Internet Appendix

Capital structure effects on the prices of equity call options

In this Appendix, first, for clarification, we present the methods to estimate no-arbitrage option models: BS, Merton, and CO. We hope the discussion below will clarify why we use both Compustat balance sheet data and implied parameters in order to implement the compound option (CO) model. For simplicity, we assume that a term structure of volatility (TSV) is not used, and introduce TSV later.

1. Estimating BS

BS has five parameters, the stock and strike prices, the option expiration date, the interest rate, and the expected volatility of the stock over the option's lifetime. As you know, the only unobservable parameter in BS is the stock volatility (all other parameters are directly observable). The stock volatility is implied from an at-the-money (ATM) option price on the preceding day, and that implied volatility is used to start the search for the one volatility that minimizes the sum of squared errors among all the option prices. That volatility is then used to price all the options on the next day.

2. Estimating Merton

Merton models common stock as a default option on the firm. His model also has five parameters, the unobservable current market value of the firm, V, the strike price of the default option, M, which is the face value of the firm debt to be paid at maturity, the date the default option is to be exercised, T_d, which is the date the debt matures (or the duration), the risk free interest rate, r_{T_d} over the remaining option time to default, and the firm's volatility, σ_V, expected over the life of the default option.

In estimating Merton, the only directly observed parameter is the interest rate, r_{T_d}, over the life of the single default option. Implementation of Merton's model requires two implied parameters, V and σ_V, and also requires construction of M and T_d, from balance sheet data. The face value of debt, M, is collected from Compustat. The debt is assumed to be a zero coupon bond, and its maturity is the duration of the liabilities (T_d), which can be estimated using Macaulay's method.

Further, in Merton's model, V and σ_V are implied from two pricing equations and two unknowns. Once V is implied, D is also immediately obtained from M&M as $V - S = D$.

[Note that D is not the present value of M, discounted at the riskfree rate, because the discount rate for risky debt is unknown.]

In conclusion, the implementation of Merton's model requires both the use of Compustat balance sheet data to estimate M and T_d, and two equations to imply both V and σ_V. Specifically, Merton's model yields a BS like option equation and a stochastic stock volatility equation which is an elasticity relating stochastic σ_S and deterministic σ_V. These two equations are sufficient to solve for V and σ_V.

3. Estimating CO

In the CO model, traded options are modeled as a compound option. The first option is an option on equity, and the second option, equity itself, is an option on the firm (the default option). Thus, the CO model has nine parameters: 1) V, the implied market value of the firm, 2) M, the face value of the firm debt, 3) T_d, the maturity of the debt, 4) K, the strike price of the option, 5) T_i, the expiration date of the first option, 6) and 7), r_{T_i} and r_{T_d}, the risk free interest rates over the time to call option expiration and the time to default option maturity, 8) $V^*_{T_i}$, the boundary condition for a specific future firm value at each option expiration date, T_i, which requires that if $V_{T_i} \geq V^*_{T_i}$, then the stock price at time T_i, $S_{T_i} \geq K$, and the first option can be exercised, and 9) the expected firm volatility σ_V.

To implement the CO model, we follow the general Merton assumptions, so we use Compustat to obtain the balance sheet values for all the defaultable liabilities, and estimate both the default option strike price (M), and the duration of each firm's balance sheet debt (T_d). The option strike price, K, and the option expiration dates, T_i, and the risk free interest rates are observable without error. Thus, six of the nine required CO parameters, M, T_d, K, T_i, r_{T_i}, r_{T_d}, are obtained, and the remaining three parameters, V, σ_V, and $V^*_{T_i}$ must be estimated. So, we use market prices to compute these parameters, by minimizing the sum of squared errors among the prices quoted on the preceding day, and then we compute option values the next day with these parameter estimates from the preceding day, which is the same technique as used in BS implementation. Thus, again, we use Compustat data for the face value of debt and its duration, and we use option prices to imply the unobserved parameters V, σ_V, and $V^*_{T_i}$, similar to Merton.

Our objective in the preceding discussion has been to illustrate why we use Compustat data and imply parameters to estimate the CO model.

In what follows we discuss and present four cases for comparison:

1. Case 1: Only one implied parameter, volatility, for each of BS and CO. No TSV for the call options or the default option.
2. Case 2: The minimum implied parameters for no-arbitrage prices: σ_S for BS and V, V^*, and σ_V for CO. Again, no TSV.
3. Case 3: Same as Case 2 but a different firm volatility for the default option.
4. Case 4: A TSV for both BS and CO. This case was presented in the original submission and is retained in the revision.

