Internet Appendix to
Options Trading Costs Are Lower than You Think

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January 18, 2020

This Internet Appendix provides additional empirical results that supplement those in the main text. Tables IA.1–IA.5 and IA.7–IA.8 report results for options on stocks that are not included in the S&P 500 index (non-S&P 500 stocks). They parallel Tables 1–5 and 7–8 in the main text which report results for options on stocks in the S&P 500 index (S&P 500 stocks). Tables IA.6 and IA.10 parallel Tables 6 and 10 but report results for all common stocks. Table IA.6 also reports results for portfolio sorts that are not included in Table 6.

Table IA.9 reports the results of stock-by-date panel regressions that explore how the fit of the predictive models as measured by R^2 varies with time-series shocks to volatility, returns, and information asymmetry.

Table IA.11 presents summary statistics related to the samples of quotes used to estimate Models 1 and 2. These regression models are estimated on quote snapshots at one-minute frequency, where the left-hand side variable is the change in the midpoint quote over the next ten minutes. Table IA.11 reports statistics about the frequency with which these ten-minute intervals contain an option trade and the frequency that these options trades consume the quoted size at the NBBO.

Table IA.12 reports trading cost estimates separately for calls and puts on S&P 500 stocks, and for options on S&P 500 stocks in different time-to-expiration buckets.

Table IA.13 reports the average correlations between the midpoint quote changes over ten-minute horizons, the price changes predicted by Model 1, and the price changes predicted by Model 1, for both S&P 500 and non-S&P 500 stocks.

Table IA.14 reports the results of stock-by-date panel regressions for both S&P 500 and non-S&P 500 stocks that explore how the measures of price impact vary with proxies for volatility and the risk of options market maker inventories of options.

Figure IA.1 consists of several panels showing how the measures of trading costs of different groups of options evolved over time. Figure IA.2 consists of several panels showing how the R^2s of Models 1 and 2 varied throughout the sample period. Figure IA.3 shows how the coefficients on the key predictive variable $\hat{P}_t^{BSM} - P_t$ evolved over time.

Table IA.1
Summary statistics for option trades (non-S&P 500 stocks)
The sample consists of all trades in options on non-S&P 500 stocks from January 2004 through December 2015. Each statistic is computed for each sample month, and the table reports the average values of the statistics across the 144 sample months. Days-to-expiration is in calendar days. Trade price, trade size in number of contracts traded, and stock price are computed immediately prior to the option trade. Market capitalization of the underlying stock is as-of the previous day's close. Minute of day is the time at which the trade occurs, measured from 9:30 a.m. eastern time. Size quoted at ask and bid are the numbers of contracts quoted at the national best ask and bid immediately prior to the option trade. The percentages and numbers of options exchanges quoting at the ask and bid are also measured immediately prior to the trade. The sample contains a total of 202,333,269 options trades in non-S&P 500 stocks, or an average of 1,405,092 trades per month.

			Percentiles						
Variable	Mean	Std.dev.	1%	5%	25%	median	75%	95%	99%
Statistics of options trades									
Call/put (call = 0, put = 1)	0.37	0.48	0	0	0	0	1	1	1
Buy/sell (buy = 1, sell = –1)	–0.036	1.00	–1	–1	–1	–0.9583	1	1	1
|Delta|	0.46	0.21	0.08	0.14	0.30	0.44	0.59	0.84	0.92
Days-to-expiration	76.68	107.19	1.83	5.34	19.28	37.46	94.32	264.93	601.07
Trade price ($)	3.04	4.46	0.18	0.32	0.83	1.67	3.44	10.23	21.27
Trade size (contracts)	15.48	57.92	1.00	1.00	2.03	6.56	11.83	48.11	158.03
Stock price ($)	52.77	52.30	3.20	6.28	18.36	33.77	64.83	163.66	206.28
Market capitalization ($million)	8,502	12,075	196	444	1,445	3,405	10,551	31,989	53,143
Minute of day (9:30 a.m. ET = 0)	170.3	117.9	4.75	12.51	61.84	152.55	277.10	364.79	377.92
Market condition at time of trade									
Size quoted at ask	594.2	1,401.9	1.0	2.6	25.3	140.6	527.6	2,789.8	6,847.2
Size quoted at bid	630.3	1,449.9	1.0	3.0	28.7	153.5	568.1	2,958.7	7,155.4
% of options exchanges at ask	59.9%	33.1%	13.1%	13.3%	24.4%	67.2%	92.1%	100.0%	100.0%
% of options exchanges at bid	60.8%	33.0%	13.1%	13.4%	25.6%	68.5%	92.6%	100.0%	100.0%
# of options exchanges at ask	4.14	2.52	1	1	1.31	4.38	6.41	7.77	8.21
# of options exchanges at bid	4.20	2.51	1	1	1.46	4.47	6.43	7.79	8.20
Changes in options prices following trades									
Actual change in quote midpoint	0.1%	5.3%	–15.0%	–8.8%	–2.3%	0.0%	2.4%	9.4%	15.7%
Change predicted by Model 1	0.1%	1.5%	–4.4%	–2.3%	–0.6%	0.0%	0.6%	2.5%	4.8%
Change predicted by Model 2	0.1%	2.4%	–6.6%	–3.7%	–1.0%	0.0%	1.1%	4.2%	7.1%

Table IA.2

Conventional measures of option trading costs and price impact (non-S&P 500 stocks)

The sample consists of all trades in options on non-S&P 500 stocks from January 2004 through December 2015. Each statistic is first computed for each trade. Then the option trades in each sample (for example, OTM options) are used to compute the averages for each stock-day. The table reports the means and other statistics describing the distributions of these stock-day averages. Panel A uses all option trades, while panel B uses only trades that fall in a particular moneyness category, defined by the absolute value of the option delta: $|\Delta| < 0.35$ for OTM, $0.35 \leq |\Delta| < 0.65$ for ATM, and $0.65 \leq |\Delta|$ for ITM options. The quoted half spread is half the difference between the ask and bid prices at the time of the trade, expressed as either a percentage of the pre-trade bid-ask midpoint or in dollars. The effective half spread is the difference between the trade price and the bid-ask midpoint (bid-ask midpoint and trade price) for trades signed as buys (sells), where a trade is signed as a buy (sell) if the trade price is greater (less) than the midpoint. The price impact for a buy (sell) is the (negative of the) difference between the bid-ask midpoint ten minutes after the trade and at the time of the trade, divided by the midpoint at the time of the trade.

A. Options on non-S&P500 stocks

Variable	Mean	Std.dev.	Median
Quoted spread (%)	12.8%	6.7%	11.3%
Effective spread (%)	9.7%	5.6%	8.5%
Price impact (%)	2.2%	2.4%	1.9%
Quoted spread ($)	0.20	0.22	0.15
Effective spread ($)	0.15	0.14	0.11
Number of stock-days	2,440,621		

B. Options split by moneyness

	OTM		ATM		ITM	
	Mean	Std.dev.	Mean	Std.dev.	Mean	Std.dev.
Quoted spread (%)	16.6%	8.1%	11.6%	7.0%	8.4%	6.1%
Effective spread (%)	12.9%	7.2%	8.8%	5.8%	6.1%	4.7%
Price impact (%)	2.7%	3.2%	2.1%	2.6%	1.6%	2.4%
Quoted spread ($)	0.14	0.13	0.19	0.20	0.29	0.33
Effective spread ($)	0.10	0.09	0.14	0.14	0.20	0.22
Num. of stock-days	1,496,725		2,055,289		1,659,885	

Table IA.3
Predictive model estimates (non-S&P 500 stocks)

Coefficient estimates and *t*-statistics for the predictive Models 1 and 2 in Equations (2) and (3) estimated using the sample of quotes at one-minute frequency during the period from January 2004 through December 2015 for options on non-S&P 500 stocks. Model 1 predicts ten-minute changes in the option bid-ask midpoint $P_{t+\tau} - P_t$ using $\hat{P}_t^{BSM} - P_t$, the difference between the BSM value and the time *t* option quote midpoint. Model 2 also uses $\%ExchBid_t$ and $\%ExchAsk_t$, the percentages of options exchanges with bid or ask price equal to the National Best Bid (Offer), $\Delta \times \left(S_{t-(j-1)\Delta t} - S_{t-j\Delta t}\right)$ for j = 1 and 2, the two most recent lagged one-minute delta-adjusted changes in the underlying stock price, and $P_{t-(j-1)\Delta t} - P_{t-j\Delta t}$, for j = 1 and 2, the two most recent lagged changes in the option quote midpoint. Moneyness categories are defined by the absolute value of the option delta: $|\Delta| < 0.35$ for OTM, $0.35 \leq |\Delta| < 0.65$ for ATM, and $0.65 \leq |\Delta|$ for ITM options. We estimate the regression models for each option contract and day using snapshots of options quotes at one-minute frequency, without using any trade data. We then compute the average coefficient estimates for each stock and month and report the averages over the pooled stock-by-month panel. We list *t*-statistics based on robust standard errors clustered by stock and month are in parentheses below the coefficient estimates.

