

Online Appendix  
The Microstructure of a U.S. Treasury ECN: The  
BrokerTec Platform

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**Table 1: Price Impact of Trade and Limit Order Flow at the Best Five Price Levels**

Security	Trade		Limit Order	
	Buy	Sell	Bid	Ask
2-Year	0.0052*	-0.0050*	0.0013*	-0.0008*
3-Year	0.0140*	-0.0143*	0.0080*	-0.0050*
5-Year	0.0248*	-0.0244*	0.0145*	-0.0151*
7-Year	0.0626*	-0.0602*	0.0435*	-0.0409*
10-Year	0.0589*	-0.0593*	0.0400*	-0.0371*
30-Year	0.3783*	-0.4079*	0.2726*	-0.2821*

The table shows the price impacts of trades and limit orders computed from a VAR(5) model of buy trade volume, sell trade volume, bid limit order flow, ask limit order flow, and return (based on the best bid-ask midpoint). The bid and ask limit order flow variables are measured as the total volume of limit orders submitted to the best five price tiers in the limit order book between trades, net of modifications/cancellations. Estimation is based on BrokerTec tick data for the 2010-2011 sample period. The number of observations used in the estimation is the same as reported in the paper. Price impacts are in 256ths of one percent of par. An asterisk (\*) indicates statistical significance at the 5% level, based on standard errors computed by bootstrapping with 1000 replications.

**Table 2: Summary Statistics of Net Limit Order Flow at Price Levels 2-5**

Statistic	2-Year	3-Year	5-Year	7-Year	10-Year	30-Year
<b>Bid Levels 2-5 (Aggregate):</b>						
Mean	1.13	1.94	-0.83	-3.10	-0.77	-0.94
Std	67.78	25.03	15.40	24.57	10.39	5.09
Correlation with Bid Level 1	-0.29	-0.42	-0.32	-0.80	-0.38	-0.39
<b>Ask Levels 2-5 (Aggregate):</b>						
Mean	0.07	1.76	-0.87	-3.23	-0.83	-0.93
Std	94.34	32.50	15.24	24.53	10.63	5.06
Correlation with Ask Level 1	-0.24	-0.36	-0.30	-0.78	-0.36	-0.37

The table reports the summary statistics of limit order flows at the outer tiers (2 to 5). These order flow variables are measured as the total volume of limit orders submitted to the second through the fifth best price levels in the limit order book between trades, net of modifications/cancellations. The statistics are computed from BrokerTec tick data for the 2010-2011 sample period.

**Table 3:** Tests of Information Decay Over Time After Announcements

Security	FOMC Announcements				8:30 Macro Announcements			
	Buy	Sell	Bid	Ask	Buy	Sell	Bid	Ask
<b>Test 1: 30-Minute Price Impact Greater than 60-Minute Price Impact?</b>								
2-Year	16.47	-0.30	26.98	20.61	22.42	17.02	22.35	56.94
3-Year	7.32	19.40	24.03	-7.19	12.48	-4.19	13.27	32.05
5-Year	7.50	1.44	7.83	22.75	38.29	-4.65	38.07	-8.92
7-Year	27.89	6.25	6.37	5.39	3.74	12.40	-13.59	30.98
10-Year	-2.55	-3.93	7.12	14.06	21.80	-3.32	-15.40	32.23
30-Year	-6.20	29.29	-2.77	16.33	-5.99	9.04	17.29	17.03
<b>Test 2: 60-Minute Price Impact Greater than 90-Minute Price Impact?</b>								
2-Year	-3.89	0.89	7.04	2.35	41.73	-0.81	31.71	-10.82
3-Year	14.62	-4.64	11.24	-1.16	27.08	9.47	14.70	23.12
5-Year	4.40	-8.09	17.79	-0.91	31.90	10.24	26.96	5.32
7-Year	8.30	4.19	-9.84	15.59	8.04	17.78	14.77	7.58
10-Year	-6.00	-10.18	13.54	5.06	25.25	5.35	20.18	28.43
30-Year	-9.52	2.20	5.29	9.84	29.21	4.05	12.90	28.76

The table shows the t-statistic of two tests of information decay over time after FOMC and 8:30 macroeconomic announcements. Test 1 (top panel) addresses whether the average price impact of trades and limit order activities is greater within the 30-minute window following an announcement than that within the longer 60-minute window. Test 2 (bottom panel) addresses whether the average price impact of trades and limit order activities is greater within the 60-minute window following an announcement than that within the longer 90-minute window. Price impacts of trades and limit orders are computed from a VAR(5) model of return, buy trade volume, sell trade volume, bid limit order flow, and ask limit order flow. The model is estimated using BrokerTec tick data in the relevant time window immediately after announcements during the 2010-2011 sample period. Each price impact estimate has a bootstrap distribution computed from 500 replications. The tests are performed on the bootstrap samples of corresponding price impact estimates.

