

## **Nasdaq ISE, LLC Annual Report for NQX**

### **Report Objective and Methodology**

This report presents an analysis relating to the June 2018 introduction of the Nasdaq ISE, LLC (“ISE”) NQX index option contract (“NQX”).

#### *Background*

The NQX contract is a cash settled index option settled on the value of the NQX index, whose value is set to one-fifth of that of the Nasdaq-100 index. As such, NQX serves as a ‘Mini’ version of the two other Nasdaq-100 contracts: the traditional a.m.-settled NDX contract, and the p.m.-settled NDXP contract. Like NDXP, the NQX is p.m.-settled, with the final settlement value of the index based on component prices set in the Nasdaq close. NQX contracts are listed on weekly expirations each Friday at the close, unless Friday is a market holiday, in which case expiration shall be the previous Thursday close.

NQX is listed pursuant to a pilot program. As specified in the pilot Data Memorandum, ISE has provided the Securities and Exchange Commission with NQX monthly data files which provide the level of trading activity and open interest for this product. The Memorandum also provides the outline for this annual report.

#### *Data Summary*

As specified in the Data Memorandum, this report starts by presenting a set of data summaries related to program introduction. Following this summary, a more detailed analysis of the impact of NQX introduction will be presented.

The following tables provide monthly information on NQX volume for all series, NQX open interest for all series, the share volume of Nasdaq-100 components, and closing values of the CBOE Nasdaq-100 Implied Volatility index (VXN). For each month, the table shows the mean, median, standard deviation, minimum and maximum values of the indicated variable during the month. The months represented run from June 2018 through January 2020. NQX launched in late June, being traded during the last four trading days of the month. The VXN table extends back to April 2018, three months prior to NQX launch.

## NQX Daily Volume

Month	Days	Mean	Std. Dev.	Min.	Median	Max.
Jun-18	4	2.0	2.2	0	2	5
Jul-18	21	7.0	13.0	0	1	44
Aug-18	23	6.6	7.0	0	6	28
Sep-18	19	30.9	60.1	1	12	272
Oct-18	23	146.8	232.2	2	36	762
Nov-18	21	74.2	131.0	4	30	522
Dec-18	19	99.2	151.2	14	44	678
Jan-19	21	68.4	67.4	4	30	219
Feb-19	19	54.5	88.7	0	23	396
Mar-19	20	49.4	44.6	0	35	174
Apr-19	21	49.2	86.8	2	22	410
May-19	22	80.0	98.0	6	29	351
Jun-19	20	70.2	108.6	2	23	422
Jul-19	22	44.2	47.1	5	26	170
Aug-19	21	96.9	182.9	4	30	632
Sep-19	20	49.9	79.0	1	26	360
Oct-19	21	48.0	85.8	1	30	407
Nov-19	20	63.8	64.4	6	39	251
Dec-19	18	80.9	149.7	1	39	520
Jan-20	21	111.8	226.1	2	48	1,073

## NQX Open Interest

Month	Days	Mean	Std. Dev.	Min.	Median	Max.
Jun-18	4	3.5	3.5	0	4	7
Jul-18	21	21.3	21.7	2	14	74
Aug-18	23	69.8	14.0	48	70	100
Sep-18	19	204.7	155.7	60	111	417
Oct-18	23	696.3	200.7	381	792	942
Nov-18	21	628.2	75.0	533	624	836
Dec-18	19	921.4	101.8	796	876	1089
Jan-19	21	1,037.3	143.1	757	1,100	1267
Feb-19	19	873.6	161.9	590	991	1037
Mar-19	21	1,039.0	93.7	832	1,066	1158
Apr-19	21	1,138.3	85.4	953	1,175	1,231
May-19	22	1,149.1	196.7	833	1,191	1,358
Jun-19	20	1,182.7	126.6	954	1,126	1,434
Jul-19	22	1,005.3	288.4	601	1,092	1,299
Aug-19	22	1,094.7	191.2	818	1,168	1,456
Sep-19	20	850.9	184.0	514	944	1,040

Oct-19	23	698.3	64.9	591	677	811
Nov-19	20	780.0	92.7	634	793	1,009
Dec-19	21	837.8	110.2	647	886	979
Jan-20	21	1,388.6	363.1	772	1,385	1,890