Cases 2 and 4 are discussed in the paper, but are repeated here for comparison purposes.

3.1. Case 1

The CO model is a no-arbitrage partial equilibrium model which at a minimum requires three unknowns which are the current market value of the firm, V, the future market value of the firm, $V^*_{T_i}$, and the firm volatility, σ_V. If we are allowed to imply only one parameter, σ_V, then we must estimate V and V^* by alternative methods before we can imply σ_V. Also we assume that the firm volatility for all the call options expiring at T_i in less than one year is the same volatility for the default option maturing at a later date T_d (σ_V for all $T_i = \sigma_{V_{T_d}}$).

In order to estimate the required current market value of the firm, $V = S + D$, given the current stock price S, we must estimate the current market value of the risky debt, D. We must estimate the firm's credit spread δ, in order to obtain the current market value of a risky zero coupon bond, $D = Me^{-(r_{T_d}+\delta)T_d}$, which is our estimate of the market value of the firm's debt. Since M, r_f, and T_d are known by observation, to value D we must use other data to compute the credit spread δ. We reiterate that the market value of debt D is not the present value of M discounted at the riskfree rate, because the discount rate for risky debt is unknown. Thus, as you can appreciate, we are not able to estimate D by knowing M alone (the credit spread δ is also needed).

To estimate δ we choose to use credit default swap spreads in conjunction with bond ratings. This choice is made because the CDS market, while not necessarily as efficient as the stock or option market, is a more efficient market than the corporate bond market or the ratings from agencies. The most liquid CDS quotes are for 5 years, but some quotes do exist for 1, 2, 3, 4, and 10 years. Thus, we must estimate the default spreads for most of the firms in our sample by imposing the credit ratings on the firms that have CDS quotes, and then interpolating for firms of similar ratings without CDS quotes. We also must find firms of similar credit ratings but different CDS maturities, and interpolate between the maturities to match the specific duration of the firm whose risky credit spread we are pricing. We perform this exercise for our sample, estimate the daily credit spreads δ, for all the firms in our sample, and use the spreads to calculate an estimated value of each firm's risky debt. Combining this daily value of risky debt D with the observed daily stock price S for each firm in our sample gives a daily estimated value, V (not an implied no-arbitrage market value) of each firm in our sample.

Next we need to construct an estimate of $V^*_{T_i}$, the future market value of the firm at date T_i necessary for the call option to be exercised. We construct our estimate of $V^*_{T_i}$ in a similar fashion to V. Since M&M holds at all future dates, any future market value of the firm at any option expiration date T_i, should be the sum of the future market values of the firm's equity and debt ($V^*_{T_i} = S^*_{T_i} + D^*_{T_i}$). Further, since the future market value of the stock at date T_i, $S^*_{T_i}$, must at a minimum be equal to the option strike price, K, for call option exercise, then we can say $V^*_{T_i} = K + D^*_{T_i}$, but $D^*_{T_i}$ is unknown. However, we use the credit spread δ calculated as explained above to compute $D_{T_i} = Me^{-(r_{T_d}+\delta)(T_d-T_i)}$.

Now we have all the CO models unknowns estimated on a daily basis and we can use them to imply the only remaining unknown parameter, σ_V, and then produce daily CO option prices to compare to daily BS option prices. The results are presented in this response as Table 6: Case 1, to be compared with Table 6 of the submission.

Table 6: Case 1 shows, for the in-the-money (ITM) options the BS average underpricing errors increase over all levels of moneyness and leverage by 11.3%, from −0.194 to −0.216, when compared to Table 6 in the submission. The CO model average ITM underpricing errors over these same categories increase by 631%, from −0.152 to −1.111.

For out-of-the-money (OTM) options, Table 6: Case 1, included herein, shows that the BS average overpricing pricing errors across all levels of moneyness and leverage increase by 24.7%, from 0.146 to 0.182, when compared to Table 6 in the submitted paper. Over the same categories of moneyness and leverage the CO average OTM overpricing errors increase by 148.6%, from 0.111 to 0.276. So, both the BS and CO pricing errors increase for all levels of moneyness and leverage.