**Table 4:** Tests of Information Decay Over Time After Announcements (Excluding First Two Minutes)

Security	FOMC Announcements				8:30 Macro Announcements			
	Buy	Sell	Bid	Ask	Buy	Sell	Bid	Ask
<b>Test 1: 30-Minute Price Impact Greater than 60-Minute Price Impact?</b>								
2-Year	9.63	1.14	43.14	5.83	10.83	5.23	14.45	55.51
3-Year	3.97	15.12	7.58	-0.29	17.31	-3.12	-6.84	48.47
5-Year	8.81	11.97	2.05	20.73	28.15	15.06	30.62	6.73
7-Year	8.60	4.76	3.36	11.07	-2.68	4.01	10.08	19.70
10-Year	-5.08	-3.16	23.51	-2.10	-3.23	9.63	22.05	13.25
30-Year	-9.93	30.95	11.92	3.59	10.82	7.68	13.01	22.46
<b>Test 2: 60-Minute Price Impact Greater than 90-Minute Price Impact?</b>								
2-Year	1.11	0.37	17.78	2.69	9.94	-0.69	34.97	8.38
3-Year	17.57	0.92	7.41	5.83	6.89	12.58	16.89	15.43
5-Year	3.25	-9.35	20.02	1.03	21.17	11.88	32.28	4.65
7-Year	8.06	8.97	-5.27	7.30	-1.20	5.02	9.53	6.55
10-Year	-9.38	-9.39	10.79	8.39	23.31	8.75	18.88	22.74
30-Year	-3.43	-1.91	5.98	3.35	8.21	6.45	16.10	7.03

The table shows the t-statistic of two tests of information decay over time after FOMC and 8:30 macroeconomic announcements, excluding the first two minutes after the announcements. Test 1 (top panel) addresses whether the average price impact of trades and limit order activities is greater within the 30-minute window which starts two minutes after an announcement than that within the longer 60-minute window. Test 2 (bottom panel) addresses whether the average price impact of trades and limit order activities is greater within the 60-minute window which starts two minutes after an announcement than that within the longer 90-minute window. Price impacts of trades and limit orders are computed from a VAR(5) model of return, buy trade volume, sell trade volume, bid limit order flow, and ask limit order flow. The model is estimated using BrokerTec tick data in the relevant time window immediately after announcements during the 2010-2011 sample period. Each price impact estimate has a bootstrap distribution computed from 500 replications. The tests are performed on the bootstrap samples of corresponding price impact estimates.

**Table 5:** Price Discovery After Announcements (Excluding First Two Minutes)

Security	Buy	Sell	Bid	Ask	# Obs	
					Ann	Non-Ann
<b>Panel A: FOMC Announcements</b>						
2-Year	59%*	80%*	125%*	448%*	2,977	10,611
3-Year	103%*	81%*	154%*	189%*	4,252	16,510
5-Year	41%*	-14%*	161%*	59%*	7,280	38,330
7-Year	146%*	20%*	81%*	33%*	4,867	20,307
10-Year	-14%*	-8%*	110%*	79%*	7,362	37,787
30-Year	24%*	121%*	94%*	80%*	6,232	32,626
<b>Panel B: 8:30 Macroeconomic Announcements</b>						
2-Year	13%*	-4%*	-14%*	35%*	28,965	8,729
3-Year	6%*	-7%*	17%*	14%*	45,008	13,026
5-Year	-8%*	3%*	24%*	-11%*	98,007	30,367
7-Year	-26%*	-1%*	8%*	-9%*	54,317	15,454
10-Year	-12%*	-18%*	3%*	9%*	95,399	29,114
30-Year	0%	-5%*	6%*	-2%*	66,452	18,761

The table reports changes in the price impact of trades and limit orders in the 60-minute window that starts two minutes after FOMC announcements (Panel A) or 8:30 macroeconomic announcements (Panel B) as compared to the same intervals on non-announcement days. The reported numbers reflect the incremental price impact in the 60-minute post-announcement period on announcement days as compared to non-announcement days, expressed in percent of the latter. Price impact estimates are based on a VAR(5) model of buy trade volume, sell trade volume, bid limit order flow, ask limit order flow and return (based on the best bid-ask midpoint). Estimation is based on BrokerTec tick data in the stated post-announcement window and similar time interval on non-announcement days over the 2010-2011 sample period. For FOMC announcements, non-announcement days include five days before and five days after each FOMC announcement. For 8:30 macroeconomic announcements, non-announcement days are days during the sample period for which there is no announcement at 8:30. An asterisk (\*) indicates significant difference at the 5% level (t-test of difference in mean based on bootstrap samples of price impact estimates with 500 replications).