	Model 1			Model 2		
	OTM	ATM	ITM	OTM	ATM	ITM
Constant	0.0007	0.0002	–0.0026	–0.0004	–0.0001	–0.0043
	(17.50)	(6.67)	(–28.89)	(–8.00)	(–4.17)	(–15.25)
Implied bias	0.3287	0.3903	0.4438	0.2428	0.37	0.4682
	(63.46)	(59.77)	(48.03)	(56.73)	(51.85)	(41.22)
$\%ExchBid_t$				0.0174	0.025	0.0383
				(46.58)	(35.13)	(27.42)
$\%ExchAsk_t$				–0.0166	–0.025	–0.0354
				(–36.60)	(–33.29)	(–29.84)
$\Delta \times (S_t - S_{t-\Delta t})$				0.1233	0.1338	0.0887
				(70.94)	(62.29)	(50.11)
$\Delta \times (S_{t-\Delta t} - S_{t-2\Delta t})$				0.0482	0.0493	0.0267
				(33.68)	(31.58)	(21.68)
$P_t - P_{t-\Delta t}$				–0.0461	–0.0546	–0.0209
				(–17.25)	(–10.41)	(–3.13)
$P_{t-\Delta t} - P_{t-2\Delta t}$				–0.0127	–0.0178	–0.0029
				(–7.80)	(–0.64)	(–4.62)
Adj. R^2	8.42%	8.23%	8.95%	16.93%	13.40%	12.95%
N	271,928	324,626	330,512	228,756	266,102	268,319

Table IA.4.

Predictive model out-of-sample performance (non-S&P 500 stocks)

This table reports measures of the out-of-sample performance of the predictive models computed using the sample of trades of options on non-S&P 500 stocks during the period from January 2004 through December 2015. The results for the out-of-sample R^2s in the first row of results are computed using the formula for the out-of-sample R^2 in Equation (6). For each month, we estimate the adjusted R^2s using all option trades on non-S&P 500 stocks during the month and then report the mean, median, and standard deviation of the monthly R^2s. The last three rows report results from no-intercept regressions of changes in mid-quote prices on the ex-ante forecasts from each model. We estimate regressions separately for each month and report the statistics for the time series of monthly estimates. In both cases, the Model 1 and 2 forecasts are computed using the pre-trade values of the covariates and the coefficient estimates from Equations (2) and (3) estimated using data from the previous month.

	Model 1			Model 2		
Parameter	Mean	Std.dev.	Median	Mean	Std.dev.	Median
Out-of-sample R^2	9.7%	2.9%	9.1%	12.3%	4.2%	12.5%
Regressions of realized price change on forecast						
b	1.08	0.14	1.09	0.80	0.08	0.83
t-statistic	(369.08)	(62.16)	(376.76)	(440.07)	(76.01)	(448.67)
Adj. R^2	9.8%	3.0%	9.2%	13.1%	3.6%	12.9%
No. obs. each month	1,399,314	571,329	1,346,300	1,393,738	569,679	1,338,997

Table IA.5.
Trading costs estimates (non-S&P 500 stocks)

The sample consists of all trades in options on non-S&P 500 stocks from January 2004 through December 2015. Each statistic is computed for each combination of stock and trade date, and the table reports the average values of the statistics across the stock-dates. Panel A uses all option trades, while the results in panel B are for trades in moneyness categories defined by the absolute value of the option delta: $|\Delta| < 0.35$ for OTM, $0.35 \leq |\Delta| < 0.65$ for ATM, and $0.65 \leq |\Delta|$ for ITM options. The quoted half-spread is half the difference between the ask and bid prices at the time of the trade, expressed as either a percentage of the pre-trade bid-ask midpoint or in dollars. The effective half-spread is the difference between the trade price and the bid-ask midpoint (bid-ask midpoint and trade price) for trades signed as buys (sells). The adjusted effective half-spread is computed using Equation (7) and represents average costs across execution timers and non-timers. The cost for execution timers (the algo spread) is computed using Equation (11). The execution timing share is the fraction of trades that show timing and is computed using Equation (9).

A. Averages for all options on non-S&P 500 stocks

Variable	Mean	Std.dev.	Median
Quoted half-spread (%)	12.8%	6.7%	11.3%
Effective half-spread (%)	9.7%	5.6%	8.5%
Adjusted half-spread (%)	7.7%	6.1%	6.4%
Algo. half-spread (%)	5.4%	8.1%	4.0%
Quoted half-spread ($)	0.20	0.22	0.15
Effective half-spread ($)	0.15	0.14	0.11
Adjusted half-spread ($)	0.11	0.14	0.08
Algo. half-spread ($)	0.07	0.14	0.05
Execution timing share (%)	37.3%	50.5%	42.9%
Number of stock-days	2,440,621		

B. Averages by moneyness category

Variable	OTM	ATM	ITM
Quoted half-spread (%)	16.6%	11.6%	8.4%
Effective half-spread (%)	12.9%	8.8%	6.1%
Adjusted half-spread (%)	10.6%	6.9%	4.4%
Algo. half-spread (%)	8.0%	4.7%	2.8%
Quoted half-spread ($)	0.14	0.19	0.29
Effective half-spread ($)	0.10	0.14	0.20
Adjusted half-spread ($)	0.09	0.11	0.14
Algo. half-spread ($)	0.06	0.07	0.08
Execution timing share (%)	38.7%	40.0%	42.5%
Number of stock-days	1,496,725	2,055,289	1,659,885

Table IA.6
Options trading costs options on stocks sorted by characteristics

This table reports average options trading costs in portfolios formed by sorting the options' underlying stocks on several characteristics. Each day we sort the stocks into five portfolios. We then compute the equally-weighted averages of the quoted half-spread, the conventional effective half-spread, the adjusted effective half-spread, and the algo half-spread for each portfolio and day, and report the portfolio averages across days. Panels A, B, C, D, and E report the results for sorts based on market capitalization on the previous day, underlying stock volatility estimated as the standard deviation of abnormal returns over the previous 21 days, the quoted option half-spread, and call and put order imbalances, respectively. The last two columns report the fraction of trades with execution timing and the average values of the variable used to sort the stocks. The last row of each panel reports the difference between portfolios 5 and 1. We list *t*-statistics for tests of the hypotheses that the differences are zero in parentheses below the differences. The sample consists of trades in options on all common stocks during the period from January 2004 through December 2015. Model 2 is used to predict the price changes and is estimated using one-minute quote snapshots over the same period.

A. Portfolios sorted on underlying stock market capitalization

	Trading cost measures (half-spreads)					Price impact		
Portfolio	Quoted spread	Effective spread	Adj. eff. spread	Algo. spread	Exec. Timing %	Conven-tional	Adjusted	Market Capitalization
1	0.148	0.113	0.093	0.073	34.2%	0.025	0.015	429
2	0.128	0.097	0.077	0.054	37.5%	0.022	0.012	1,283
3	0.117	0.089	0.068	0.045	38.3%	0.020	0.010	2,734
4	0.101	0.078	0.059	0.034	38.8%	0.018	0.008	6,953
5	0.073	0.059	0.042	0.017	37.8%	0.013	0.005	42,935
Diff. 5 – 1	–0.075	–0.054	–0.051	–0.056	3.6%	–0.012	–0.010	42,506
	(–171.0)	(–203.7)	(–192.0)	(–201.6)	(18.2)	(–118.8)	(–185.6)	

B. Portfolios sorted on underlying stock volatility

	Trading cost measures (half-spreads)					Price impact		
Portfolio	Quoted spread	Effective spread	Adj. eff. spread	Algo. spread	Exec. Timing %	Conven-tional	Adjusted	Volatility
1	0.103	0.080	0.062	0.039	37.8%	0.018	0.009	0.009
2	0.107	0.082	0.063	0.040	38.2%	0.019	0.009	0.014
3	0.111	0.085	0.065	0.042	37.9%	0.020	0.010	0.018
4	0.118	0.090	0.070	0.046	37.3%	0.021	0.011	0.025
5	0.128	0.099	0.079	0.055	35.3%	0.022	0.012	0.044
Diff. 5 – 1	0.025	0.019	0.018	0.016	–2.5%	0.004	0.004	0.035
	[59.4)	(81.9)	[69.6)	(56.8)	(–13.3)	(48.6)	[79.5)	

C. Portfolios sorted on options quoted spread

	Trading cost measures (half-spreads)					Price impact		
Portfolio	Quoted spread	Effective spread	Adj. eff. spread	Algo. spread	Exec. Timing %	Conven-tional	Adjusted	Quoted Spread
1	0.047	0.040	0.024	0.003	40.1%	0.014	0.006	0.047
2	0.076	0.061	0.041	0.016	42.5%	0.018	0.008	0.076
3	0.101	0.079	0.058	0.032	40.1%	0.021	0.010	0.101
4	0.132	0.101	0.081	0.056	36.5%	0.023	0.013	0.132
5	0.211	0.155	0.136	0.117	27.3%	0.023	0.014	0.211
Diff. 5 –1	0.164	0.115	0.113	0.114	–12.8%	0.008	0.008	0.164
	(304.6)	(334.1)	(320.1)	(322.0)	(–59.2)	(77.0)	(121.1)	