#### Daily Volume of Nasdaq-100 Components (millions of shares)

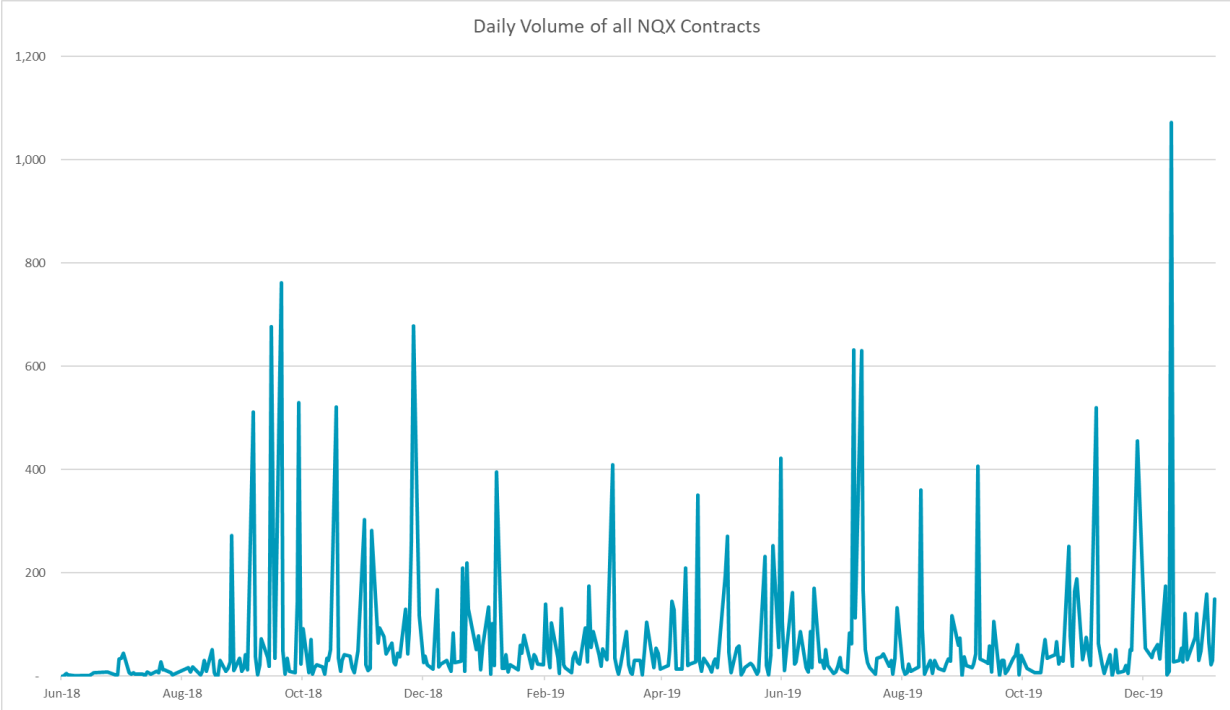
Month	Days	Mean	Std. Dev.	Min.	Median	Max.
Jun-18	4	2,297	67	2,208	2,306	2,367
Jul-18	21	1,999	325	1,185	1,906	2,629
Aug-18	23	1,888	177	1,629	1,870	2,268
Sep-18	19	2,195	458	1,843	2,106	3,978
Oct-18	23	2,641	500	2,109	2,422	3,421
Nov-18	21	2,504	447	1,048	2,531	3,181
Dec-18	19	2,863	711	1,784	2,692	5,099
Jan-19	21	2,562	294	2,114	2,545	3,550
Feb-19	19	2,263	172	2,064	2,204	2,677
Mar-19	21	2,290	391	1,844	2,257	3,817
Apr-19	21	2,033	240	1,660	2,111	2,452
May-19	22	2,099	223	1,669	2,045	2,600
Jun-19	20	2,048	409	1,602	1,963	3,093
Jul-19	22	1,811	303	1,125	1,786	2,766
Aug-19	22	2,088	379	1,628	2,066	2,761
Sep-19	20	1,972	388	1,610	1,882	3,348
Oct-19	23	1,848	215	1,396	1,893	2,221
Nov-19	20	1,924	378	901	1,947	2,645
Dec-19	21	1,781	601	619	1,727	3,684
Jan-20	21	2,011	214	1,662	2,001	2,647

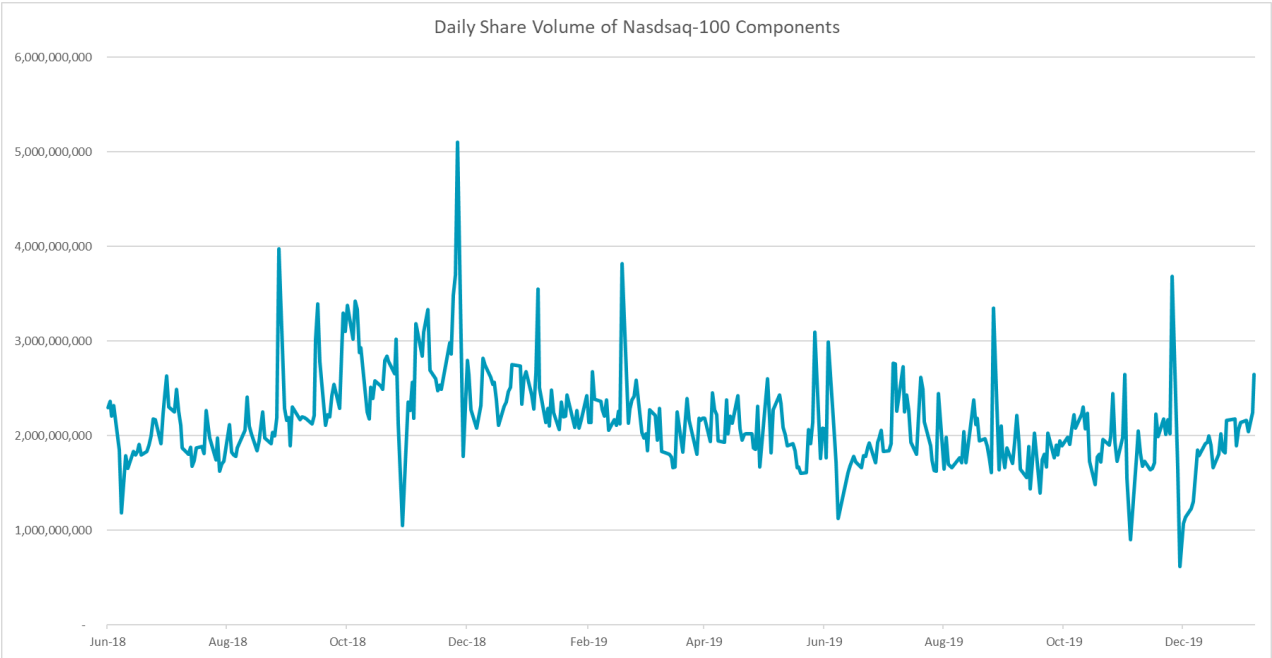
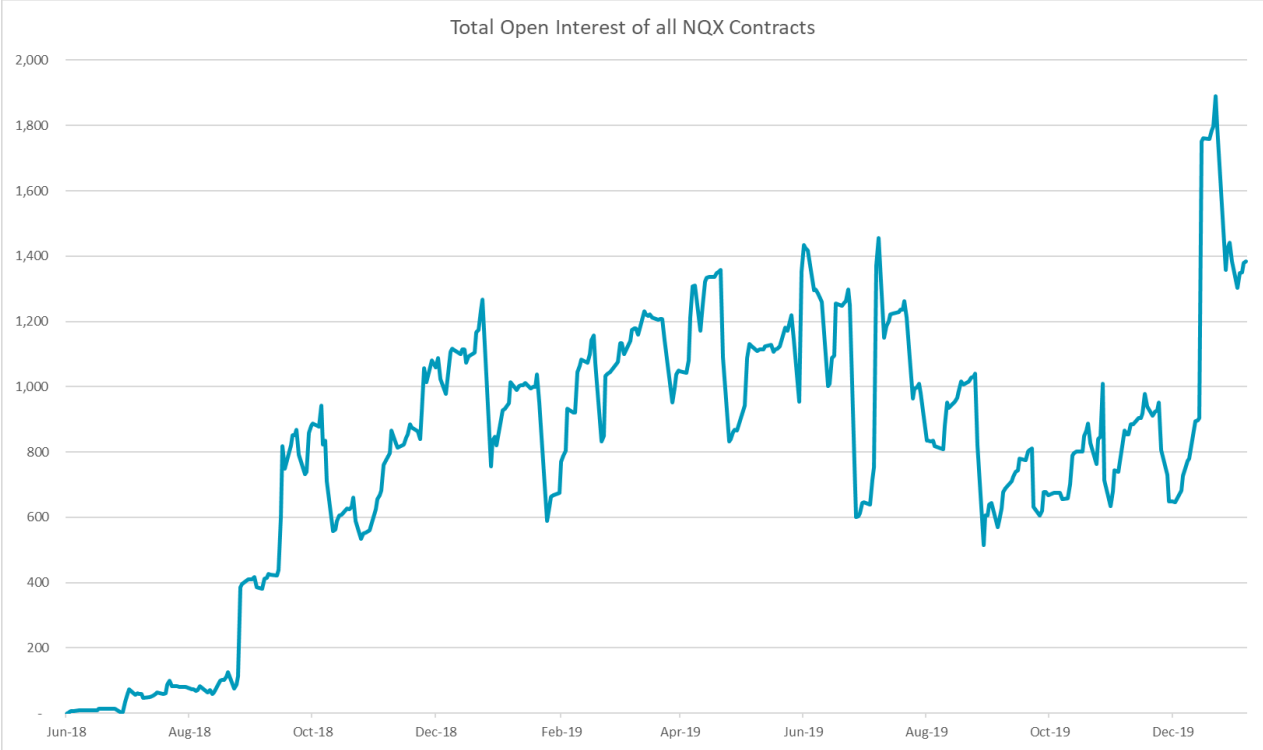
#### Daily VIX Close