This implies that when we are only allowed to imply one parameter (firm volatility) in CO, the compound option model performs substantially worse than Black-Scholes. Why do the CO average ITM and OTM pricing errors increase by 631% and 148.6% respectively, when the comparable BS errors increase by 11.3% and 24.7%, in Case 1 relative to that in the paper? This discrepancy occurs because the CO model was implemented with exogenous data (i.e., using imputed rates from non-traded assets–e.g., via CDS interpolations and credit rating imputations), instead of implying the required input values from market prices of the securities used to construct the CO no-arbitrage portfolio, which are the traded option, the firm (which includes S and D), and the risk free bond. Since the credit spread is estimated with a large amount of error, the error accordingly translates to CO values. In the ensuing analysis, we will argue that other cases improve the pricing performance of *both* BS and CO, but the pricing performance of CO is superior to that of BS. Indeed, in the case we present in the paper (Case 4 above), CO produces the smallest pricing error across all other cases involving BS as well as CO.

3.2. Case 2

In this case both the BS and CO models use the market prices of the securities used to construct each (BS and CO) no-arbitrage portfolio in order to imply each model's unknown parameters on a given day, which are then used to value all the options with no-arbitrage prices the next day. Since this method has already been described above, we proceed to the results. The difference between Case 2 and the analysis in the previous submitted version is only that the latter considers a term structure of volatility and our Case 2 does not. Here, for brevity, we only discuss the equivalent of Table 6 in the paper.

The table labeled Table 6: Case 2 shows that the BS pricing errors by leverage and moneyness with no TSV are the same as in Case 1. As before the BS average in-the-money (ITM) underpricing errors over all levels of moneyness and leverage increase by 11.3%, from −0.194 to −0.216, when compared to Table 6 in the submitted paper.

We can conclude that using no-arbitrage prices to imply each model's unknown parameters, and then comparing BS with and without a TSV, the ITM average BS pricing errors increase by 11.3%, from −0.194 to −0.216 when a TSV is not used, or the reverse conclusion is that if you add a TSV the BS average ITM errors are reduced by 10.2% (from −0.216 to −0.194).

However, now by implementing the CO model by implying the unobservable CO parameters using the no-arbitrage portfolio security prices, the CO average ITM underpricing errors over these categories substantially decrease by 83.8% relative to the much larger Case 1 errors, from −1.111 to −0.180. In fact the CO average errors of −0.180 are now smaller than the BS errors of −0.216 for the same ITM options when both models are implemented for their minimum number of implied parameters using the no-arbitrage portfolio securities market prices, but without a TSV. However, when the Case 2: Table 6 CO average ITM errors without a TSV are compared to Table 6 in the submitted paper, the CO errors increase.

The average CO underpricing errors increase by 18.4%, from -0.152 to -0.180 without a TSV.

A comparison allows us to separate these two effects of 1) using the no-arbitrage securities market prices to imply parameters and 2) of using a TSV. When the compound option model is implemented with both no-arbitrage implied parameters and a TSV, the ITM average pricing errors across moneyness and leverage are -0.152 from Table 6 in the submitted paper, and if the TSV is not used, the errors increase to -0.180. This is either an 18.4% increase in average ITM pricing errors by not implementing the CO model with a TSV, or a 15.6% decrease in average ITM pricing errors by implementing the CO model with a TSV. Since the CO average ITM pricing errors increase to -1.111 when the no-arbitrage implied parameters are not used, this represents a 612.6% increase in average CO ITM pricing errors when the CO model is implemented without the no-arbitrage pricing implied parameters and without a TSV. (Note that $612.6\% + 18.4\%$ equals 631%.)

For out-of-the-money (OTM) options, the BS average overpricing errors across all levels of moneyness and leverage maintain the same change as in Case 1, an increase of 24.7% with no TSV, from 0.146 to 0.182, when compared to Table 6 in the submitted paper. The CO average OTM overpricing errors increase by 34.2%, from 0.111 to 0.149 over the same categories of moneyness and leverage. The Case 2 CO average OTM pricing errors are 0.149, again less than the BS average OTM errors of 0.182. This increase in OTM average pricing errors for both the BS and CO models can be attributed to not using a TSV.

Once again we can separate what portion of the CO OTM average pricing errors are attributable to implementing it without a TSV (18.4%) and what portion of the errors can be attributed to implementing it without using market prices to imply parameters. We previously showed in Case 1, Table 6, that the CO average OTM overpricing errors increase by 148.6%, from 0.111 to 0.276 over the same categories of moneyness and leverage. We just demonstrated that 18.4% of this increase in pricing errors was attributable to not using a TSV, so 130.2% of this increase in pricing errors can be attributed to not using market prices to imply the necessary parameters.