**Table 6:** Average Trade Size Around Announcements

Security	Panel A: Before Announcement			Panel B: After Announcement			
	Ann. Days	Non-Ann. Days	Difference	Ann. Days	Non-Ann. Days	Difference	
	(1)	(2)	(3)	(4)=(2)-(3)	(5)	(6)	(7)=(5)-(6)
<b>FOMC Announcements:</b>							
2-Year	28.6	36.2	36.2	-7.6*	43.5	35.2	8.3*
3-Year	14.9	14.2	14.2	0.7	15.2	14.5	0.7
5-Year	12.1	13.4	13.4	-1.2*	18.3	13.4	4.9*
7-Year	6.5	6.6	6.6	-0.1	7.9	6.5	1.4*
10-Year	10.3	11.6	11.6	-1.4*	15.8	12.0	3.9*
30-Year	2.7	2.8	2.8	-0.1	4.0	3.3	0.7*
<b>Macroeconomic Announcements at 8:30:</b>							
2-Year	29.4	27.6	27.6	1.8	39.7	34.3	5.4*
3-Year	11.1	10.8	10.8	0.3	15.3	13.5	1.8*
5-Year	10.0	9.2	9.2	0.8*	15.8	12.5	3.3*
7-Year	5.4	5.3	5.3	0.1	7.1	6.3	0.8*
10-Year	8.8	8.2	8.2	0.6*	14.6	11.0	3.6*
30-Year	2.5	2.4	2.4	0.1*	3.1	2.7	0.4*

The table reports the average trade size (in \$ million par value) around FOMC announcements and 8:30 macroeconomic announcements. Panel A shows the statistics computed over the 60-minute window before announcements, and Panel B provides similar statistics for the 60-minute window after announcements. Within each panel, we report the announcement day statistics in the column “Ann. Days”, and the corresponding statistics computed from the same time window on non-announcement days in the column “Non-Ann. Days”. The differences between announcement day statistics and non-announcement day statistics are reported in the column “Difference”. An asterisk (\*) indicates the difference is significant at the 5% level. The statistics are computed from BrokerTec tick data for the 2010-2011 sample period. The FOMC announcement statistics exclude three (out of 16) FOMC announcements that are not made at the more regular 14:15 time during the sample period.

**Table 7: Probability of Iceberg Order Submitted to Inside Tier Around Announcements**

Security	Panel A: Before Announcement			Panel B: After Announcement		
	Ann. Days	Non-Ann. Days	Difference	Ann. Days	Non-Ann. Days	Difference
(1)	(2)	(3)	(4)=(2)-(3)	(5)	(6)	(7)=(5)-(6)
<b>FOMC Announcements:</b>						
2-Year	3.0%	2.6%	0.5%	1.8%	2.4%	-0.6%*
3-Year	3.3%	1.3%	2.0%*	1.3%	1.4%	-0.1%
5-Year	1.2%	1.0%	0.2%	0.8%	0.9%	-0.2%*
7-Year	0.6%	0.7%	-0.1%	0.4%	0.7%	-0.4%*
10-Year	1.1%	0.6%	0.6%*	0.3%	0.6%	-0.2%*
30-Year	1.6%	1.1%	0.5%*	1.0%	1.5%	-0.5%*
<b>Macroeconomic Announcements at 8:30:</b>						
2-Year	2.6%	2.9%	-0.3%	1.8%	2.1%	-0.3%
3-Year	1.6%	1.9%	-0.4%*	0.9%	1.2%	-0.2%*
5-Year	1.1%	1.1%	0.0%	0.7%	0.9%	-0.2%*
7-Year	0.6%	0.9%	-0.3%*	0.3%	0.6%	-0.3%*
10-Year	0.6%	0.7%	-0.1%*	0.4%	0.5%	-0.1%*
30-Year	2.0%	2.1%	-0.1%	0.9%	0.9%	-0.1%*

The table reports the probability of an iceberg order submitted to the best price level around FOMC announcements and 8:30 macroeconomic announcements. Panel A shows the statistics computed over the 60-minute window before announcements, and Panel B provides similar statistics for the 60-minute window after announcements. Within each panel, we report the announcement day statistics in the column “Ann. Days”, and the corresponding statistics computed from the same time window on non-announcement days in the column “Non-Ann. Days”. The differences between announcement day statistics and non-announcement day statistics are reported in the column “Difference”. An asterisk (\*) indicates the difference is significant at the 5% level. The statistics are computed from BrokerTec tick data for the 2010-2011 sample period. The FOMC announcement statistics exclude three (out of 16) FOMC announcements that are not made at the more regular 14:15 time during the sample period.

**Table 8:** Probability of Workup Around Announcements

Security	Panel A: Before Announcement			Panel B: After Announcement		
	Ann. Days	Non-Ann. Days	Difference	Ann. Days	Non-Ann. Days	Difference
(1)	(2)	(3)	(4)=(2)-(3)	(5)	(6)	(7)=(5)-(6)
<b>FOMC Announcements:</b>						
2-Year	45%	50%	-5%*	66%	48%	18%*
3-Year	56%	60%	-4%*	72%	59%	13%*
5-Year	61%	63%	-2%*	75%	63%	11%*
7-Year	52%	53%	-2%	63%	53%	9%*
10-Year	59%	62%	-3%*	75%	62%	13%*
30-Year	41%	42%	-1%	53%	45%	9%*
<b>Macroeconomic Announcements at 8:30:</b>						
2-Year	51%	51%	1%	62%	56%	6%*
3-Year	55%	56%	0%	67%	61%	6%*
5-Year	59%	58%	2%*	70%	64%	6%*
7-Year	49%	48%	1%	56%	53%	4%*
10-Year	60%	57%	3%*	70%	63%	7%*
30-Year	39%	38%	1%	46%	41%	5%*