D. Portfolios sored by call order imbalances

	Trading cost measures (half-spreads)					Price impact		
Portfolio	Quoted spread	Effective spread	Adj. eff. spread	Algo. spread	Exec. Timing %	Conven-tional	Adjusted	Order imbalance
1	0.107	0.086	0.065	0.041	42.0%	0.021	0.010	-0.267
2	0.091	0.074	0.054	0.029	40.5%	0.018	0.008	-0.070
3	0.086	0.071	0.052	0.027	39.5%	0.017	0.008	0.003
4	0.095	0.078	0.057	0.032	40.4%	0.019	0.009	0.080
5	0.112	0.091	0.068	0.045	41.8%	0.022	0.011	0.283
Diff. 5 –1	0.005	0.004	0.005	0.004	–0.2%	0.001	0.0007	0.550
	(7.6)	(12.3)	(12.1)	(12.3)	(–0.9)	(7.2)	(9.2)	

E. Portfolios sorted by put order imbalances

	Trading cost measures (half-spreads)					Price impact		
Portfolio	Quoted spread	Effective spread	Adj. eff. spread	Algo spread	Exec. Timing %	Conven-tional	Adjusted	Order imbalance
1	0.112	0.091	0.069	0.045	41.4%	0.021	0.011	-0.351
2	0.092	0.075	0.055	0.029	40.6%	0.018	0.008	-0.086
3	0.085	0.070	0.051	0.026	39.6%	0.017	0.008	0.009
4	0.092	0.075	0.055	0.030	40.8%	0.018	0.008	0.110
5	0.109	0.089	0.067	0.043	41.9%	0.021	0.010	0.371
Diff. 5 –1	–0.0026	–0.002	–0.0022	–0.0023	0.5%	–0.0003	–0.0003	0.723
	(–4.2)	(–6.1)	(–7.4)	(–7.1)	(2.5)	(–2.2)	(–4.2)	

Table IA.7

Time series variation in options trading costs (non-S&P 500 stocks)

This table presents regression results showing how options trading costs respond to time-series shocks to stock volatility and proxies for information asymmetry. We estimate stock-day panel regressions with stock fixed effects and dependent variables consisting of the relative conventional and algo effective half-spreads, their difference, and the execution timing share. The independent variables include short and mid-term volatility measures: the absolute abnormal stock return from the previous day($|StkRet_{t-1}|$) and the standard deviation of abnormal stock returns over the previous 21 days ($Std(AR)_{1m}$), and proxies for information asymmetry: indicator variables for the earnings and pre-earnings announcement days (EAD_t, EAD_{t-1}). We list *t*-statistics in parentheses below the coefficient estimates. The panel includes 2,440,507 stock-days. Standard errors are clustered by stock and by day.

	Conv. half-spread	Algo half-spread	Difference	Exec. timing share
$\lvert Ret_{t-1}\rvert$	0.028	–0.04	0.068	0.2015
	(9.3)	(–11.1)	(26.3)	(10.7)
$Std(AR)_{1m}$	0.0045	–0.0135	0.018	–0.0156
	(15.8)	(–29.6)	(48.9)	(–6.4)
EAD_t	0.0036	–0.0028	0.0064	–0.0211
	(11.0)	(–6.5)	(19.7)	(–8.1)
EAD_{t-1}	0.1136	0.059	0.0546	0.2457
	(10.7)	(6.1)	(13.2)	(6.4)
Adj. R^2	12%	8%	1%	1%

Table IA.8
Estimates of price impact (non-S&P 500 stocks)

Conventional and adjusted measures of price impact. The price impact of a buy trade is the difference between the midpoint ten minutes after the trade and the pre-trade midpoint, expressed as a percentage of the pre-trade midpoint, or the negative of this for a sell trade. Adjusted price impacts are computed using Equation (9) by subtracting the expected change in the option price computed using Model 1 or 2 from the actual price change during the ten minute period following a trade. Each statistic is computed for each combination of stock and trade date, and the table reports the average values of the statistics across the stock-dates. Panel A uses all option trades, while each set of results in panel B uses only trades for the indicated moneyness category, which is defined by absolute option delta: $|\Delta| < 0.35$ for OTM, $0.35 \leq |\Delta| < 0.65$ for ATM, and $0.65 \leq |\Delta|$ for ITM options. The sample consists of all trades in options on S&P 500 stocks during the period from January 2004 through December 2015.

A. Averages for all options on non-S&P 500 stocks

Variable	Mean	Std.dev.	Median
Conventional measure	2.225%	2.418%	1.865%
Adjusted using Model 1	1.561%	2.137%	1.257%
Adjusted using Model 2	1.233%	2.124%	0.914%
No. of stock-days	2,440,621		

B. Averages by moneyness category

	OTM	ATM	ITM
Conventional measure	2.655%	2.084%	1.580%
Adjusted using Model 1	1.951%	1.418%	0.966%
Adjusted using Model 2	1.530%	1.100%	0.709%
No. of stock-days	1,496,725	2,055,289	1,659,885

Table IA.9.

Time series variation in model R^2s

This table reports regression results showing how the fit of the predictive models as measured by R^2 depends on time-series shocks to stock volatility, returns, and proxies for information asymmetry. We estimate stock-day panel regression with stock fixed effects that explain the R^2s of Models 1 and 2 using the samples of options on S&P 500 and non-S&P 500 stocks. The independent variables include the absolute abnormal stock return on the previous day ($|Ret._{t-1}|$), the standard deviation of abnormal stock returns over the previous 21 days ($Std(AR)_{1m}$), indicator variables for the earnings and pre-earnings announcement days (EAD_t, EAD_{t-1}), the previous-day stock return, and stock market capitalization in millions of dollars. Standard errors are clustered by stock and by day. Results are reported separately for Models 1 and 2 and for options on S&P 500 and non-S&P 500 stocks.

	S&P 500 stocks		Non-S&P 500 stocks	
	R^2 for Model 1	R^2 for Model 2	R^2 for Model 1	R^2 for Model 2
Market Cap	–0.00	–0.00	–0.00	–0.00
	(–1.3)	(–0.2)	(–5.0)	(–4.6)
$Std(AR)_{1m}$	–0.0734	–0.145	–0.0408	–0.0922
	(–3.9)	(–4.0)	(–7.7)	(–7.8)
EAD_t	–0.0121	–0.0118	–0.0068	–0.0108
	(–24.2)	(–15.4)	(–19.8)	(–18.3)
EAD_{t-1}	–0.006	–0.0107	–0.0045	–0.012
	(–16.8)	(–18.5)	(–15.3)	(–22.3)
Ret_{t-1}	0.0195	0.0321	–0.0004	0.0075
	(3.6)	(3.5)	(–0.2)	(1.9)
$\|Ret_{t-1}\|$	–0.0815	–0.1557	0.0005	–0.0594
	(–11.0)	(–12.3)	(0.2)	(–12.5)
Adj. R^2	0.12	0.24	0.04	0.1
N	1,324,195	1,322,223	3,982,003	3,619,382

Table IA.10

Impact of execution timing on the after-cost profitability of options trading strategies (all stocks)

Returns from selling straddles with several assumptions about transactions costs. On the trading day following the expiration of options on the regular cycle, we sell a straddle consisting of a call and a put with the same strike and expiration in about one month and hold the straddle until it expires. We compute straddle returns as in Equation (10). We form ten portfolios each month and report the portfolio average return over all months. Panels A and B report the equally-weighted average returns of portfolios sorted by the difference between implied and historical volatility (*IV – HV*) and by the previous month's stock return, respectively. The first row of results reports straddle returns assuming that trades are executed at quote midpoints, and thus assumes that there are no transactions costs. The next two rows adjust returns using estimates of conventional and algo effective half-spreads by subtracting the half-spreads from the no transactions costs straddle returns. The last three rows of the table report the estimates of the transactions costs and the average values of the sorting variable (*IV – HV* or the previous month's stock return) for the portfolios. The *t*-statistics are based on standard errors adjusted for heteroscedasticity and autocorrelation. The sample period runs from January 2004 through December 2015.