3.3. Case 3

Next, we briefly discuss Case 3 which focuses on analysis of the idea that the firm volatility for the default option, which in almost all cases (indeed, in every case in our sample of over two million option prices) matures years after the current equity call options, is likely to be different from the single firm volatility which is used to price all the listed call options which all expire within the next year. Thus, in Case 3 we allow the volatility for valuing the default option to be different from the single volatility that we use to value all the listed call options. This can be analyzed by adding one more equation for another (closest to ATM) option price for each maturity bucket, which will allow researchers to imply four unknowns, V, V^*, σ_{V_i}, and $\sigma_{V_{T_d}}$. Note that $\sigma_{V_{T_d}}$ is the same at each date for all of the firm's options, as explained in more detail within the paper. The results are presented in Table 6: Case 3. BS ITM and OTM pricing errors do not change in Case 3. However, for the CO model, with the addition of another implied volatility parameter, the average pricing errors for both the ITM and the OTM options are shown to be reduced. We can observe this when we compare Table 6: Case 2 to Table 6: Case 3. The CO average ITM underpricing errors across all leverage and moneyness categories are reduced from -0.180 to -0.178, and the average OTM overpricing errors are reduced from 0.149 to 0.128. This represents just a 1% error reduction for ITM options, but 14.1% for the OTM options. Also note that the error reductions are greater for the options which are further ITM and OTM as compared to ATM.

As a final additional comparison of the effects of adding a TSV for the listed call options, we can compare Table 6: Case 3 herein, to Table 6: Case 4 presented in the submission. This shows that valuing the listed call options with a TSV significantly reduces the pricing errors for both the BS and the CO model. When a TSV for the listed call options is added to the CO following the addition of a different firm volatility for the default option this further reduces the average ITM underpricing errors from -0.178 to -0.152, a 14.6% reduction. For the OTM options the addition of a TSV for the call option valuation, following the addition of a different volatility for the default option, also further reduces the average OTM pricing errors from 0.128 to 0.111, a reduction of 13.3%.

3.4. Concluding Remarks on Estimation

In conclusion, we reiterate the importance of using market prices for the securities specified in the no-arbitrage portfolios to imply the unknown parameters required for producing no-arbitrage options values, instead of using exogenous data not related directly to the no-arbitrage portfolios. BS is not so concerned with this methodology choice because most researchers have accepted the usefulness of the no-arbitrage option prices produced by implying equity volatility, σ_S, from the stock price, the risk free bond price, and option prices, as required for BS valuations.

In Section 4.2.2 of the revised paper we have included selected results for Case 3, where both BS and CO models are implemented with a single implied volatility instead of TSV. We believe this is an important and a valuable addition to the paper.

With regard to the practice of implying volatility daily, we conduct a sensitivity analysis by implying the volatility weekly, for Case 4 above. In this exercise, instead of recalculating firm volatility σ_V (for CO) and equity volatility σ_S (for BS) daily, we keep it constant for a week (i.e., keep the Monday value constant till Friday). The estimation process for all other parameters is unchanged. We present the equivalent of Table 6 these results as the last table. Comparing to Table 6 in the revised paper, the patterns are similar, but the pricing errors increase.

One final note worth emphasizing is that the compound option model estimation using Case 4, which is the focus of the paper itself, produces the maximal pricing improvement across all eight implementations (four each for BS and CO corresponding to the four cases), thus justifying its emphasis from a practical standpoint.

Table 6: **Case 1 Pricing Error by Leverage and Moneyness**

The reported numbers are respectively the average pricing error, defined as the difference of model value and market price, for all categories partitioned by leverage and moneyness jointly. *ITM* and *OTM* denote in-the-money and out-of-the money options, respectively.

