}] = (\sigma^2 + \mu^2)\Phi - \sigma(b + \mu)\phi \tag{A.15}$$

Proof.

$$E[Z1_{Z < b}] = E[Z|Z < b]Pr(Z < b) = \left(\mu - \frac{\sigma\phi}{\Phi}\right)\Phi = \mu\Phi - \sigma\phi$$

The second result is shown similarly:

$$\begin{aligned} E[Z^2 1_{Z < b}] &= E[Z^2|Z < b]Pr(Z < b) \\ &= (Var[Z^2|Z < b] + E[Z|Z < b]^2)Pr(Z < b) \\ &= \left(\sigma^2 - \frac{\sigma(b-\mu)\phi}{\Phi} - \sigma^2\frac{\phi^2}{\Phi^2} + \left[\mu - \frac{\sigma\phi}{\Phi}\right]^2\right)\Phi \\ &= (\sigma^2 + \mu^2)\Phi - \sigma(b + \mu)\phi. \end{aligned}$$

□

A.VI. Option Liquidity

Table A.4 reports summary statistics for the liquidity of put options on the S&P 500 index, sector indices (a value-weighted average across all 9 sectors), the financial sector index, all individual stock options (a value-weighted average), and individual financial stock options. The table reports daily averages of the bid-ask spread in dollars, the bid-ask spread in percentage of the midpoint price, trading volume, and open interest. The columns cover the full range of moneyness, from deep OTM ($\Delta < 20$) to deep ITM ($\Delta > 80$), while the rows report a range of option maturities. We separately report averages for the pre-crisis and crisis periods. A substantial fraction of trade in index options takes place in over-the-counter markets, which are outside our database. Hence, the bid-ask and volume numbers understate the degree of liquidity. However, absent arbitrage opportunities across trading locations, the option prices in our database do reflect this additional liquidity.

OTM put options with $\Delta < 20$ have large spreads, and volume is limited. OTM puts with Δ between 20 and 50 still have substantial option spreads. For long-dated OTM puts (maturity in excess of 180 days), the average pre-crisis spread is 5.5% for the S&P 500, 12.8% for the sector options, 10.8% for the financial sector options, 6.8% for all individual stock options, and 7.0% for individual stock options in the financial sector. Financial sector index options appear, if anything, more liquid than other sector index options. The liquidity difference between index and individual put options is smaller for the financial sector than for the average sector.

Furthermore, during the financial crisis, the liquidity of the options appears to increase. For long-dated OTM puts, the spreads decrease from 5.5% to 4.7% for S&P 500 options, from 12.8 to 7.8% for sector options, from 10.8% to 4.5% for financial sector options, from 6.8 to 5.5% for all individual options, and from 7.0% to 5.8% for financial firms' options. (We note that the absolute bid-ask spreads increase during the crisis but this is explained by the rise in put prices during the crisis. The absolute bid-ask spreads increase by less than the price.) At the same time, volume and open interest for long-dated OTM puts increased. Volume increased from 400 to 507 contracts for the S&P 500 index options, from 45 to 169 for the sector options, from 287 to 1049 for financial index options, and from 130 to 162 for individual stock options in the financial sector. During the crisis, trade in OTM financial sector put options exceeds not only trade in the other sector OTM put options but also trade in the OTM S&P 500 options. The absolute increase in liquidity of financial sector index puts during the financial crisis and the relative increase versus individual put options suggest that index options should have become more expensive, not cheaper during the crisis.

Table A.5 reports the same liquidity statistics for calls. Calls and puts are similarly liquid yet display very different basket-index spread behavior. Finally, the increase in the basket-index spread during the crisis is also present in shorter-dated options, which are more liquid. All these facts suggest that illiquidity is an unlikely explanation for our findings.