A. Portfolios sorted on IV – HV

Portfolio:	1 (low)	2	8	9	10 (high)	High – Low
Short straddle return:						
No transactions costs	0.001	0.019	0.03	0.044**	0.089***	0.088***
	(0.0)	(0.8)	(1.4)	(2.3)	(6.1)	(6.4)
Adj. for algo eff. half-spread	–0.047**	–0.023	–0.012	0.002	0.041***	
	(–2.2)	(–1.0)	(–0.6)	(0.1)	(2.9)	
Adj. for conven. eff. half-spread	–0.075***	–0.051**	–0.039*	–0.026	0.014	
	(–3.6)	(–2.1)	(–1.9)	(–1.3)	(1.0)	
Other statistics:						
Conv. eff. half-spread	0.076	0.07	0.069	0.07	0.075	-0.001
Algo eff. half-spread	0.047	0.042	0.042	0.042	0.048	0.001
IV – HV	–0.204	–0.084	0.037	0.067	0.195	0.399

B. Portfolios sorted on previous month's stock return

Portfolio:	1 (low)	2	8	9	10 (high)	High – Low
Short straddle return:						
No transactions costs	0.037*	0.012	0.033	0.043**	0.061***	0.025
	(1.7)	(0.5)	(1.6)	(2.1)	(3.7)	(1.4)
Adj. for algo eff. half-spread	–0.01	–0.031	–0.007	0.001	0.017	0.027
	(–0.5)	(–1.3)	(–0.3)	(0.1)	(1.0)	(1.6)
Adj. for conven. eff. half-spread	–0.039*	–0.059**	–0.034	–0.026	–0.01	0.029*
	(–1.8)	(–2.6)	(–1.6)	(–1.3)	(–0.6)	(1.7)
Other statistics:						
Conv. eff. half-spread	0.076	0.07	0.067	0.069	0.072	–0.004
Algo eff. half-spread	0.047	0.042	0.04	0.041	0.044	–0.002
Previous month's stock return	–0.204	–0.084	0.063	0.098	0.202	0.406

Table IA.11

Frequency of options trades in the quote sample used to estimate the predictive models

The predictive models estimate changes in the quote midpoint over a ten minute horizon. We estimate the models for each option contract and day using quote snapshots at one-minute frequency. We then average the coefficients across all options with given moneyness for each stock-day. For S&P 500 stocks, a typical stock-day includes 12.9 ATM option contracts, and these ATM options have 238 trades in total. The table provides information about the number of ten minute intervals that contain trades, and the fraction of trades that consume the bid or ask quoted at the time of the trade. A typical ATM contract and day has only 3.9 ten-minute intervals that contain any trades. Conditional on a trade, only 22% of the trades consume the quoted size at the NBBO. A typical ATM option trade is about 34% of the quoted size at the reporting exchange.

A. Options on S&P 500 stocks	OTM options		ATM options		ITM options	
	Mean	Median	Mean	Median	Mean	Median
Number of options used in the model estimation, per stock day	15.21	8.09	12.94	8.45	10.08	5.48
Number of trades	219.73	42.00	238.19	49.00	89.44	19.00
Number of the 10-minute intervals that contain trades, per stock day	2.97	2.43	3.94	3.06	2.85	2.29
Fraction of trades that consume the NBBO bid or ask size at the time of the trade	0.19	0.17	0.22	0.19	0.25	0.21
Ratio of trade size to NBBO quoted size	0.33	0.29	0.34	0.31	0.35	0.31

B. Options on non-S&P 500 stocks	OTM options		ATM options		ITM options	
	Mean	Median	Mean	Median	Mean	Median
Number of options used in the model estimation, per stock day	5.48	1.94	5.30	2.46	3.96	1.92
Number of trades	44.85	9.00	47.01	10.00	21.41	5.00
Number of the 10-minute intervals that contain trades, per stock day	2.17	1.75	2.48	2.00	2.06	1.50
Fraction of trades that consume the NBBO bid or ask size at the time of the trade	0.25	0.19	0.27	0.22	0.29	0.22
Ratio of trade size to NBBO quoted size	0.42	0.33	0.42	0.35	0.41	0.33

Table IA.12
Trading cost estimates by option characteristics
The sample consists of all trades in options on S&P 500 stocks between January 2004 and December 2015. Each statistic is computed for each combination of stock and trade date, and the table reports the average values of the statistics across the stock-dates. Panel A reports results for call and put trades separately, while panel B reports results for trades grouped by time to maturity measured in trading days. Short-term options expire within 5 to 21 trading days, mid-term options within 22 to 63 days, and long-term options within 64 to 251 days.

A. Trading costs of calls and puts

	Calls			Puts		
Variable	Mean	Std.dev.	Median	Mean	Std.dev.	Median
Quoted half-spread (%)	12.8%	7.3%	11.4%	10.6%	6.5%	9.2%
Effective half-spread (%)	10.4%	6.4%	9.0%	8.3%	5.4%	7.1%
Adjusted spread (%)	8.2%	6.7%	6.5%	6.3%	5.5%	4.9%
Algo half-spread (%)	5.4%	8.4%	3.8%	4.1%	7.0%	2.8%
Quoted half-spread ($)	0.088	0.092	0.069	0.095	0.105	0.071
Effective half-spread ($)	0.068	0.062	0.055	0.072	0.070	0.056
Adjusted half-spread ($)	0.053	0.058	0.041	0.054	0.065	0.039
Algo half-spread ($)	0.034	0.062	0.022	0.035	0.065	0.023
Execution timing (%)	35.8%	46.2%	39.1%	41.6%	45.8%	45.5%
Number of stock-days	1,029,832			1,030,319		

B. Trading costs for options in various time-to-expiration buckets

	Short-term			Mid-term			Long-term		
Variable	Mean	Std.dev.	Median	Mean	Std.dev.	Median	Mean	Std.dev.	Median
Quoted half-spread (%)	15.4%	9.1%	13.2%	12.9%	8.0%	11.2%	10.1%	6.9%	8.4%
Effective half-spread (%)	12.1%	8.0%	9.8%	10.1%	7.0%	8.5%	8.2%	5.9%	6.7%
Adjusted half-spread (%)	9.0%	8.3%	6.7%	7.7%	7.2%	5.6%	6.5%	6.0%	4.8%
Algo half-spread (%)	5.1%	10.0%	3.1%	4.8%	8.5%	3.0%	4.6%	7.0%	3.1%
Quoted half-spread ($)	0.063	0.077	0.050	0.075	0.083	0.060	0.098	0.114	0.071
Effective half-spread ($)	0.046	0.046	0.041	0.056	0.051	0.050	0.076	0.078	0.057
Adjusted half-spread ($)	0.032	0.039	0.023	0.040	0.046	0.031	0.058	0.070	0.042
Algo half-spread ($)	0.015	0.047	0.009	0.022	0.054	0.015	0.040	0.071	0.026
Execution timing (%)	37.2%	48.5%	40.2%	39.0%	46.8%	42.9%	39.5%	48.9%	44.7%
Number of stock-days	392,346			921,205			1,016,382		

Table IA.13
Correlations between actual and predicted price changes
The sample consists of all option trades between January 2004 and December 2015. Each correlation is computed for all trades in each calendar month and the table reports the average values of the correlations across months. Actual change refers to the change in the option quote midpoint from immediately before a trade to ten minutes after a trade. Predicted changes for Models 1 and 2 for the same trade are computed combining pre-trade information with model coefficients estimated using the sample of quotes. Correlations are reported separately for S&P 500 and non S&P 500 stocks.

A. Options on S&P 500 stocks

Variable	Actual change in option midpoint	Change predicted by Model 1	Change predicted by Model 2
Actual change in option midpoint	100%	22%	28%
Change predicted by Model 1	22%	100%	70%
Change predicted by Model 2	28%	70%	100%

B. Options on non-S&P 500 stocks

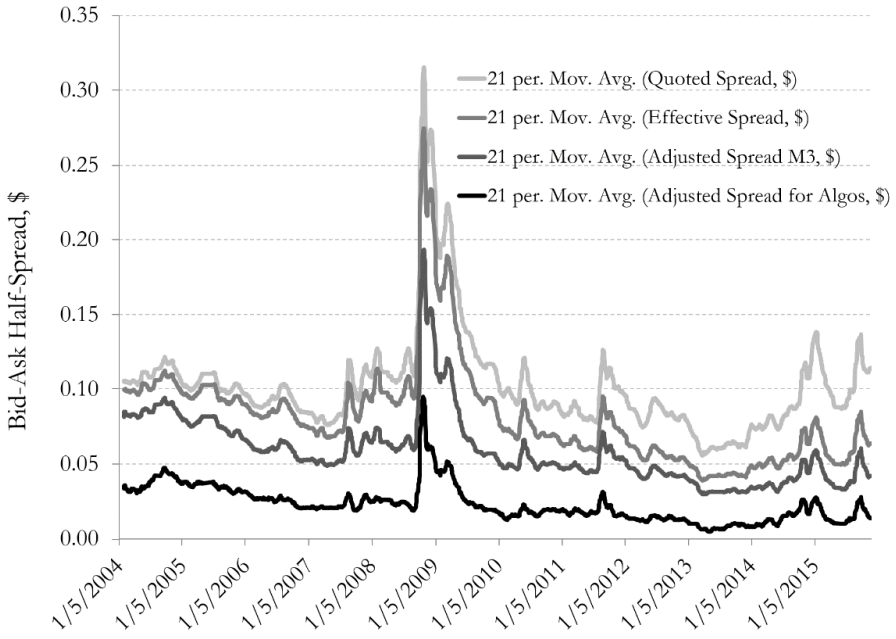
Variable	Actual change in option midpoint	Change predicted by Model 1	Change predicted by Model 2
Actual change in option midpoint	100%	31%	36%
Change predicted by Model 1	31%	100%	73%
Change predicted by Model 2	36%	73%	100%

Table IA.14
Relation between price impact and measures of uncertainty and inventory risk
Results of regressions relating estimates of price impact to covariates that are proxies for uncertainty and inventory risk. The measures of price impact are the conventional measure defined as the difference between the quote midpoint ten minutes after the trade and the quote midpoint at the time of the trade, and the adjusted measure defined as the difference between the quote midpoint ten minutes after the trade and the estimate of fair value at the time of the trade computed using Model 2. The covariates include the absolute abnormal stock return on the previous day $|Ret_{t-1}|$, the standard deviation of abnormal stock returns over the previous 21 days $Std(AR)_{1m}$, indicator variables for the earnings and pre-earnings announcement days (EAD_t, EAD_{t-1}), and the absolute value of inventory risk for calls and puts, where inventory risk is computed as non-market-maker order imbalance divided by total volume in the previous thirty days. All regressions include stock fixed effects. Standard errors are clustered by stock and date.