Panel A: CALL *ITM* BS Pricing Errors by Leverage and Moneyness						
D/E	[0.40–0.60)	[0.60–0.70)	[0.70–0.80)	[0.80–0.90)	[0.90–0.95)	***Total***
11%-20%	−0.227	−0.233	−0.221	−0.206	−0.186	***−0.204***
21%-30%	−0.257	−0.248	−0.239	−0.221	−0.202	***−0.218***
31%-60%	−0.263	−0.305	−0.273	−0.238	−0.211	***−0.237***
61%-100%	−0.296	−0.253	−0.243	−0.215	−0.191	***−0.213***
101%-150%	−0.239	−0.218	−0.227	−0.200	−0.176	***−0.197***
151%-200%	−0.163	−0.183	−0.305	−0.237	−0.164	***−0.218***
Subtotal	***−0.245***	***−0.254***	***−0.240***	***−0.218***	***−0.196***	***−0.216***
Panel B: CALL *ITM* CO Pricing Errors by Leverage and Moneyness						
D/E	[0.40–0.60)	[0.60–0.70)	[0.70–0.80)	[0.80–0.90)	[0.90–0.95)	***Total***
11%-20%	−2.437	−2.254	−2.064	−1.556	−0.812	***−1.242***
21%-30%	−2.126	−1.985	−1.956	−1.474	−0.772	***−1.165***
31%-60%	−2.129	−1.964	−1.761	−1.293	−0.683	***−1.061***
61%-100%	−1.829	−1.757	−1.538	−1.097	−0.541	***−0.928***
101%-150%	−1.701	−1.541	−1.389	−0.975	−0.408	***−0.823***
151%-200%	−1.597	−1.576	−1.238	−0.721	−0.283	***−0.700***
Subtotal	***−2.054***	***−1.950***	***−1.813***	***−1.372***	***−0.717***	***−1.111***
Panel C: CALL *OTM* BS Pricing Errors by Leverage and Moneyness						
D/E	(1.05–1.10]	(1.10–1.20]	(1.20–1.30]	(1.30–1.40]	(1.40–2.50]	***Total***
11%-20%	0.143	0.182	0.247	0.304	0.390	***0.194***
21%-30%	0.127	0.175	0.247	0.303	0.377	***0.177***
31%-60%	0.130	0.178	0.256	0.333	0.421	***0.186***
61%-100%	0.118	0.151	0.204	0.258	0.386	***0.151***
101%-150%	0.100	0.113	0.158	0.253	0.365	***0.113***
151%-200%	0.080	0.084	0.178	0.180	0.208	***0.170***
Subtotal	***0.132***	***0.175***	***0.243***	***0.306***	***0.393***	***0.182***
Panel D: CALL *OTM* CO Pricing Errors by Leverage and Moneyness						
D/E	(1.05–1.10]	(1.10–1.20]	(1.20–1.30]	(1.30–1.40]	(1.40–2.50]	***Total***
11%-20%	0.201	0.357	0.610	0.760	0.976	***0.301***
21%-30%	0.165	0.379	0.543	0.540	0.663	***0.286***
31%-60%	0.159	0.375	0.557	0.610	0.863	***0.303***
61%-100%	0.104	0.190	0.367	0.584	0.865	***0.278***
101%-150%	0.102	0.197	0.383	0.606	0.472	***0.250***
151%-200%	0.101	0.194	0.305	0.302	0.517	***0.290***
Subtotal	***0.157***	***0.340***	***0.535***	***0.621***	***0.812***	***0.276***

Table 6: **Case 2 Pricing Error by Leverage and Moneyness**
The reported numbers are respectively the average pricing error, defined as the difference of model value and market price, for all categories partitioned by leverage and moneyness jointly. *ITM* and *OTM* denote in-the-money and out-of-the money options, respectively.

Panel A: CALL *ITM* BS Pricing Errors by Leverage and Moneyness						
D/E	[0.40–0.60)	[0.60–0.70)	[0.70–0.80)	[0.80–0.90)	[0.90–0.95)	***Total***
11%-20%	−0.227	−0.233	−0.221	−0.206	−0.186	***−0.204***
21%-30%	−0.257	−0.248	−0.239	−0.221	−0.202	***−0.218***
31%-60%	−0.263	−0.305	−0.273	−0.238	−0.211	***−0.237***
61%-100%	−0.296	−0.253	−0.243	−0.215	−0.191	***−0.213***
101%-150%	−0.239	−0.218	−0.227	−0.200	−0.176	***−0.197***
151%-200%	−0.163	−0.183	−0.305	−0.237	−0.164	***−0.218***
Subtotal	***−0.245***	***−0.254***	***−0.240***	***−0.218***	***−0.196***	***−0.216***
Panel B: CALL *ITM* CO Pricing Errors by Leverage and Moneyness						
D/E	[0.40–0.60)	[0.60–0.70)	[0.70–0.80)	[0.80–0.90)	[0.90–0.95)	***Total***
11%-20%	−0.185	−0.192	−0.178	−0.172	−0.169	***−0.179***
21%-30%	−0.200	−0.194	−0.192	−0.188	−0.180	***−0.186***
31%-60%	−0.191	−0.227	−0.206	−0.191	−0.180	***−0.191***
61%-100%	−0.188	−0.157	−0.164	−0.156	−0.148	***−0.155***
101%-150%	−0.154	−0.122	−0.135	−0.128	−0.119	***−0.126***
151%-200%	−0.071	−0.084	−0.221	−0.153	−0.095	***−0.138***
Subtotal	***−0.188***	***−0.196***	***−0.190***	***−0.182***	***−0.171***	***−0.180***
Panel C: CALL *OTM* BS Pricing Errors by Leverage and Moneyness						
D/E	(1.05–1.10]	(1.10–1.20]	(1.20–1.30]	(1.30–1.40]	(1.40–2.50]	***Total***
11%-20%	0.143	0.182	0.247	0.304	0.390	***0.194***
21%-30%	0.127	0.175	0.247	0.303	0.377	***0.177***
31%-60%	0.130	0.178	0.256	0.333	0.421	***0.186***
61%-100%	0.118	0.151	0.204	0.258	0.386	***0.151***
101%-150%	0.100	0.113	0.158	0.253	0.365	***0.113***
151%-200%	0.080	0.084	0.178	0.180	0.208	***0.170***
Subtotal	***0.132***	***0.175***	***0.243***	***0.306***	***0.393***	***0.182***
Panel D: CALL *OTM* CO Pricing Errors by Leverage and Moneyness						
D/E	(1.05–1.10]	(1.10–1.20]	(1.20–1.30]	(1.30–1.40]	(1.40–2.50]	***Total***
11%-20%	0.108	0.118	0.152	0.177	0.240	***0.171***
21%-30%	0.107	0.115	0.123	0.160	0.206	***0.147***
31%-60%	0.106	0.110	0.133	0.140	0.187	***0.141***
61%-100%	0.105	0.108	0.156	0.157	0.164	***0.102***
101%-150%	0.098	0.108	0.140	0.144	0.149	***0.067***
151%-200%	0.096	0.094	0.117	0.128	0.129	***0.040***
Subtotal	***0.102***	***0.104***	***0.150***	***0.174***	***0.205***	***0.149***