The table reports the probability of workup around FOMC announcements and 8:30 macroeconomic announcements. The probability of workup is computed as the number of trades whose volume contains a positive quantity transacted during the workup window, divided by the total number of trades. Panel A shows the statistics computed over the 60-minute window before announcements, and Panel B provides similar statistics for the 60-minute window after announcements. Within each panel, we report the announcement day statistics in the column “Ann. Days”, and the corresponding statistics computed from the same time window on non-announcement days in the column “Non-Ann. Days”. The differences between announcement day statistics and non-announcement day statistics are reported in the column “Difference”. An asterisk (\*) indicates the difference is significant at the 5% level. The statistics are computed from BrokerTec tick data for the 2010-2011 sample period. The FOMC announcement statistics exclude three (out of 16) FOMC announcements that are not made at the more regular 14:15 time during the sample period.



**Table 9: Price Impact of Limit Order In Different Market Depth Conditions**

Statistic	\$1m Shock in Bid Limit Order Flow			\$1m Shock in Ask Limit Order Flow		
	Low Depth	Mid Depth	High Depth	Low Depth	Mid Depth	High Depth
<b>2-Year:</b>						
Depth Level	13	270	748	13	260	738
Price Impact	0.0021 (0.0020, 0.0022)	0.0018 (0.0018, 0.0019)	0.0014 (0.0013, 0.0014)	-0.0016 (-0.0016, -0.0015)	-0.0013 (-0.0013, -0.0012)	-0.0008 (-0.0008, -0.0007)
<b>3-Year:</b>						
Depth Level	3	72	176	3	72	175
Price Impact	0.0098 (0.0094, 0.0102)	0.0087 (0.0085, 0.0090)	0.0070 (0.0068, 0.0072)	-0.0079 (-0.0082, -0.0077)	-0.0069 (-0.0072, -0.0067)	-0.0055 (-0.0057, -0.0053)
<b>5-Year:</b>						
Depth Level	2	25	83	2	25	81
Price Impact	0.0187 (0.0180, 0.0195)	0.0177 (0.0171, 0.0184)	0.0151 (0.0147, 0.0155)	-0.0188 (-0.0196, -0.0182)	-0.0179 (-0.0185, -0.0173)	-0.0156 (-0.0161, -0.0151)
<b>7-Year:</b>						
Depth Level	1	28	102	1	28	98
Price Impact	0.0308 (0.0294, 0.0327)	0.0288 (0.0277, 0.0300)	0.0232 (0.0214, 0.0244)	-0.0302 (-0.0315, -0.0290)	-0.0278 (-0.0288, -0.0269)	-0.0217 (-0.0228, -0.0204)
<b>10-Year:</b>						
Depth Level	2	21	69	2	20	67
Price Impact	0.0448 (0.0408, 0.0501)	0.0416 (0.0387, 0.0455)	0.0336 (0.0327, 0.0346)	-0.0479 (-0.0498, -0.0453)	-0.0440 (-0.0458, -0.0416)	-0.0339 (-0.0355, -0.0319)
<b>30-Year:</b>						
Depth Level	1	2	9	1	2	9
Price Impact	0.3879 (0.3741, 0.4092)	0.3842 (0.3717, 0.4027)	0.3583 (0.3460, 0.3675)	-0.3683 (-0.3859, -0.3535)	-0.3657 (-0.3819, -0.3519)	-0.3481 (-0.3568, -0.3363)

The table shows the price impact of limit order under different market depth conditions (low, medium, and high, defined by the 5th, 50th, and 95th percentile of the corresponding depth distribution). For each maturity, we first report these depth levels (in \$m par), and next the corresponding price impact (in 256ths) of a \$1m shock in the limit order flow. The 95% confidence interval for price impact estimate is computed by bootstrapping with 1000 replications, and reported in parentheses below. Price impact is computed from a VAR(5) model of buy trade volume, sell trade volume, bid limit order flow, ask limit order flow, bid limit order flow interacted with inside bid depth level, ask limit order flow interacted with inside ask depth level, and return (based on the best bid-ask midpoint). The bid and ask limit order flow variables are measured as the total volume of limit orders submitted to the top of the book between trades, net of modifications/cancellations. Estimation is based on BrokerTec tick data for the 2010-2011 sample period.