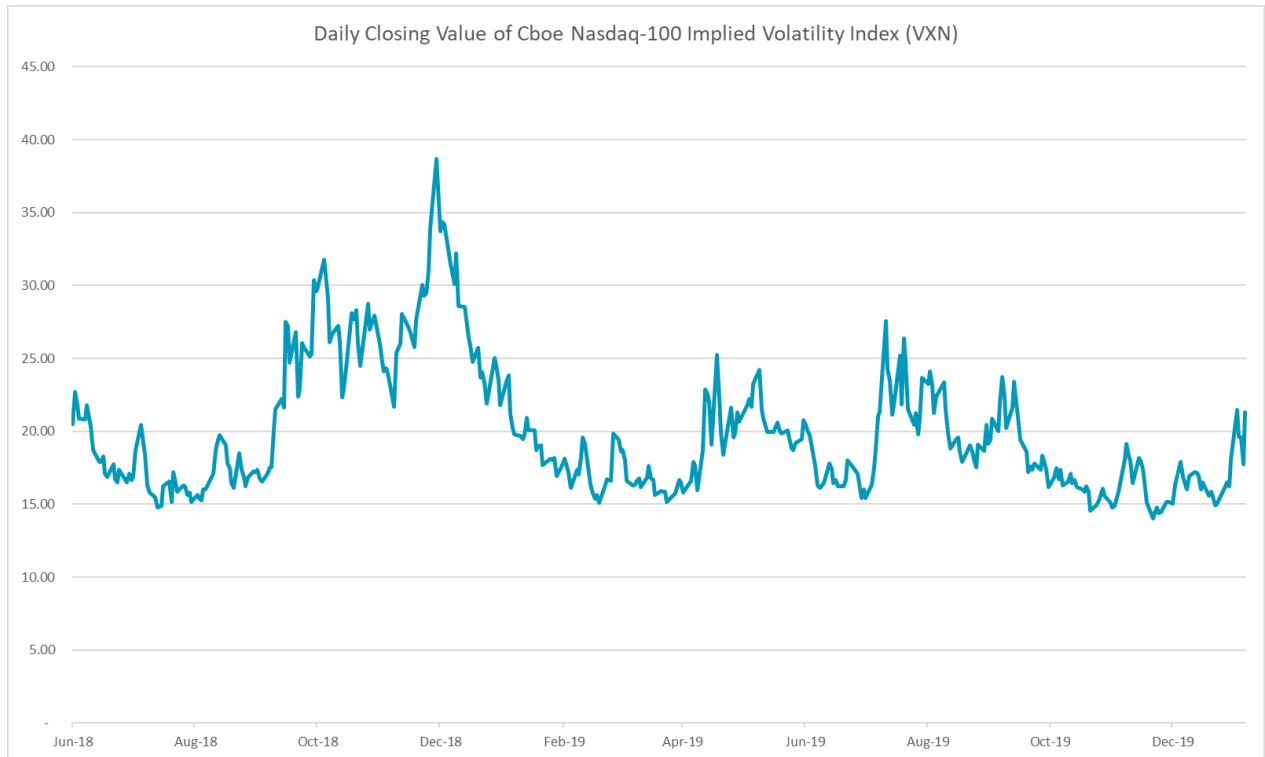
Month	Days	Mean	Std. Dev.	Min.	Median	Max.
Apr-18	21	23.4	3.1	19.4	22.9	29.9
May-18	22	17.4	1.2	15.8	17.0	19.8
Jun-18	21	17.6	2.5	15.1	16.5	22.7
Jul-18	21	18.1	1.6	16.5	17.7	21.8
Aug-18	23	15.9	0.8	14.8	15.8	18.5
Sep-18	19	17.5	1.1	16.1	17.3	19.8
Oct-18	23	24.9	4.4	17.1	25.3	31.8
Nov-18	21	25.9	1.9	22.3	26.1	28.8
Dec-18	19	29.5	4.1	21.7	29.3	38.7
Jan-19	21	25.1	3.0	20.2	24.5	32.2

Feb-19	19	18.7	1.1	17.0	18.7	20.9
Mar-19	21	17.3	1.5	15.1	16.7	19.8
Apr-19	21	16.3	0.5	15.2	16.3	17.7
May-19	22	20.6	2.2	16.0	21.0	25.3
Jun-19	20	20.2	1.2	18.7	20.0	24.2
Jul-19	21	16.8	0.9	15.4	16.5	18.8
Aug-19	22	22.7	2.0	19.8	22.1	27.6
Sep-19	20	19.4	1.4	17.6	19.1	23.4
Oct-19	23	19.1	2.4	16.2	17.8	23.7
Nov-19	20	15.8	0.7	14.6	15.9	17.1
Dec-19	21	16.4	1.6	14.0	16.4	19.2
Jan-20	21	17.2	1.9	15.0	16.5	21.5

The following charts present times series of daily values of the same four variables.