Table 6: **Case 3 Pricing Error by Leverage and Moneyness**

The reported numbers are respectively the average pricing error, defined as the difference of model value and market price, for all categories partitioned by leverage and moneyness jointly. *ITM* and *OTM* denote in-the-money and out-of-the money options, respectively.

Panel A: CALL *ITM* BS Pricing Errors by Leverage and Moneyness						
D/E	[0.40–0.60)	[0.60–0.70)	[0.70–0.80)	[0.80–0.90)	[0.90–0.95)	***Total***
11%-20%	−0.227	−0.233	−0.221	−0.206	−0.186	***−0.204***
21%-30%	−0.257	−0.248	−0.239	−0.221	−0.202	***−0.218***
31%-60%	−0.263	−0.305	−0.273	−0.238	−0.211	***−0.237***
61%-100%	−0.296	−0.253	−0.243	−0.215	−0.191	***−0.213***
101%-150%	−0.239	−0.218	−0.227	−0.200	−0.176	***−0.197***
151%-200%	−0.163	−0.183	−0.305	−0.237	−0.164	***−0.218***
Subtotal	***−0.245***	***−0.254***	***−0.240***	***−0.218***	***−0.196***	***−0.216***
Panel B: CALL *ITM* CO Pricing Errors by Leverage and Moneyness						
D/E	[0.40–0.60)	[0.60–0.70)	[0.70–0.80)	[0.80–0.90)	[0.90–0.95)	***Total***
11%-20%	−0.176	−0.186	−0.183	−0.180	−0.169	***−0.177***
21%-30%	−0.195	−0.187	−0.186	−0.186	−0.180	***−0.184***
31%-60%	−0.180	−0.219	−0.201	−0.190	−0.180	***−0.189***
61%-100%	−0.177	−0.156	−0.154	−0.150	−0.148	***−0.151***
101%-150%	−0.148	−0.125	−0.125	−0.126	−0.120	***−0.124***
151%-200%	−0.079	−0.092	−0.227	−0.156	−0.104	***−0.143***
Subtotal	***−0.180***	***−0.190***	***−0.185***	***−0.180***	***−0.170***	***−0.178***
Panel C: CALL *OTM* BS Pricing Errors by Leverage and Moneyness						
D/E	(1.05–1.10]	(1.10–1.20]	(1.20–1.30]	(1.30–1.40]	(1.40–2.50]	***Total***
11%-20%	0.143	0.182	0.247	0.304	0.390	***0.194***
21%-30%	0.127	0.175	0.247	0.303	0.377	***0.177***
31%-60%	0.130	0.178	0.256	0.333	0.421	***0.186***
61%-100%	0.118	0.151	0.204	0.258	0.386	***0.151***
101%-150%	0.100	0.113	0.158	0.253	0.365	***0.113***
151%-200%	0.080	0.084	0.178	0.180	0.208	***0.170***
Subtotal	***0.132***	***0.175***	***0.243***	***0.306***	***0.393***	***0.182***
Panel D: CALL *OTM* CO Pricing Errors by Leverage and Moneyness						
D/E	(1.05–1.10]	(1.10–1.20]	(1.20–1.30]	(1.30–1.40]	(1.40–2.50]	***Total***
11%-20%	0.108	0.119	0.143	0.164	0.213	***0.135***
21%-30%	0.106	0.115	0.136	0.159	0.194	***0.130***
31%-60%	0.103	0.103	0.138	0.122	0.211	***0.127***
61%-100%	0.103	0.101	0.100	0.109	0.154	***0.119***
101%-150%	0.092	0.100	0.097	0.098	0.104	***0.106***
151%-200%	0.091	0.096	0.097	0.090	0.097	***0.103***
Subtotal	***0.100***	***0.106***	***0.140***	***0.152***	***0.198***	***0.128***