Table A.4: LIQUIDITY IN PUTS

	$0 \leq \Delta < 20$			$20 \leq \Delta < 50$			$50 \leq \Delta < 80$			$80 \leq \Delta < 100$		
	Spr. (\$)	Spr. (%)	Vol.	Spr. (\$)	Spr. (%)	Vol.	Spr. (\$)	Spr. (%)	Vol.	Spr. (\$)	Spr. (%)	Vol.
Pre-Crisis Sample												
S&P 500	0.450	80.5	1072	1.295	9.4	2219	1.821	5.8	693	1.959	3.7	93
All Sector SPDRs	0.133	150.5	80	0.141	35.0	867	7606	13.7	269	0.239	7.9	26
Financial SPDR	0.096	142.3	187	0.109	30.9	1791	19708	12.4	502	0.182	7.0	44
Indiv. Stocks	0.088	106.3	169	0.106	13.2	836	9225	6.2	473	0.230	3.1	76
Fin. Indiv. Stocks	0.095	103.5	142	0.116	13.4	691	7667	6.4	380	0.254	3.3	65
S&P 500	0.701	56.3	373	1.719	6.9	1242	22052	3.4	198	2.076	1.5	14
All Sector SPDRs	0.141	96.0	21	0.156	19.0	163	3057	8.7	40	0.273	6.3	3
Financial SPDR	0.103	71.0	103	0.119	16.8	452	13713	7.6	96	0.182	4.9	16
Indiv. Stocks	0.094	72.4	66	0.133	8.1	278	7760	4.3	123	0.242	2.3	21
Fin. Indiv. Stocks	0.103	68.4	56	0.147	8.3	229	6509	4.4	103	0.271	2.5	18
S&P 500	1.067	33.7	237	2.093	5.5	400	10895	2.6	52	2.174	1.1	4
All Sector SPDRs	0.130	60.6	9	0.156	12.8	45	1290	6.8	10	0.273	4.7	2
Financial SPDR	0.095	47.5	24	0.105	10.8	287	7823	5.6	53	0.188	4.0	4
Indiv. Stocks	0.103	55.3	52	0.156	6.8	170	6880	3.8	65	0.255	2.1	15
Fin. Indiv. Stocks	0.112	49.8	48	0.174	7.0	130	5582	3.9	50	0.278	2.2	11
Crisis Sample												
S&P 500	1.120	61.7	1369	2.663	9.4	2652	18992	4.5	871	3.033	2.4	120
All Sector SPDRs	0.087	59.4	667	0.130	11.8	2849	20540	6.9	963	0.388	4.8	72
Financial SPDR	0.042	24.7	4422	0.054	6.5	12983	88367	4.4	4336	0.206	3.7	376
Indiv. Stocks	0.108	55.5	344	0.153	7.9	1170	9400	4.5	529	0.481	2.9	87
Fin. Indiv. Stocks	0.126	56.2	296	0.181	8.1	1041	8047	4.6	452	0.516	3.0	83
S&P 500	1.723	35.2	568	3.003	6.2	1147	18511	2.8	212	3.255	1.3	25
All Sector SPDRs	0.112	31.1	209	0.184	8.1	527	8681	4.9	162	0.407	3.6	17
Financial SPDR	0.055	18.7	1421	0.079	5.3	3012	49466	4.0	1008	0.227	3.0	129
Indiv. Stocks	0.133	38.2	119	0.214	5.5	339	7705	3.2	115	0.492	2.2	15
Fin. Indiv. Stocks	0.154	37.9	106	0.253	5.6	301	6235	3.3	94	0.536	2.2	16
S&P 500	2.402	22.3	272	3.409	4.7	507	13293	2.1	60	3.593	1.1	8
All Sector SPDRs	0.177	22.1	57	0.300	7.8	169	3428	4.8	50	0.474	3.3	44
Financial SPDR	0.057	12.9	238	0.089	4.5	1049	19391	3.5	300	0.219	2.4	121
Indiv. Stocks	0.186	30.4	69	0.294	5.5	173	5372	3.1	55	0.623	2.2	9
Fin. Indiv. Stocks	0.208	30.6	54	0.338	5.8	162	4654	3.3	47	0.630	2.3	9

Notes: The full sample covers 1/2003-6/2009. The pre-crisis sample covers 1/2003-7/2007. The crisis sample covers 8/2007-6/2009. The stats reported for individual and sector options are value-weighted.