## Price Reversals

A central question addressed in the report is whether the introduction of NQX has had an impact on the closing auctions of the Nasdaq-100 components. One way to measure the impact is through analysis of how prices move before, during, and after the closing on option expiration dates. Generically, there are two broad types of outcomes. A ‘reversal’ refers to cases in which: 1) the stock price rises into the close, then falls into the open the next trading day, or 2) the price falls into the close, then rises into the next day’s open. In other words, the price direction reverses before and after the close. By contrast, a ‘run’ refers to cases in which the price direction is the same before and after the close: price increasing into the close, and increases again into the next open, or the reverse.

In an efficiently closing process, the incidence of reversals and runs should equalize, consistent with the ‘random walk’ nature of efficient prices. The following two tables indicate the number of runs and reversals for expiration Fridays for the indicated month. In addition to Reversals and Runs, the table also shows the number of cases in which the price did not move either before or after the close. These cases are labeled ‘Neutral.’ The tables also indicate the time horizon used to measure the reversals. The 30-second horizon, for example, compares the price 30-seconds before the close (i.e., 3:59:30) with the close, and the price 30-seconds after 9:30 (i.e., 9:30:30). Horizons of 30 seconds, 1 minute, 5 minutes, and 30 minutes are used.

The tables record outcomes for Friday closes for the 96 components of the Nasdaq-100 index that were components during the entire period covered in the table. For a given month, the sum

of the number of reversals, runs, and neutral cases will be either 4 or 5 times 96, depending on the number of Fridays in the month. More extensive analysis of reversals will be presented in the analysis section of the report that follows.

### Closing Price Reversals and Runs

Month	30-Second			1-Minute		
	Reversal	Neutral	Run	Reversal	Neutral	Run
Apr-18	249	20	115	254	14	116
May-18	151	37	196	150	22	212
Jun-18	237	29	214	186	26	268
Jul-18	225	34	125	195	31	158
Aug-18	195	49	236	245	31	204
Sep-18	131	45	208	172	28	184
Oct-18	132	21	231	131	16	237
Nov-18	157	12	215	140	16	228
Dec-18	169	29	186	127	15	242
Jan-19	249	30	105	276	16	92
Feb-19	141	22	221	145	17	222
Mar-19	190	48	242	208	29	243
Apr-19	175	40	169	191	38	155
May-19	179	35	266	239	34	207
Jun-19	169	28	187	192	32	160
Jul-19	230	19	123	241	11	120
Aug-19	210	37	218	242	14	209
Sep-19	163	32	177	154	22	196
Oct-19	198	36	138	222	23	127
Nov-19	200	23	149	190	17	165
Dec-19	179	35	158	209	26	137
Jan-20	251	33	181	278	25	162
<b>Total</b>	<b>4102</b>	<b>671</b>	<b>3969</b>	<b>4310</b>	<b>484</b>	<b>3948</b>

	5-Minute			30-Minute		
	Reversal	Neutral	Run	Reversal	Neutral	Run
Apr-18	244	10	130	128	6	250
May-18	159	15	210	203	4	177
Jun-18	195	18	267	195	6	279
Jul-18	171	22	191	212	6	166
Aug-18	236	29	215	270	12	198
Sep-18	128	13	243	199	11	174
Oct-18	222	5	157	188	4	192
Nov-18	141	10	233	147	13	224

Dec-18	156	11	217	193	11	180
Jan-19	272	7	105	248	3	133
Feb-19	139	13	232	181	10	193
Mar-19	193	10	277	175	10	295
Apr-19	199	16	169	200	6	178
May-19	286	11	183	227	3	250
Jun-19	165	11	208	207	9	168
Jul-19	229	8	135	191	8	173
Aug-19	228	11	226	228	11	226
Sep-19	160	7	205	158	3	211
Oct-19	189	15	168	204	3	165
Nov-19	166	11	195	203	8	161
Dec-19	185	21	166	150	11	211
Jan-20	182	21	262	197	6	262
<b>Total</b>	<b>4171</b>	<b>279</b>	<b>4292</b>	<b>4214</b>	<b>154</b>	<b>4374</b>

### Short-Term Volatility

The report also examines whether the introduction of NQX has impacted volatility during the last half-hour of trading on expiration Fridays, and the first half-hour of trading on the following Mondays. During both periods, volatility was measured during very short time intervals of 30 seconds, 1 minute, and 5 minutes. Two volatility measures were used: the standard deviation of the logarithmic price change during the interval; and the average high/low range during the interval, expressed as a fraction of the average of the high and low price. Volatility was measured for the 96 Nasdaq-100 components that were index members during the entire sample period. The following 12 tables show monthly averages of the indicated volatility metric over the 96 Nasdaq-100 components under study.

#### Avg Standard Deviation of 30-second Price Returns: Fridays 3:30 – 4:00

Month	Mean	Std. Dev.	Min.	Median	Max.
Apr-18	0.00055	0.00023	0.00024	0.00050	0.00225
May-18	0.00036	0.00015	0.00013	0.00033	0.00158
Jun-18	0.00042	0.00016	0.00017	0.00039	0.00197
Jul-18	0.00036	0.00014	0.00010	0.00034	0.00137
Aug-18	0.00035	0.00015	0.00014	0.00032	0.00110
Sep-18	0.00040	0.00027	0.00010	0.00035	0.00439
Oct-18	0.00070	0.00030	0.00022	0.00062	0.00211
Nov-18	0.00056	0.00017	0.00026	0.00053	0.00126
Dec-18	0.00088	0.00030	0.00024	0.00089	0.00297
Jan-19	0.00046	0.00015	0.00016	0.00045	0.00160
Feb-19	0.00043	0.00124	0.00015	0.00034	0.02457