Table 6: **Case 4 Pricing Error by Leverage and Moneyness**

The reported numbers are respectively the average pricing error, defined as the difference of model value and market price, for all categories partitioned by leverage and moneyness jointly. *ITM* and *OTM* denote in-the-money and out-of-the money options, respectively.

Panel A: CALL *ITM* BS Pricing Errors by Leverage and Moneyness						
D/E	[0.40–0.60)	[0.60–0.70)	[0.70–0.80)	[0.80–0.90)	[0.90–0.95)	***Total***
11%-20%	−0.233	−0.242	−0.223	−0.192	−0.150	***−0.187***
21%-30%	−0.249	−0.244	−0.229	−0.198	−0.159	***−0.191***
31%-60%	−0.253	−0.289	−0.259	−0.224	−0.183	***−0.217***
61%-100%	−0.262	−0.224	−0.207	−0.178	−0.143	***−0.173***
101%-150%	−0.228	−0.208	−0.193	−0.152	−0.130	***−0.154***
151%-200%	−0.134	−0.172	−0.197	−0.127	−0.017	***−0.105***
Total	***−0.242***	***−0.251***	***−0.231***	***−0.199***	***−0.159***	***−0.194***
Panel B: CALL *ITM* CO Pricing Errors by Leverage and Moneyness						
D/E	[0.40–0.60)	[0.60–0.70)	[0.70–0.80)	[0.80–0.90)	[0.90–0.95)	***Total***
11%-20%	−0.181	−0.194	−0.185	−0.166	−0.133	***−0.160***
21%-30%	−0.180	−0.176	−0.174	−0.163	−0.135	***−0.155***
31%-60%	−0.153	−0.189	−0.175	−0.166	−0.144	***−0.160***
61%-100%	−0.120	−0.103	−0.110	−0.107	−0.093	***−0.102***
101%-150%	−0.109	−0.096	−0.083	−0.070	−0.067	***−0.073***
151%-200%	−0.033	−0.039	−0.032	−0.034	−0.039	***−0.035***
Total	***−0.169***	***−0.180***	***−0.172***	***−0.158***	***−0.131***	***−0.152***
Panel C: CALL *OTM* BS Pricing Errors by Leverage and Moneyness						
D/E	(1.05–1.10]	(1.10–1.20]	(1.20–1.30]	(1.30–1.40]	(1.40–2.50]	***Total***
11%-20%	0.112	0.128	0.155	0.177	0.191	***0.141***
21%-30%	0.109	0.132	0.169	0.172	0.097	***0.131***
31%-60%	0.125	0.157	0.211	0.263	0.267	***0.177***
61%-100%	0.101	0.109	0.130	0.160	0.184	***0.124***
101%-150%	0.084	0.103	0.117	0.155	0.187	***0.112***
151%-200%	0.084	0.104	0.118	0.185	0.120	***0.112***
Total	***0.113***	***0.134***	***0.169***	***0.197***	***0.190***	***0.146***
Panel D: CALL *OTM* CO Pricing Errors by Leverage and Moneyness						
D/E	(1.05–1.10]	(1.10–1.20]	(1.20–1.30]	(1.30–1.40]	(1.40–2.50]	***Total***
11%-20%	0.100	0.109	0.124	0.137	0.140	***0.115***
21%-30%	0.094	0.105	0.126	0.119	0.037	***0.100***
31%-60%	0.102	0.118	0.148	0.186	0.208	***0.133***
61%-100%	0.076	0.068	0.069	0.076	0.096	***0.074***
101%-150%	0.057	0.059	0.049	0.058	0.062	***0.057***
151%-200%	0.069	0.074	0.061	0.035	0.027	***0.066***
Total	***0.095***	***0.105***	***0.123***	***0.138***	***0.130***	***0.111***