**Table 10: Autocorrelation of Residuals of Key VAR(5) Specifications****Panel A: VAR(5) Model of  $\{r_t, q_t\}$  (Eqn. (1))**

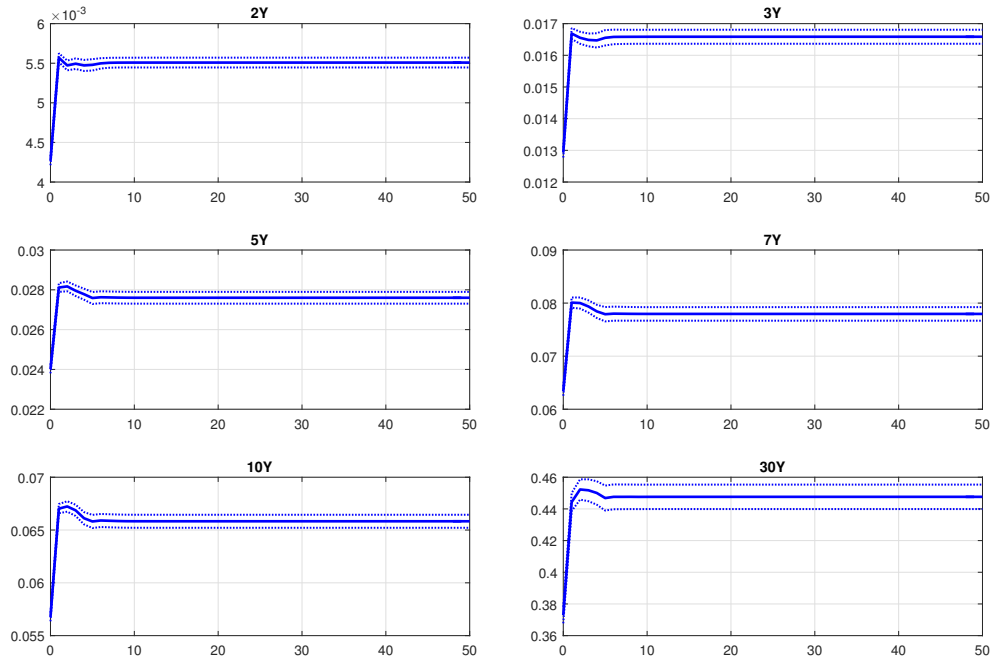
Security	$r_t$	$q_t$
2-Year	-0.0016	-0.0005
3-Year	-0.0004	-0.0002
5-Year	-0.0001	-0.0001
7-Year	-0.0003	-0.0001
10-Year	-0.0002	-0.0001
30-Year	-0.0001	0.0000

**Panel B: VAR(5) Model of  $\{r_t, VB_t, VS_t, lb_t, la_t\}$  (Eqn. (3))**

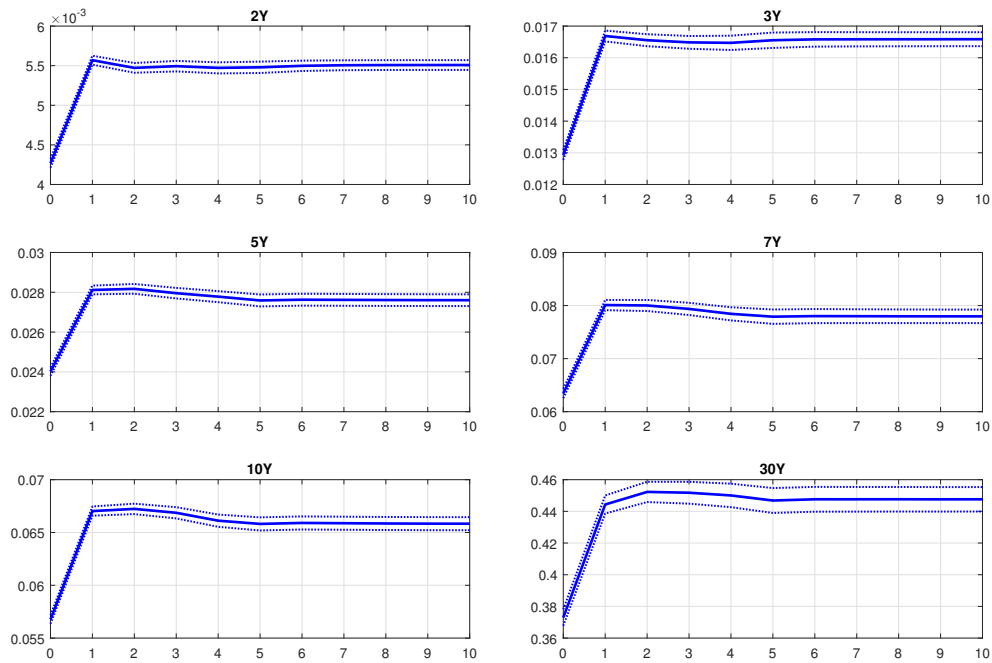
Security	$r_t$	$VB_t$	$VS_t$	$lb_t$	$la_t$
2-Year	-0.0004	-0.0012	-0.0014	0.0000	0.0000
3-Year	0.0000	-0.0013	-0.0015	-0.0001	-0.0002
5-Year	-0.0001	-0.0019*	-0.0020*	0.0000	0.0000
7-Year	0.0000	-0.0011	-0.0010	-0.0001	-0.0001
10-Year	-0.0001	-0.0022*	-0.0024*	0.0000	0.0000
30-Year	0.0000	-0.0010	-0.0010	-0.0003	-0.0002

The table shows the first order autocorrelation of residuals of key VAR(5) models estimated in the paper. Panel A corresponds to the VAR(5) model of return  $r_t$  and signed trade volume  $q_t$  as specified in equation (1) in the paper. Panel B corresponds to the VAR(5) model of return  $r_t$ , buy trade volume  $VB_t$ , sell trade volume  $VS_t$ , bid limit order flow  $lb_t$ , and ask limit order flow  $la_t$ , as specified in equation (3) in the paper. Estimation is based on BrokerTec tick data for the 2010-2011 sample period. An asterisk (\*) indicates the autocorrelation is significantly different from 0 at the 5% level.