Mar-19	0.00044	0.00014	0.00016	0.00041	0.00108
Apr-19	0.00035	0.00015	0.00013	0.00031	0.00142
May-19	0.00047	0.00018	0.00018	0.00044	0.00143
Jun-19	0.00048	0.00026	0.00015	0.00041	0.00238
Jul-19	0.00038	0.00015	0.00016	0.00036	0.00117
Aug-19	0.00051	0.00031	0.00023	0.00048	0.00641
Sep-19	0.00044	0.00019	0.00016	0.00040	0.00148
Oct-19	0.00047	0.00024	0.00017	0.00038	0.00145
Nov-19	0.00036	0.00016	0.00014	0.00034	0.00232
Dec-19	0.00035	0.00012	0.00015	0.00032	0.00091
Jan-20	0.00046	0.00016	0.00019	0.00042	0.00136

Avg High/Low Range of 30-second Intervals: Fridays 3:30 – 4:00

	Mean	Std. Dev.	Min.	Median	Max.
Apr-18	0.00073	0.00033	0.00028	0.00066	0.00304
May-18	0.00047	0.00024	0.00018	0.00042	0.00274
Jun-18	0.00051	0.00019	0.00021	0.00047	0.00159
Jul-18	0.00048	0.00019	0.00017	0.00044	0.00144
Aug-18	0.00046	0.00020	0.00017	0.00041	0.00175
Sep-18	0.00051	0.00024	0.00014	0.00045	0.00229
Oct-18	0.00094	0.00040	0.00037	0.00084	0.00255
Nov-18	0.00074	0.00023	0.00032	0.00071	0.00194
Dec-18	0.00119	0.00041	0.00033	0.00116	0.00415
Jan-19	0.00065	0.00034	0.00025	0.00058	0.00327
Feb-19	0.00050	0.00025	0.00022	0.00045	0.00269
Mar-19	0.00058	0.00023	0.00020	0.00054	0.00233
Apr-19	0.00049	0.00031	0.00019	0.00043	0.00331
May-19	0.00064	0.00025	0.00023	0.00059	0.00198
Jun-19	0.00058	0.00022	0.00022	0.00054	0.00183
Jul-19	0.00049	0.00020	0.00023	0.00045	0.00161
Aug-19	0.00072	0.00038	0.00029	0.00067	0.00729
Sep-19	0.00056	0.00020	0.00026	0.00053	0.00178
Oct-19	0.00063	0.00030	0.00024	0.00050	0.00238
Nov-19	0.00047	0.00020	0.00020	0.00043	0.00214
Dec-19	0.00045	0.00015	0.00020	0.00042	0.00130
Jan-20	0.00062	0.00023	0.00023	0.00055	0.00187

Avg Standard Deviation of 1-minute Price Returns: Fridays 3:30 – 4:00

	Mean	Std. Dev.	Min.	Median	Max.
Apr-18	0.00078	0.00034	0.00030	0.00071	0.00325
May-18	0.00051	0.00024	0.00018	0.00046	0.00270
Jun-18	0.00057	0.00023	0.00020	0.00053	0.00198
Jul-18	0.00050	0.00020	0.00013	0.00046	0.00214
Aug-18	0.00049	0.00022	0.00018	0.00044	0.00178
Sep-18	0.00056	0.00039	0.00015	0.00050	0.00625
Oct-18	0.00105	0.00051	0.00033	0.00087	0.00325
Nov-18	0.00078	0.00026	0.00036	0.00072	0.00179
Dec-18	0.00123	0.00042	0.00029	0.00124	0.00419
Jan-19	0.00062	0.00021	0.00016	0.00060	0.00237
Feb-19	0.00053	0.00020	0.00020	0.00050	0.00180
Mar-19	0.00061	0.00020	0.00023	0.00058	0.00146
Apr-19	0.00048	0.00020	0.00015	0.00043	0.00200
May-19	0.00065	0.00025	0.00023	0.00062	0.00242
Jun-19	0.00066	0.00036	0.00021	0.00056	0.00354
Jul-19	0.00054	0.00022	0.00020	0.00050	0.00189
Aug-19	0.00074	0.00047	0.00027	0.00068	0.00964
Sep-19	0.00063	0.00030	0.00023	0.00055	0.00246
Oct-19	0.00066	0.00035	0.00020	0.00053	0.00237
Nov-19	0.00050	0.00024	0.00020	0.00046	0.00373
Dec-19	0.00049	0.00018	0.00019	0.00045	0.00135
Jan-20	0.00066	0.00024	0.00026	0.00059	0.00214

Avg High/Low Range of 1-Minute Intervals: Fridays 3:30 – 4:00

	Mean	Std. Dev.	Min.	Median	Max.
Apr-18	0.00109	0.00048	0.00045	0.00100	0.00457
May-18	0.00070	0.00037	0.00028	0.00062	0.00524
Jun-18	0.00076	0.00027	0.00033	0.00070	0.00241
Jul-18	0.00070	0.00027	0.00025	0.00065	0.00250
Aug-18	0.00068	0.00029	0.00026	0.00061	0.00245
Sep-18	0.00075	0.00034	0.00020	0.00069	0.00331
Oct-18	0.00140	0.00059	0.00057	0.00126	0.00384
Nov-18	0.00110	0.00033	0.00045	0.00107	0.00319
Dec-18	0.00176	0.00060	0.00053	0.00176	0.00612
Jan-19	0.00097	0.00057	0.00034	0.00086	0.00609
Feb-19	0.00074	0.00041	0.00032	0.00067	0.00507
Mar-19	0.00087	0.00036	0.00030	0.00081	0.00444
Apr-19	0.00072	0.00054	0.00028	0.00063	0.00639

May-19	0.00094	0.00036	0.00034	0.00088	0.00256
Jun-19	0.00085	0.00031	0.00030	0.00079	0.00296
Jul-19	0.00073	0.00029	0.00033	0.00066	0.00239
Aug-19	0.00104	0.00057	0.00041	0.00097	0.01113
Sep-19	0.00084	0.00028	0.00042	0.00078	0.00228
Oct-19	0.00093	0.00047	0.00035	0.00075	0.00405
Nov-19	0.00069	0.00029	0.00031	0.00064	0.00308
Dec-19	0.00066	0.00021	0.00031	0.00062	0.00177
Jan-20	0.00092	0.00034	0.00037	0.00083	0.00305