Table 6: **Case 4 Pricing Error by Leverage and Moneyness, Volatility Implied Weekly**

The reported numbers are respectively the average pricing error, defined as the difference of model value and market price, for all categories partitioned by leverage and moneyness jointly. ITM and OTM denote in-the-money and out-of-the money options, respectively. Instead of recalibrating $\sigma_{S_{T_i}}$ for BS, and $\sigma_{V_{T_i}}$ and $\sigma_{V_{T_d}}$ for CO daily, we calibrate once at the beginning of each week. For BS, we keep $\sigma_{S_{T_i}}$ constant within the same week (i.e., keep the Monday value constant till Friday). Similarly, for CO, we keep $\sigma_{V_{T_i}}$ and $\sigma_{V_{T_d}}$ constant within the same week. The estimation processes for other parameters are unchanged from Table 6 in the revision.

Panel A: CALL ITM BS Pricing Errors by Leverage and Moneyness						
D/E	[0.40–0.60)	[0.60–0.70)	[0.70–0.80)	[0.80–0.90)	[0.90–0.95)	***Total***
11%-20%	−0.202	−0.217	−0.213	−0.206	−0.195	***−0.204***
21%-30%	−0.205	−0.203	−0.202	−0.204	−0.196	***−0.201***
31%-60%	−0.174	−0.225	−0.221	−0.225	−0.229	***−0.225***
61%-100%	−0.196	−0.181	−0.166	−0.161	−0.164	***−0.164***
101%-150%	−0.154	−0.137	−0.109	−0.102	−0.114	***−0.110***
151%-200%	−0.068	−0.082	−0.173	−0.099	−0.000	***−0.075***
Subtotal	***−0.194***	***−0.211***	***−0.207***	***-0.203***	***−0.199***	***−0.203***
Panel B: CALL ITM CO Pricing Errors by Leverage and Moneyness						
D/E	[0.40–0.60)	[0.60–0.70)	[0.70–0.80)	[0.80–0.90)	[0.90–0.95)	***Total***
11%-20%	−0.194	−0.207	−0.197	−0.181	−0.151	***−0.176***
21%-30%	−0.196	−0.186	−0.182	−0.169	−0.144	***−0.164***
31%-60%	−0.174	−0.206	−0.184	−0.173	−0.152	***−0.168***
61%-100%	−0.155	−0.116	−0.129	−0.116	−0.104	***−0.114***
101%-150%	−0.135	−0.147	−0.099	−0.095	−0.069	***−0.089***
151%-200%	−0.055	−0.047	−0.233	−0.142	−0.036	***−0.111***
Subtotal	***−0.187***	***−0.196***	***−0.184***	***−0.169***	***−0.144***	***−0.165***
Panel C: CALL OTM BS Pricing Errors by Leverage and Moneyness						
D/E	(1.05–1.10]	(1.10–1.20]	(1.20–1.30]	(1.30–1.40]	(1.40–2.50]	***Total***
11%-20%	0.099	0.138	0.196	0.247	0.334	***0.174***
21%-30%	0.085	0.124	0.196	0.240	0.238	***0.147***
31%-60%	0.084	0.136	0.212	0.275	0.397	***0.181***
61%-100%	0.069	0.092	0.125	0.158	0.212	***0.118***
101%-150%	0.064	0.091	0.107	0.132	0.193	***0.109***
151%-200%	0.060	0.083	0.094	0.133	0.173	***0.102***
Subtotal	***0.087***	***0.128***	***0.188***	***0.236***	***0.309***	***0.161***
Panel D: CALL OTM CO Pricing Errors by Leverage and Moneyness						
D/E	(1.05–1.10]	(1.10–1.20]	(1.20–1.30]	(1.30–1.40]	(1.40–2.50]	***Total***
11%-20%	0.100	0.108	0.118	0.128	0.144	***0.114***
21%-30%	0.095	0.106	0.123	0.128	0.128	***0.110***
31%-60%	0.107	0.121	0.140	0.155	0.185	***0.131***
61%-100%	0.090	0.089	0.095	0.106	0.146	***0.100***
101%-150%	0.095	0.082	0.067	0.058	0.066	***0.078***
151%-200%	0.172	0.158	0.136	0.116	0.086	***0.141***
Subtotal	***0.101***	***0.109***	***0.121***	***0.130***	***0.148***	***0.116***