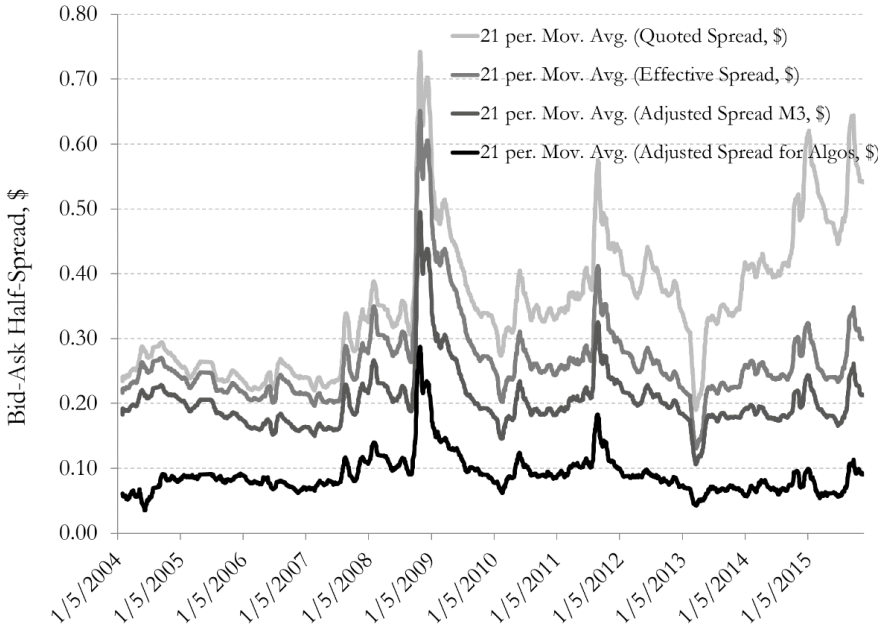
	S&P 500 stocks		Non-S&P 500 stocks	
	Conventional Measure	Based on Model 2	Conventional Measure	Based on Model 2
$Std(AR)_{1m}$,	0.0741	0.0517	0.0418	0.0165
	(13.6)	(10.7)	(8.1)	(8.2)
$\|Ret_{t-1}\|$	0.018	0.0158	0.0189	0.0148
	(10.6)	(12.4)	(16.1)	(19.4)
EAD_t	0.0019	0.0019	0.0023	0.0025
	(13.6)	(18.9)	(13.2)	(23.9)
EAD_{t-1}	0.0017	0.0003	0.0016	0.0004
	(13.6)	(3.3)	(10.0)	(4.0)
$\|Inventory_{call}\|$	0.0009	0.0001	0.0028	0.0004
	(3.3)	(0.4)	(12.5)	(2.9)
$\|Inventory_{put}\|$	0.0007	0.0001	0.0022	0.0004
	(2.9)	(0.9)	(12.6)	(4.7)
Adj. R^2	14%	9%	6%	3%
N	743,560	743,560	1,079,483	1,079,483
Fixed effects	625	625	1877	1,877

Figure IA.1
Options trading costs over time
This figure extends Figure 1 and shows the evolution of the average quoted half-spread (light grey), the conventionally measured effective half-spread (grey), the adjusted effective half-spread (dark grey) bid-ask half-spreads and the algo half-spread (black) over the period from January 2004 to December 2015. We separately report spreads for S&P500 and non-S&P500 stocks, relative and dollar spreads, and spreads for trades of OTM/ATM/ITM options. Each point on the graph is a 21-day moving average of the average across all option trades in the category on a given day.

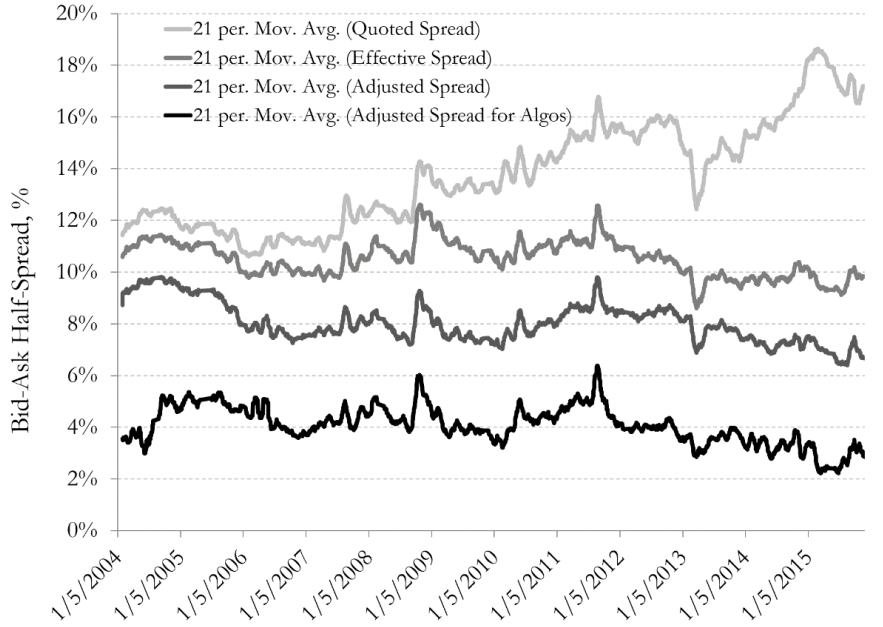
A. Dollar half-spreads of options on S&P500 stocks



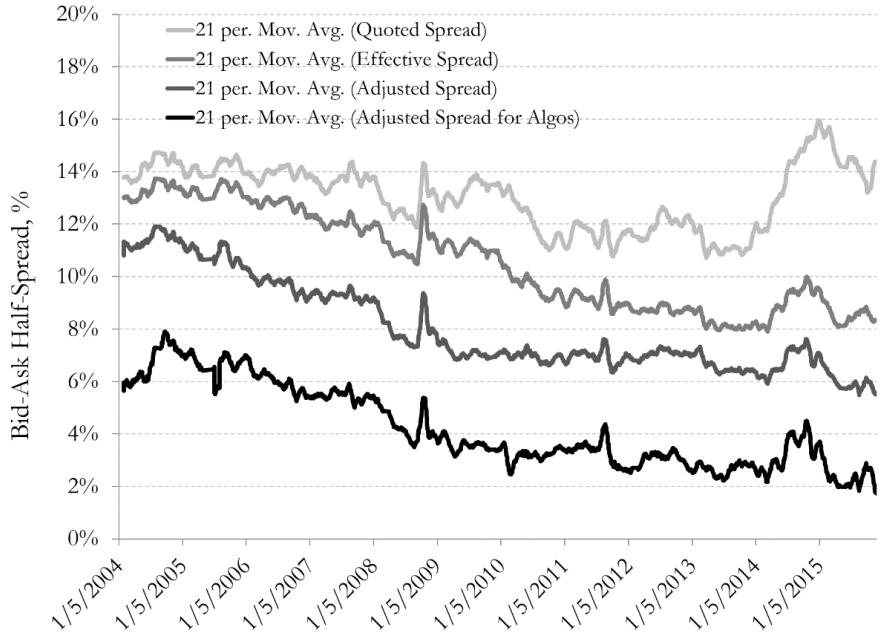
B. Dollar half-spreads of options on non-S&P500 stocks