Avg Standard Deviation of 5-minute Price Returns: Fridays 3:30 – 4:00

	Mean	Std. Dev.	Min.	Median	Max.
Apr-18	0.00166	0.00096	0.00025	0.00137	0.00748
May-18	0.00114	0.00057	0.00023	0.00104	0.00444
Jun-18	0.00115	0.00058	0.00022	0.00106	0.00558
Jul-18	0.00102	0.00043	0.00019	0.00097	0.00281
Aug-18	0.00094	0.00051	0.00012	0.00085	0.00360
Sep-18	0.00108	0.00065	0.00025	0.00092	0.00496
Oct-18	0.00242	0.00133	0.00022	0.00196	0.00872
Nov-18	0.00170	0.00090	0.00041	0.00151	0.00616
Dec-18	0.00269	0.00123	0.00044	0.00265	0.01401
Jan-19	0.00143	0.00059	0.00023	0.00136	0.00455
Feb-19	0.00122	0.00053	0.00020	0.00113	0.00339
Mar-19	0.00133	0.00065	0.00019	0.00121	0.00468
Apr-19	0.00108	0.00059	0.00013	0.00097	0.00491
May-19	0.00128	0.00064	0.00020	0.00118	0.00497
Jun-19	0.00136	0.00086	0.00012	0.00116	0.00726
Jul-19	0.00114	0.00065	0.00013	0.00097	0.00383
Aug-19	0.00154	0.00136	0.00032	0.00135	0.02671
Sep-19	0.00125	0.00077	0.00020	0.00107	0.00545
Oct-19	0.00129	0.00074	0.00026	0.00113	0.00599
Nov-19	0.00106	0.00067	0.00024	0.00094	0.00953
Dec-19	0.00107	0.00054	0.00008	0.00095	0.00445
Jan-20	0.00136	0.00072	0.00020	0.00124	0.00591

Avg High/Low Range of 5-Minute Intervals: Fridays 3:30 – 4:00

	Mean	Std. Dev.	Min.	Median	Max.
Apr-18	0.00260	0.00120	0.00096	0.00228	0.01182
May-18	0.00175	0.00139	0.00067	0.00155	0.02458
Jun-18	0.00187	0.00067	0.00080	0.00176	0.00614
Jul-18	0.00168	0.00074	0.00059	0.00159	0.01073
Aug-18	0.00159	0.00073	0.00048	0.00145	0.00824
Sep-18	0.00183	0.00089	0.00047	0.00165	0.01031
Oct-18	0.00348	0.00158	0.00124	0.00299	0.01046
Nov-18	0.00261	0.00093	0.00108	0.00248	0.01135
Dec-18	0.00403	0.00155	0.00133	0.00396	0.01754
Jan-19	0.00250	0.00240	0.00069	0.00214	0.02761
Feb-19	0.00189	0.00160	0.00069	0.00162	0.02336
Mar-19	0.00216	0.00135	0.00071	0.00193	0.02078
Apr-19	0.00186	0.00248	0.00064	0.00155	0.03052
May-19	0.00219	0.00084	0.00074	0.00206	0.00639
Jun-19	0.00205	0.00092	0.00060	0.00184	0.00972
Jul-19	0.00175	0.00071	0.00070	0.00158	0.00600
Aug-19	0.00242	0.00142	0.00093	0.00221	0.02783
Sep-19	0.00203	0.00071	0.00077	0.00188	0.00490
Oct-19	0.00220	0.00135	0.00081	0.00180	0.01444
Nov-19	0.00166	0.00084	0.00070	0.00152	0.01206
Dec-19	0.00158	0.00048	0.00075	0.00148	0.00364
Jan-20	0.00215	0.00087	0.00080	0.00192	0.00975

Avg Standard Deviation of 30-second Price Returns: Mondays 9:30 – 10:00

	Mean	Std. Dev.	Min.	Median	Max.
Apr-18	0.00132	0.00059	0.00052	0.00122	0.00676
May-18	0.00116	0.00054	0.00044	0.00104	0.00496
Jun-18	0.00121	0.00053	0.00041	0.00111	0.00442
Jul-18	0.00119	0.00059	0.00040	0.00107	0.00493
Aug-18	0.00115	0.00053	0.00035	0.00103	0.00476
Sep-18	0.00120	0.00047	0.00039	0.00113	0.00312
Oct-18	0.00154	0.00060	0.00054	0.00144	0.00496
Nov-18	0.00156	0.00068	0.00048	0.00146	0.00633
Dec-18	0.00167	0.00064	0.00043	0.00157	0.00475
Jan-19	0.00150	0.00060	0.00036	0.00141	0.00401
Feb-19	0.00122	0.00058	0.00024	0.00112	0.00373
Mar-19	0.00117	0.00048	0.00038	0.00108	0.00312

Apr-19	0.00115	0.00045	0.00039	0.00108	0.00335
May-19	0.00147	0.00062	0.00033	0.00135	0.00483
Jun-19	0.00133	0.00051	0.00042	0.00127	0.00319
Jul-19	0.00113	0.00049	0.00045	0.00105	0.00532
Aug-19	0.00142	0.00062	0.00049	0.00130	0.00608
Sep-19	0.00125	0.00049	0.00049	0.00114	0.00371
Oct-19	0.00124	0.00057	0.00038	0.00116	0.00739
Nov-19	0.00116	0.00049	0.00038	0.00107	0.00469
Dec-19	0.00105	0.00042	0.00038	0.00098	0.00375
Jan-20	0.00132	0.00069	0.00040	0.00118	0.00644