Table A.5: LIQUIDITY IN CALLS

		$0 \leq \Delta < 20$		$20 \leq \Delta < 50$		$50 \leq \Delta < 80$		$80 \leq \Delta < 100$		
		Spr. (\$)	Spr. (%)	Vol.	O.I.	Spr. (\$)	Spr. (%)	Vol.	O.I.	
Pre-Crisis Sample										
S&P 500		0.405	96.9	1002	11990	1.204	10.3	1598	12885	11351
All Sector SPDRs		0.123	169.3	23	745	0.135	42.3	262	2970	2790
Financial SPDR		0.081	177.4	22	1497	0.107	38.2	512	6477	6428
Indiv. Stocks		0.077	140.7	203	5916	0.100	14.6	1430	14839	11702
Fin. Indiv. Stocks		0.083	138.1	179	4926	0.110	15.1	1145	11640	9123
10 Days < TTM ≤ 90 Days										
S&P 500		0.592	85.7	301	10160	1.662	8.2	703	17315	13038
All Sector SPDRs		0.134	122.8	8	434	0.154	24.1	59	1481	1365
Financial SPDR		0.085	94.5	12	1012	0.120	22.2	134	4566	3734
Indiv. Stocks		0.082	112.2	77	4798	0.122	9.5	512	11756	8052
Fin. Indiv. Stocks		0.089	111.2	60	3468	0.136	9.9	395	8320	5686
90 Days < TTM ≤ 180 Days										
S&P 500		0.872	50.0	113	6705	2.001	6.9	249	10021	7283
All Sector SPDRs		0.121	89.4	3	455	0.151	17.2	23	1070	825
Financial SPDR		0.088	64.8	7	493	0.108	15.1	48	2362	2548
Indiv. Stocks		0.090	93.6	51	5189	0.143	8.5	259	9021	6730
Fin. Indiv. Stocks		0.096	96.1	40	3962	0.158	8.9	207	6783	5349
180 Days < TTM ≤ 365 Days										
S&P 500		1.067	118.6	580	10797	2.497	11.4	1857	16012	9846
All Sector SPDRs		0.080	103.7	390	7908	0.121	14.1	3386	19642	11705
Financial SPDR		0.037	47.7	3007	52259	0.050	8.5	17312	93957	56259
Indiv. Stocks		0.094	96.6	341	6754	0.141	9.5	1623	11596	7407
Fin. Indiv. Stocks		0.110	93.6	293	5739	0.169	10.0	1362	9587	6157
90 Days < TTM ≤ 180 Days										
S&P 500		1.067	97.4	183	10138	2.913	8.8	637	12846	4394
All Sector SPDRs		0.099	81.2	109	4741	0.168	10.8	480	7791	3878
Financial SPDR		0.051	50.3	749	25321	0.077	8.2	2916	42929	18780
Indiv. Stocks		0.118	75.5	100	5023	0.197	7.5	460	9358	5972
Fin. Indiv. Stocks		0.136	73.9	93	4523	0.236	7.9	375	7207	4543
180 Days < TTM ≤ 365 Days										
S&P 500		1.625	66.6	62	8211	3.420	7.7	237	8752	4713
All Sector SPDRs		0.151	63.6	45	2964	0.280	11.6	162	4348	2034
Financial SPDR		0.054	35.2	154	8949	0.088	7.5	836	18346	11201
Indiv. Stocks		0.159	62.1	57	4033	0.274	8.0	210	5991	3886
Fin. Indiv. Stocks		0.170	63.9	54	4381	0.311	8.6	190	5345	3124
90 Days < TTM ≤ 180 Days										
S&P 500		1.625	66.6	62	8211	3.420	7.7	237	8752	4713
All Sector SPDRs		0.151	63.6	45	2964	0.280	11.6	162	4348	2034
Financial SPDR		0.054	35.2	154	8949	0.088	7.5	836	18346	11201
Indiv. Stocks		0.159	62.1	57	4033	0.274	8.0	210	5991	3886
Fin. Indiv. Stocks		0.170	63.9	54	4381	0.311	8.6	190	5345	3124

Notes: The full sample covers 1/2003-6/2009. The pre-crisis sample covers 1/2003-7/2007. The crisis sample covers 8/2007-6/2009. The stats reported for individual and sector options are value-weighted.