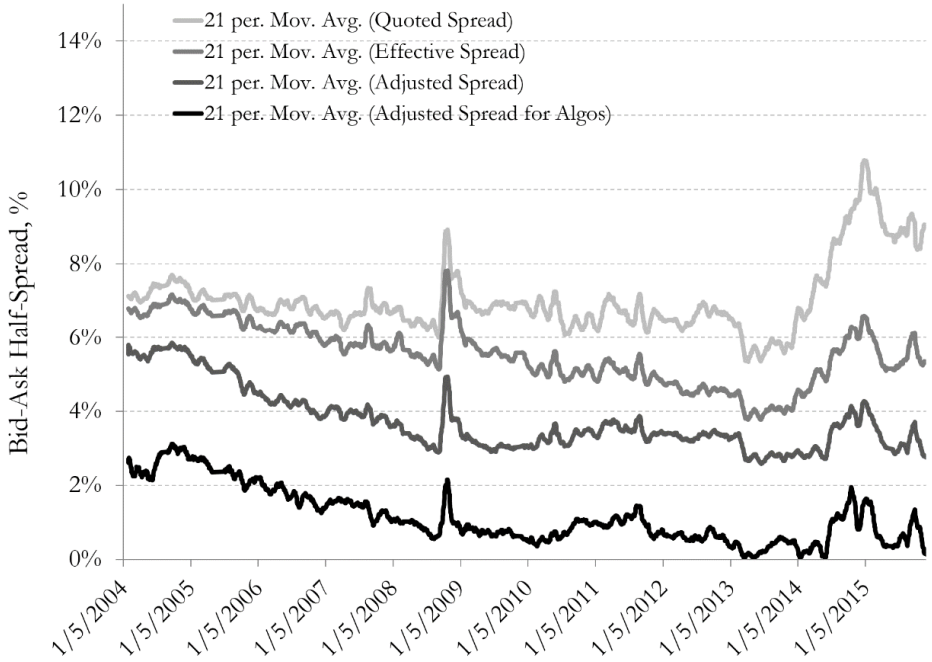
C. Relative half-spreads of options on non-S&P 500 stocks



D. Relative half-spreads of OTM options on S&P500 stocks



E. Relative half-spreads of ATM options on S&P500 stocks



F. Relative half-spreads of ITM options on S&P500 stocks

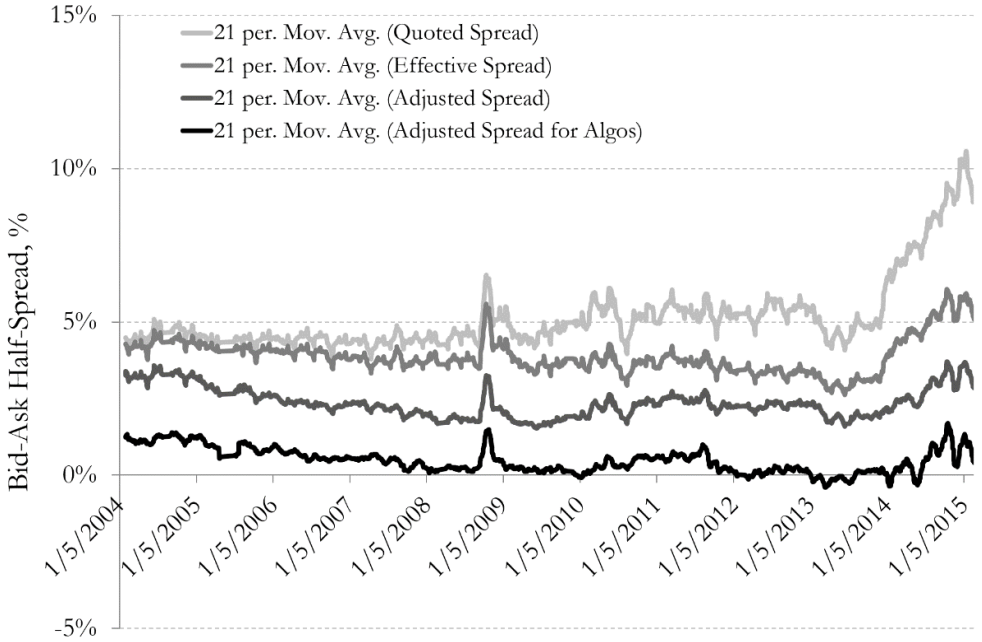
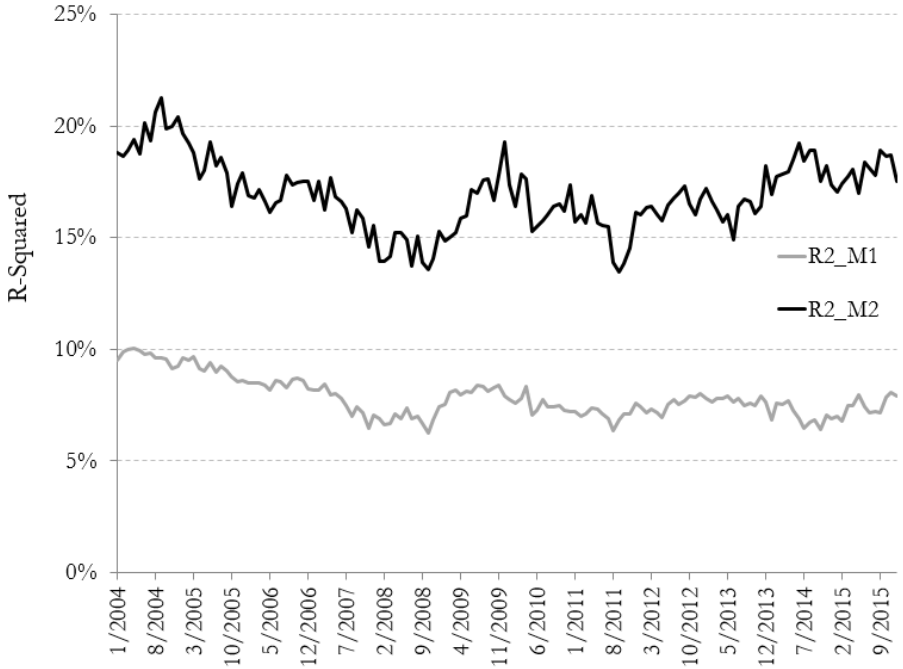
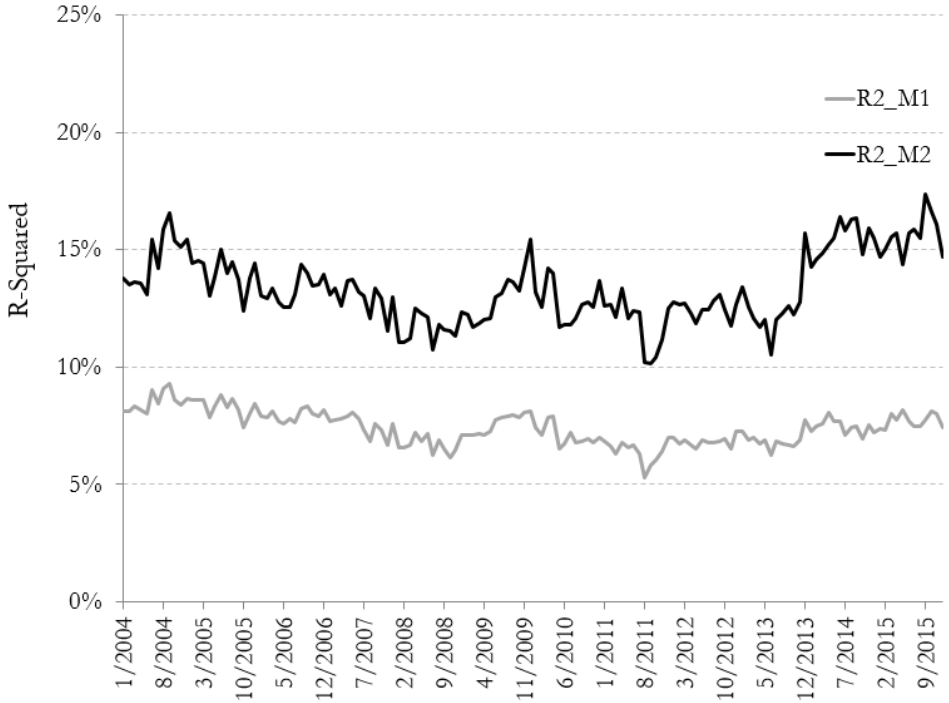


Figure IA.2
Predictive model R^2s over time
This figure shows the evolution of the average R^2 in Model 1 (grey) and Model 2 (black) estimated by equations (2) and (3) over the period from January 2004 to December 2015. Each point on the graph is an average over stock-by-day estimates for a given moneyness category in a given month, 144 months in total. Moneyness categories are defined by absolute option delta: $|\Delta| < 0.35$ for OTM, $0.35 \leq |\Delta| < 0.65$ for ATM, and $0.65 \leq |\Delta|$ for ITM.