Avg High/Low Range of 30-second Intervals: Mondays 9:30 – 10:00

	Mean	Std. Dev.	Min.	Median	Max.
Apr-18	0.00150	0.00064	0.00058	0.00137	0.00557
May-18	0.00140	0.00063	0.00052	0.00125	0.00570
Jun-18	0.00145	0.00062	0.00046	0.00133	0.00499
Jul-18	0.00138	0.00068	0.00043	0.00122	0.00602
Aug-18	0.00136	0.00063	0.00044	0.00122	0.00443
Sep-18	0.00145	0.00061	0.00049	0.00133	0.00484
Oct-18	0.00184	0.00076	0.00066	0.00171	0.00638
Nov-18	0.00195	0.00090	0.00059	0.00179	0.00729
Dec-18	0.00217	0.00104	0.00054	0.00193	0.01053
Jan-19	0.00188	0.00089	0.00033	0.00170	0.01019
Feb-19	0.00153	0.00078	0.00034	0.00136	0.00572
Mar-19	0.00146	0.00060	0.00044	0.00132	0.00454
Apr-19	0.00140	0.00063	0.00038	0.00125	0.00706
May-19	0.00191	0.00082	0.00047	0.00178	0.00697
Jun-19	0.00165	0.00069	0.00051	0.00150	0.00504
Jul-19	0.00136	0.00059	0.00047	0.00127	0.00711
Aug-19	0.00177	0.00078	0.00059	0.00163	0.00925
Sep-19	0.00148	0.00051	0.00060	0.00140	0.00437
Oct-19	0.00139	0.00050	0.00053	0.00129	0.00425
Nov-19	0.00144	0.00063	0.00041	0.00129	0.00544
Dec-19	0.00130	0.00049	0.00050	0.00124	0.00372
Jan-20	0.00172	0.00084	0.00056	0.00151	0.00707

Avg Standard Deviation of 1-minute Price Returns: Mondays 9:30 – 10:00

	Mean	Std. Dev.	Min.	Median	Max.
Apr-18	0.00176	0.00080	0.00070	0.00161	0.00911
May-18	0.00154	0.00076	0.00049	0.00136	0.00722
Jun-18	0.00164	0.00076	0.00057	0.00146	0.00608
Jul-18	0.00161	0.00086	0.00041	0.00140	0.00720
Aug-18	0.00153	0.00072	0.00048	0.00137	0.00577
Sep-18	0.00159	0.00067	0.00049	0.00150	0.00474
Oct-18	0.00205	0.00082	0.00078	0.00185	0.00592
Nov-18	0.00206	0.00090	0.00060	0.00189	0.00681
Dec-18	0.00222	0.00091	0.00057	0.00208	0.00657
Jan-19	0.00198	0.00086	0.00058	0.00181	0.00614
Feb-19	0.00161	0.00080	0.00032	0.00146	0.00564
Mar-19	0.00157	0.00067	0.00052	0.00144	0.00437
Apr-19	0.00153	0.00066	0.00051	0.00139	0.00423
May-19	0.00199	0.00091	0.00047	0.00180	0.00899
Jun-19	0.00175	0.00072	0.00046	0.00162	0.00443
Jul-19	0.00147	0.00065	0.00048	0.00133	0.00834
Aug-19	0.00187	0.00090	0.00061	0.00165	0.00929
Sep-19	0.00160	0.00063	0.00061	0.00149	0.00580
Oct-19	0.00159	0.00075	0.00052	0.00148	0.00977
Nov-19	0.00151	0.00067	0.00053	0.00139	0.00497
Dec-19	0.00141	0.00062	0.00039	0.00130	0.00525
Jan-20	0.00177	0.00100	0.00048	0.00153	0.00865

Avg High/Low Range of 1-minute Intervals: Mondays 9:30 – 10:00

	Mean	Std. Dev.	Min.	Median	Max.
Apr-18	0.00230	0.00094	0.00100	0.00211	0.00791
May-18	0.00211	0.00094	0.00084	0.00190	0.00847
Jun-18	0.00220	0.00090	0.00074	0.00203	0.00691
Jul-18	0.00210	0.00097	0.00062	0.00188	0.00893
Aug-18	0.00206	0.00092	0.00064	0.00183	0.00631
Sep-18	0.00220	0.00090	0.00076	0.00205	0.00664
Oct-18	0.00279	0.00108	0.00108	0.00259	0.00931
Nov-18	0.00293	0.00125	0.00095	0.00270	0.00966
Dec-18	0.00327	0.00150	0.00080	0.00295	0.01526
Jan-19	0.00282	0.00127	0.00057	0.00258	0.01372
Feb-19	0.00229	0.00113	0.00050	0.00204	0.00806
Mar-19	0.00219	0.00087	0.00069	0.00199	0.00688
Apr-19	0.00211	0.00092	0.00069	0.00191	0.01034

May-19	0.00283	0.00116	0.00075	0.00262	0.00876
Jun-19	0.00247	0.00100	0.00078	0.00227	0.00772
Jul-19	0.00205	0.00086	0.00077	0.00188	0.01100
Aug-19	0.00264	0.00110	0.00091	0.00244	0.01309
Sep-19	0.00225	0.00075	0.00089	0.00213	0.00651
Oct-19	0.00213	0.00074	0.00085	0.00200	0.00637
Nov-19	0.00215	0.00091	0.00070	0.00195	0.00715
Dec-19	0.00194	0.00070	0.00076	0.00185	0.00556
Jan-20	0.00254	0.00120	0.00086	0.00225	0.00954

Avg Standard Deviation of 5-minute Price Returns: Mondays 9:30 – 10:00

	Mean	Std. Dev.	Min.	Median	Max.
Apr-18	0.00348	0.00204	0.00028	0.00313	0.01343
May-18	0.00312	0.00176	0.00055	0.00274	0.01514
Jun-18	0.00325	0.00190	0.00023	0.00287	0.01514
Jul-18	0.00326	0.00236	0.00043	0.00266	0.02364
Aug-18	0.00300	0.00175	0.00062	0.00253	0.01355
Sep-18	0.00318	0.00175	0.00051	0.00267	0.01363
Oct-18	0.00386	0.00204	0.00068	0.00346	0.01283
Nov-18	0.00380	0.00206	0.00064	0.00343	0.01490
Dec-18	0.00485	0.00296	0.00056	0.00421	0.02114
Jan-19	0.00398	0.00220	0.00057	0.00355	0.01328
Feb-19	0.00333	0.00212	0.00058	0.00278	0.01360
Mar-19	0.00315	0.00171	0.00052	0.00268	0.01008
Apr-19	0.00298	0.00169	0.00041	0.00270	0.01091
May-19	0.00402	0.00224	0.00079	0.00349	0.01398
Jun-19	0.00332	0.00180	0.00053	0.00290	0.01034
Jul-19	0.00298	0.00180	0.00050	0.00258	0.02307
Aug-19	0.00338	0.00208	0.00045	0.00300	0.02148
Sep-19	0.00293	0.00145	0.00063	0.00266	0.00954
Oct-19	0.00294	0.00148	0.00066	0.00260	0.01055
Nov-19	0.00282	0.00149	0.00054	0.00252	0.01431
Dec-19	0.00278	0.00157	0.00053	0.00242	0.01160
Jan-20	0.00337	0.00219	0.00054	0.00287	0.01672