**Figure 1: Permanent Price Impact of Trade**



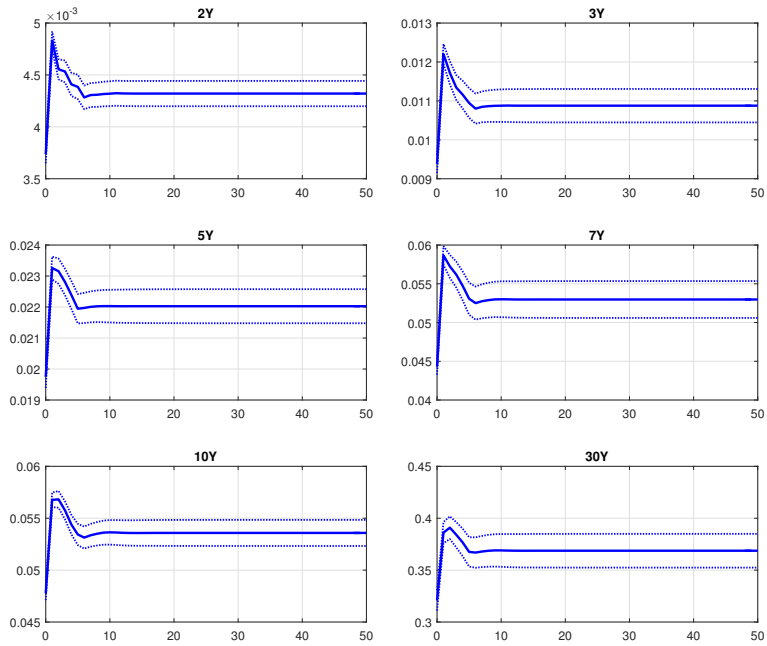
(a) Panel A: 50-tick Horizon



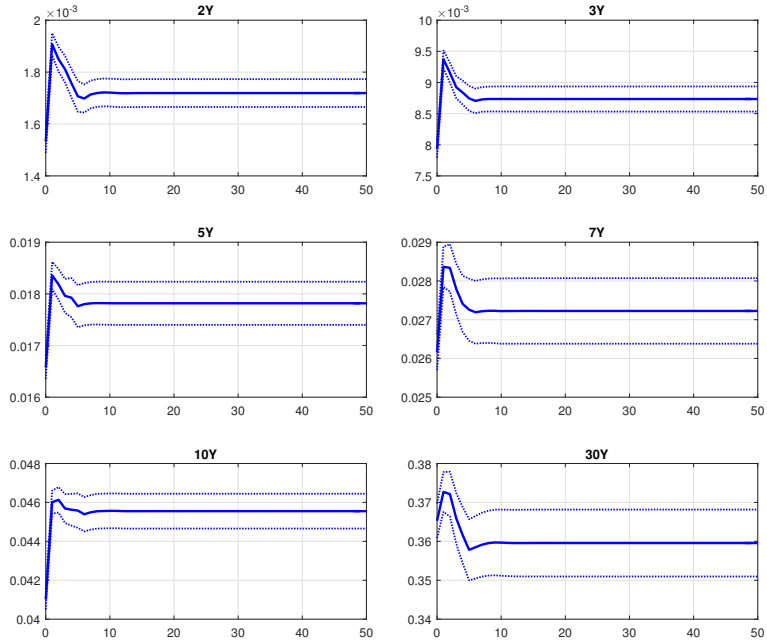
(b) Panel B: 10-tick Horizon

The figure shows the cumulative price impact (in 256ths of one percent of par) per \$1M shock in buyer-initiated trade volume (solid line), together with the 95% confidence band (dotted lines). Panel A shows the price impact up to 50 ticks following the shock, while Panel B zooms in the 10-tick horizon following the shock. Price impact is estimated from a bivariate VAR model of price revision and signed trade volume, and based on BrokerTec tick data for the 2010-2011 sample period. The 95% confidence band is computed by Runkle (1987)'s bootstrapping method with 1000 replications.