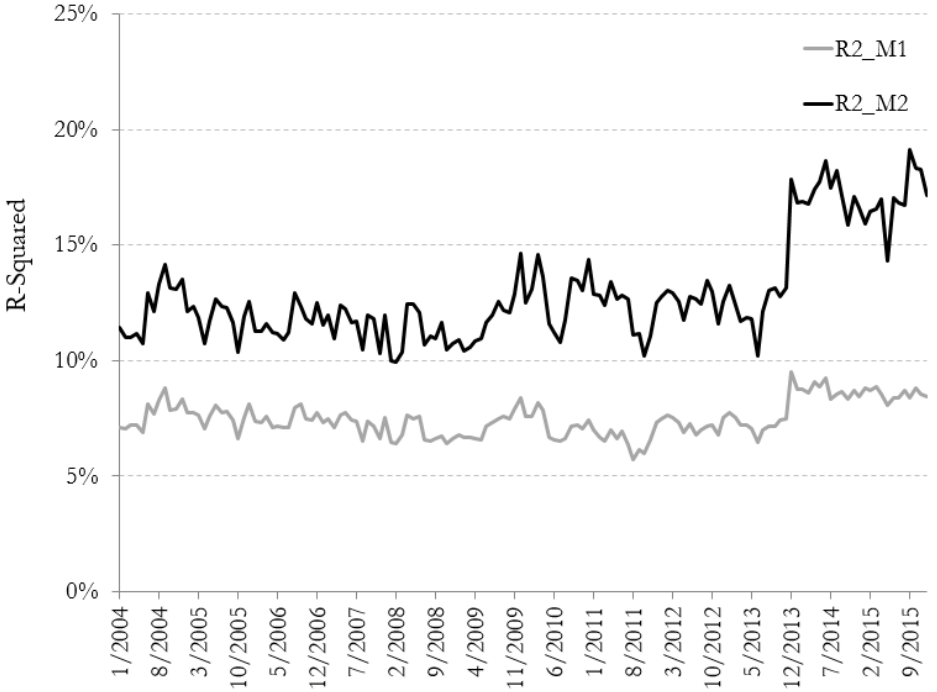
A. R^2 for OTM options on S&P500 stocks



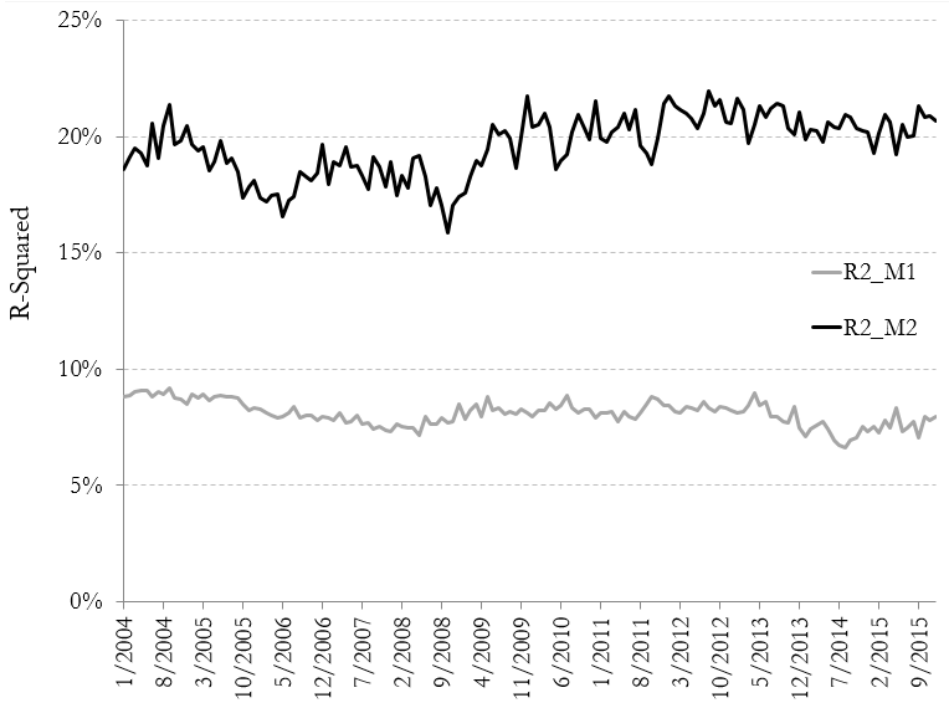
B. R^2 for ATM options on S&P500 stocks



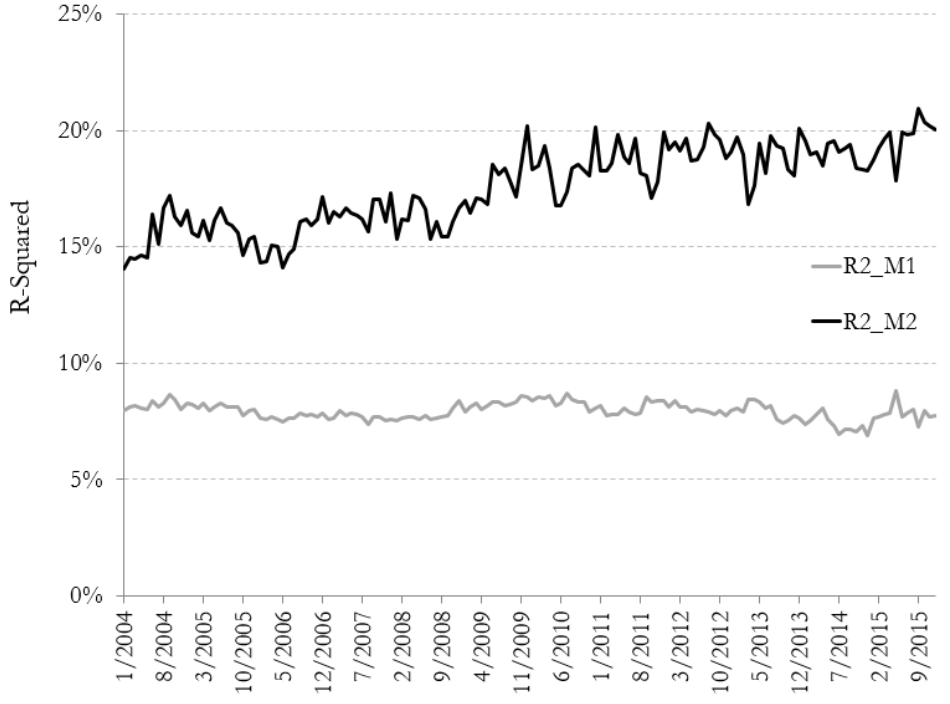
C. R^2 for ITM options on S&P500 stocks



D. R^2 for OTM options on non-S&P500 stocks



E. R^2 for ATM options on non-S&P 500 stocks



F. R^2 for ITM options on non-S&P500 stocks

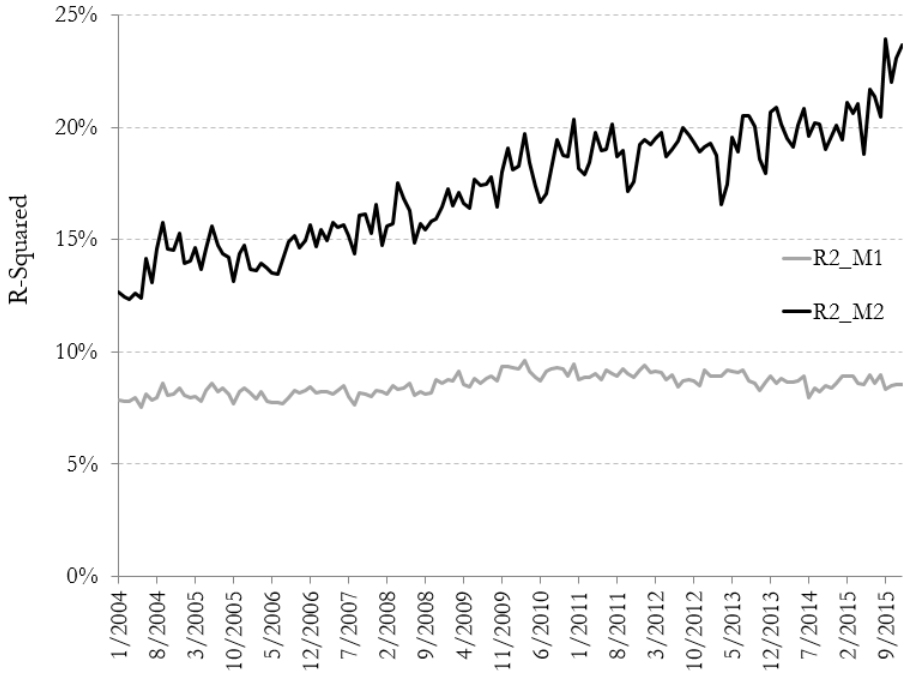
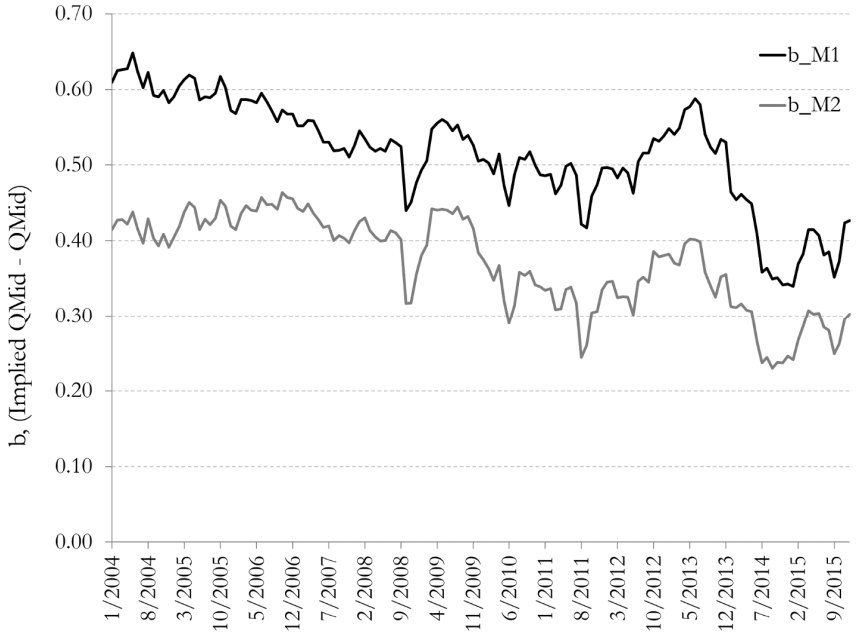