**Figure 2: Permanent Price Impact of Trade and Limit Order Flow**



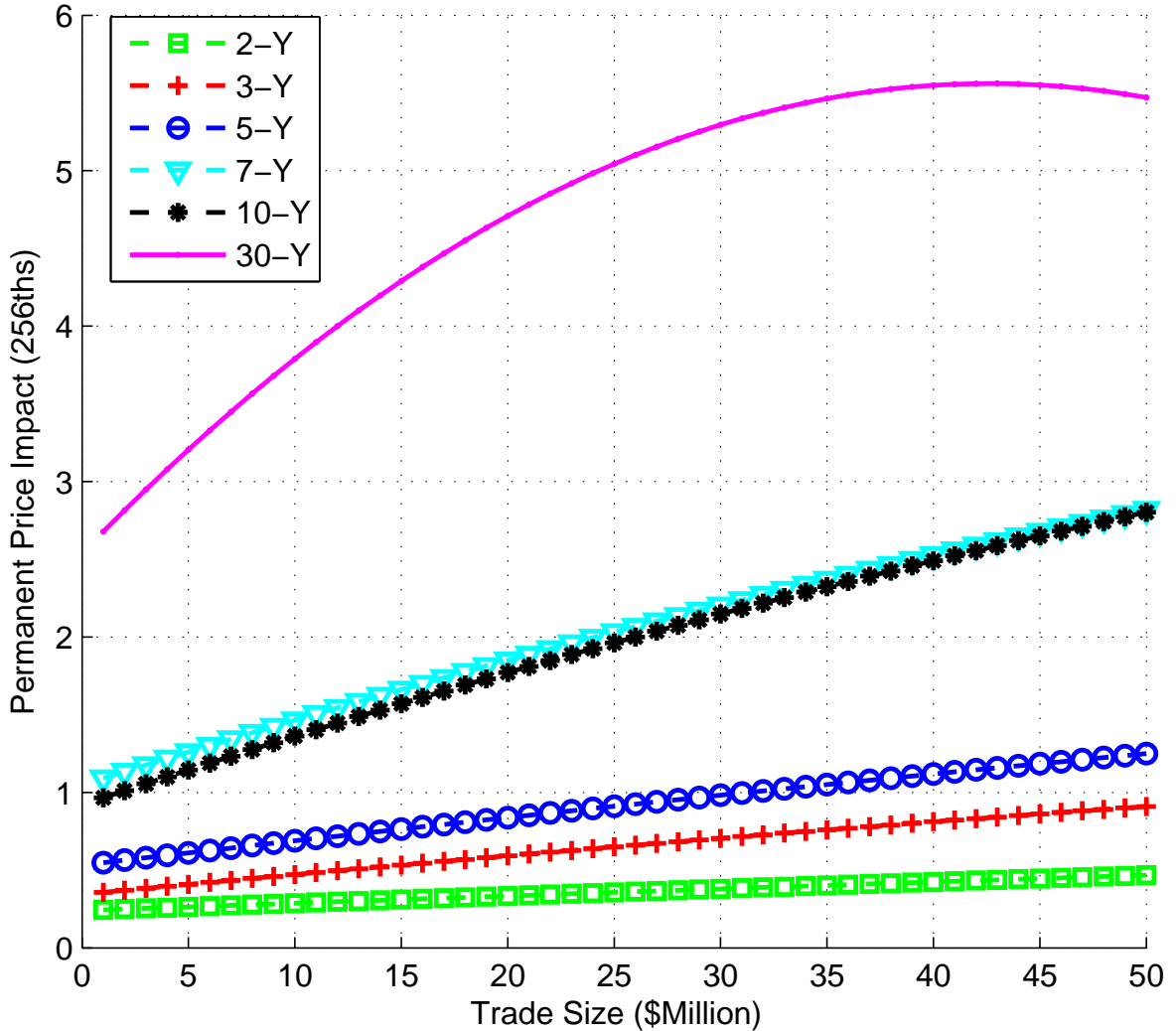
(a) Panel A: Price Impact of \$1M Shock in Buyer-Initiated Trade Volume



(b) Panel B: Price Impact of \$1M Shock in Bid Limit Order Flow

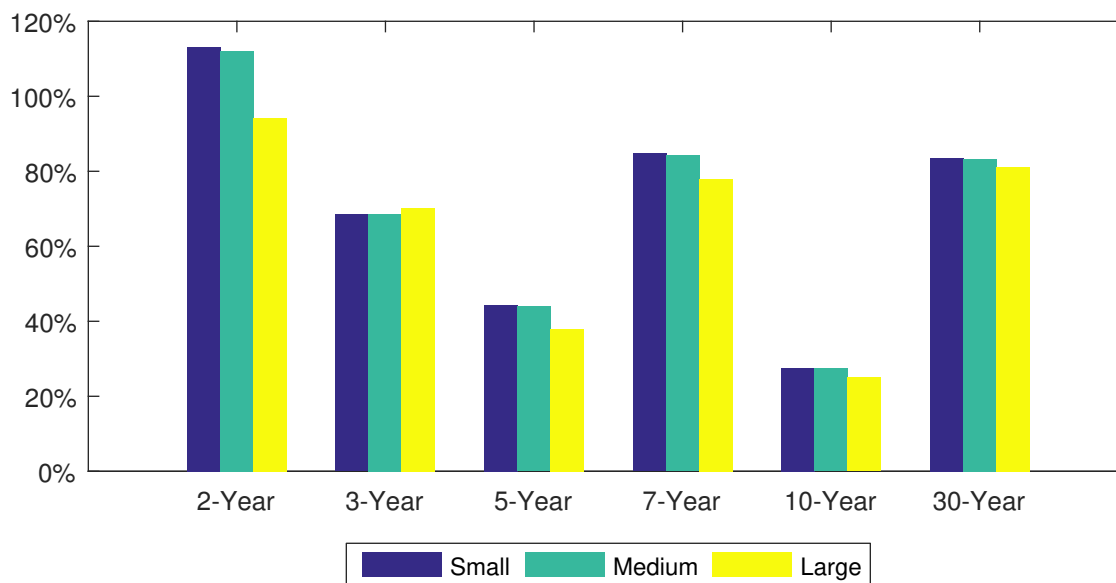
The figure shows the cumulative price impact (in 256ths of one percent of par) per \$1M shock in buyer-initiated trade (Panel A), and per \$1M shock in bid order flow (Panel B). In each plot, the solid line represents the estimated price impact, while the dotted lines represent the 95% confidence band. Price impact is estimated from a VAR model of price revision, buyer-initiated trade volume, seller-initiated trade volume, bid limit order flow, and ask limit order flow. Estimation is based on BrokerTec tick data for the 2010-2011 sample period. The 95% confidence band is computed by Runkle (1987)'s bootstrapping method with 1000 replications.

**Figure 3: Non-linear Price Impact of Trade Size**

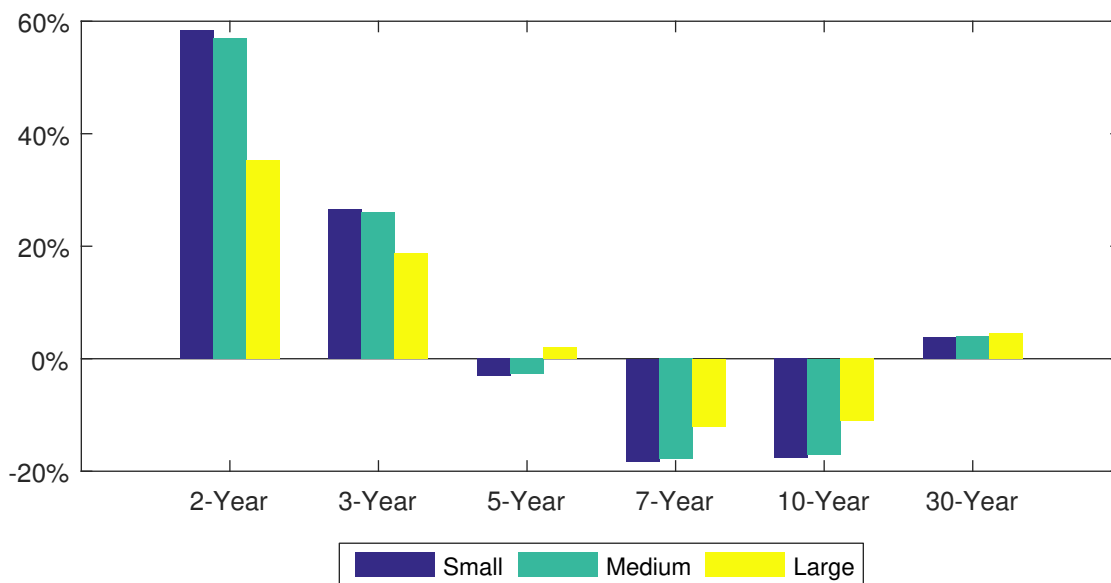


The figure plots the permanent price impact (y-axis) for different buyer-initiated trade sizes (x-axis). The permanent price impact of a given trade size is the cumulative price change (measured in 256ths of one percent of par) over a 50-tick horizon following the trade. This is based on a VAR(5) model of return (based on the best bid-ask midpoint), signed trade volume and signed trade volume squared. Signed trade volume is the volume of trade, signed positive for buys and negative for sells. Signed trade volume squared is the squared volume of trade, signed positive for buys and negative for sell. Estimation is based on BrokerTec tick data for the 2010-2011 sample period.

**Figure 4: Increase in Price Impact of Trades After Announcements**



(a) Panel A: FOMC Announcements



(b) Panel B: 8:30 Macroeconomic Announcements

The figure shows the increase in price impact in the 60 minutes after announcements as compared to price impact calculated for the same time interval on non-announcement days, expressed in percent of the latter. Price impact is estimated from a VAR model of price revision, signed trade volume, and signed trade volume squared. Price impact is calculated separately for small, medium, and large trade sizes, corresponding to the 5th, 50th, and 95th percentiles of the trade size distribution of the relevant security. Small trade size is \$1 million for all securities. Medium trade size is \$9, 5, 5, 3, 5, and 2 million respectively for the 2-, 3-, 5-, 7-, 10-, and 30-year securities. Large trade size is \$118, 50, 45, 25, 37, and 9 million respectively. Estimation is based on BrokerTec tick data for the 2010-2011 sample period.