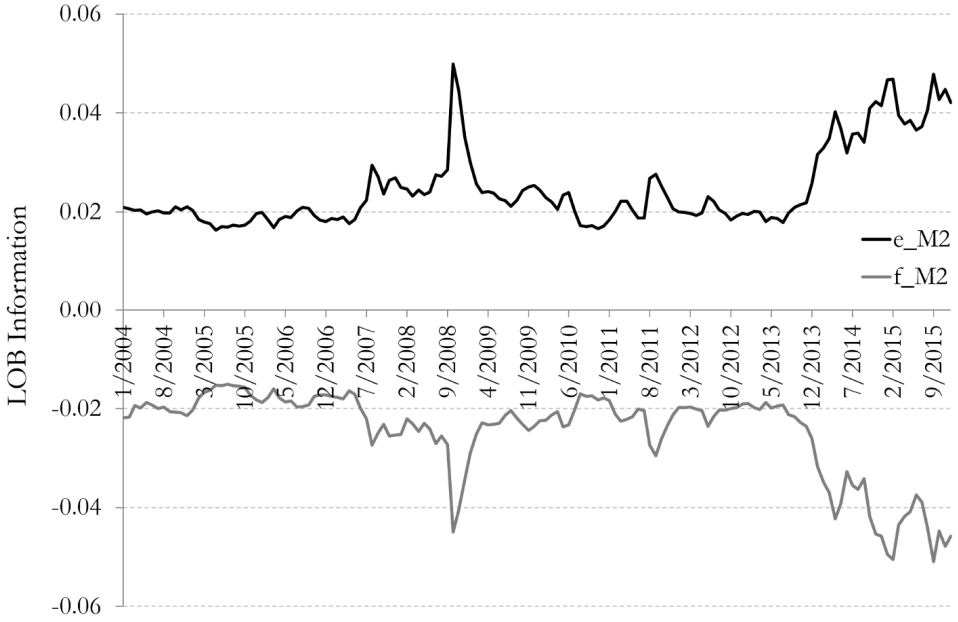
Figure IA.3
Predictive model coefficient estimates over time
Evolution of the coefficient estimates on the predictive variables in Models 1 and 2 estimated using ATM options over the period from January 2004 through December 2015. Each point on the graph is an average over stock-by-day estimates for the ATM options in a given month. ATM options are those for which $0.35 \leq |\Delta| < 0.65$, where Δ denotes the option delta.

A. Coefficients on the key predictive variable $\hat{P}_t^{BSM} - P_t$ for ATM options on S&P 500 stocks

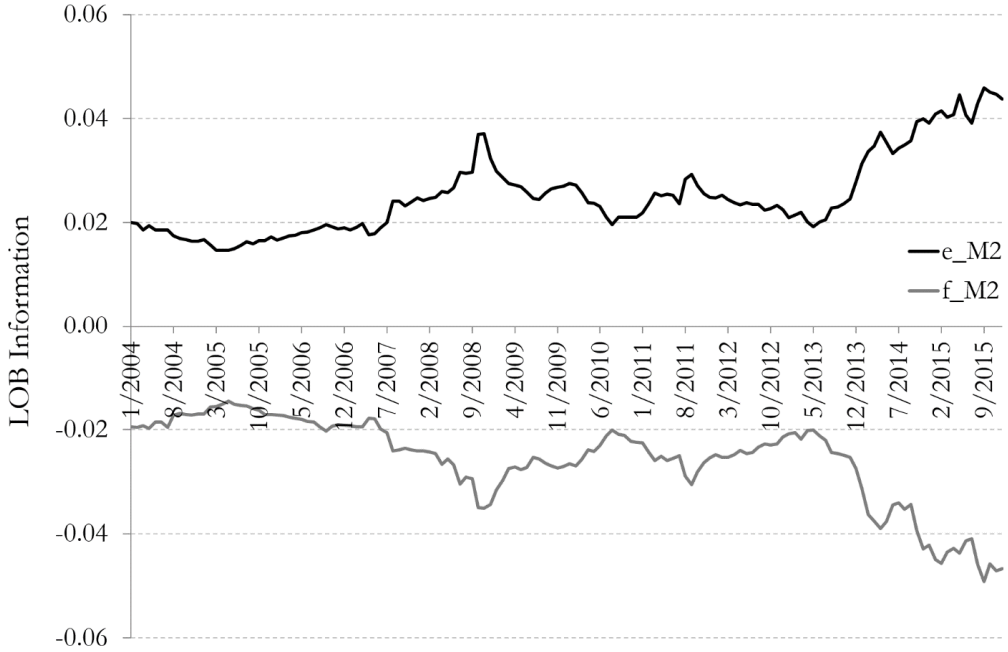


B. Coefficients on the key predictive variable $\hat{P}_t^{BSM} - P_t$ for ATM options on non-S&P 500 stocks

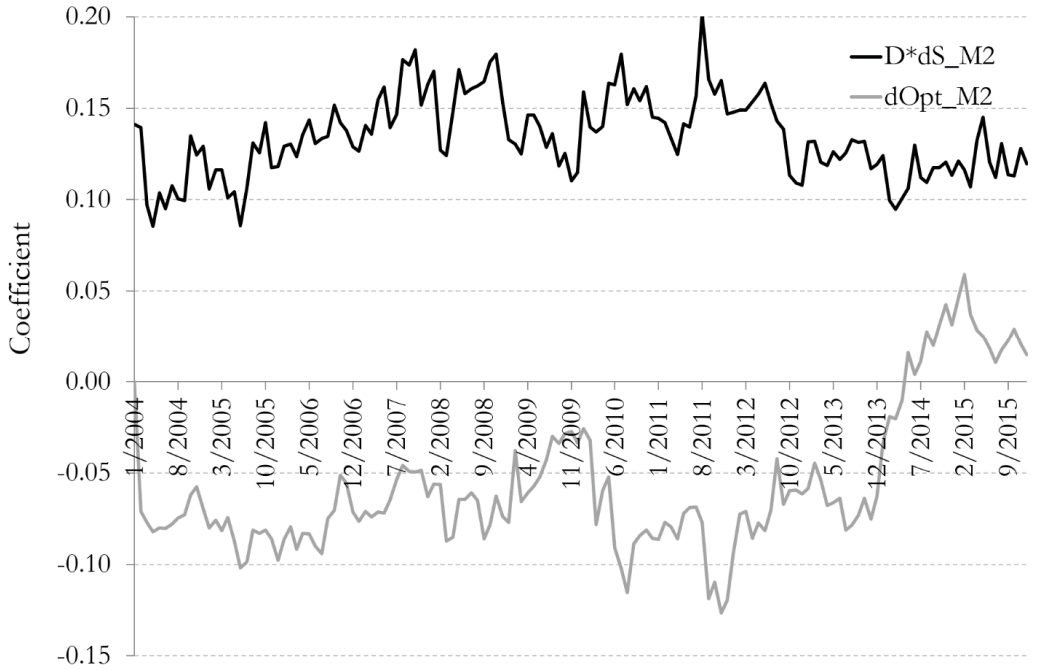
C. Coefficients on the percentages of exchanges at the best bid (black) and ask (gray) prices for ATM options on S&P 500 stocks



D. Coefficients on the percentages of exchanges at the best bid (black) and ask (gray) prices for ATM options on non-S&P 500 stocks



E. Coefficients on the delta-adjusted stock price (black) and option price (gray) lagged changes for ATM options on S&P 500 stocks



F. Coefficients on the delta-adjusted stock price (black) and option price (gray) lagged changes for ATM options on non-S&P 500 stocks