Avg High/Low Range of 5-minute Intervals: Mondays 9:30 – 10:00

	Mean	Std. Dev.	Min.	Median	Max.
Apr-18	0.00558	0.00241	0.00244	0.00522	0.02710
May-18	0.00504	0.00232	0.00189	0.00455	0.02196
Jun-18	0.00538	0.00227	0.00198	0.00495	0.01976

Jul-18	0.00515	0.00243	0.00141	0.00448	0.02093
Aug-18	0.00500	0.00225	0.00169	0.00441	0.01603
Sep-18	0.00531	0.00228	0.00151	0.00485	0.02247
Oct-18	0.00664	0.00243	0.00260	0.00615	0.02024
Nov-18	0.00694	0.00284	0.00225	0.00639	0.01985
Dec-18	0.00789	0.00353	0.00204	0.00721	0.03017
Jan-19	0.00664	0.00304	0.00138	0.00598	0.02935
Feb-19	0.00543	0.00289	0.00129	0.00479	0.02695
Mar-19	0.00515	0.00205	0.00142	0.00468	0.01369
Apr-19	0.00500	0.00218	0.00148	0.00466	0.02244
May-19	0.00668	0.00281	0.00192	0.00608	0.02149
Jun-19	0.00584	0.00249	0.00169	0.00529	0.01659
Jul-19	0.00487	0.00204	0.00190	0.00441	0.02508
Aug-19	0.00604	0.00252	0.00205	0.00566	0.03118
Sep-19	0.00521	0.00182	0.00191	0.00489	0.01437
Oct-19	0.00509	0.00189	0.00214	0.00479	0.01567
Nov-19	0.00498	0.00203	0.00166	0.00465	0.01335
Dec-19	0.00459	0.00175	0.00138	0.00429	0.01337
Jan-20	0.00584	0.00277	0.00167	0.00522	0.02366

### *Analysis*

This section of the report focuses on the potential impact of the NQX contract on the prices of the underlying Nasdaq-100 components at settlement. Specifically, ISE examined whether options trading activity near and at final expiration and settlement has led to negative spillover effects on the cash equity market for the Nasdaq-100 components.

The market quality metrics used in this study can be broadly classified into two categories: price volatility and price reversals. Analysis of price reversals compares the movement of prices from a pre-close benchmark, to the closing price itself, and then to a post-close price benchmark. Details regarding the calculation of these metrics will be provided in the following sections of the report.

For a given market quality metric, the impact of NQX introduction is assessed using multiple regression analysis. This approach starts with consideration of the stocks potentially impacted by NQX, in this case Nasdaq-100 components. Stock-level averages of the metric are computed separately for dates prior to the contract launch and dates after the launch. In this study, a 3-month ‘pre’ period runs from April 2018 through the end of June 2018. The ‘post’ period runs from January 2019 to December 20, 2019. (The latter date was chosen as it was just prior to the annual Nasdaq-100 index rebalance for 2019.)

The identical procedure is then carried out for a set of stocks that would have been unaffected by the NQX introduction. These stocks can be considered ‘control stocks’ as contrasted with the Nasdaq-100 ‘treatment’ stocks. The advantage of using a set of control stocks is that they may



pick up market-wide changes to the stock-trading environment unrelated to the introduction of the NQX contract. The analysis is enhanced to the extent that the control stocks are as similar as possible to the treatment stocks. To achieve this end, a ‘matched-pairs’ approach was used. For each Nasdaq-100 treatment stock, a control stock was found that was as similar as possible to the treatment stock along four dimensions: market capitalization, price, average daily dollar volume, and close-to-close return standard deviation, all measured prior to contract introduction.

Another source of control observations uses trading from the treatment stocks, but from dates other than the settlement date. For instance, price volatility from Thursday afternoons can serve as controls for Friday afternoons. Closing price reversals from Thursday/Friday can serve as controls for Friday/Monday reversals. This analysis uses observations from dates just before expirations as stock-level controls.

In sum, then, the analysis is carried out using a dataset comprised of three sources: the treatment stocks trading around weekly expirations; market-level controls provided by the matched pairs sample trading around weekly expirations; and stock-level controls provided by the treatments stocks trading around on the day before the weekly expiration. The multiple regression model can be expressed as:

$$y_{it} = \alpha + \beta_1 D_{Trt} + \beta_2 D_{Ctrl} + \beta_3 D_{Prd} + \beta_4 D_{Trt} \times D_{Prd}$$

where  $y_{it}$  represents the metric of interest for stock  $i$  in time period  $t$  (pre or post). The ‘dummy’ variable  $D_{Trt}$  is constructed such that  $D_{Trt}$  has the value of 1 for the treatment stocks, 0 otherwise. In similar fashion,  $D_{Ctrl}$  has value of 1 when the stock is from the matched-pairs control sample. The dummy variable  $D_{Prd}$  has a value of 1 when the observation is from the post period, 0 otherwise. (Note that there is no dummy variable for the non-expiration data control observations—the associated impact of these observations is reflected in the intercept term  $\alpha$ .) The coefficient  $\beta_4$  on the interaction term provides the estimate of interest. It indicates the change in the average value of  $y_{it}$  for the treatment stocks in the post period, controlling for changes in the control observations. Standard regression routines provide both the estimated coefficient as well as its standard error and t-statistic. The level of statistical significance can be assessed using the t-statistic.

### Matched Sample Creation

The Data Memorandum calls for four samples of matched pairs to be created and analyzed. In creating these samples, the treatment stocks were drawn from Nasdaq-100 components that were in the index during the entire timeframe of the study—April 2018 through December 2019. Thus, stocks that were added or deleted from the index during the December 2018 rebalance were of necessity excluded from consideration in addition to a small number of stocks not listed during the entire sample period. The universe of control stocks were all US-listed common stocks that were listed during the entire period. Membership in the S&P500 index was determined. The data used for match was drawn from May 2018 for market capitalization, daily dollar volume, and price. The close-to-close return standard deviation was computed with data from December 2017 through May 2018.

The four samples may be briefly described as follows:

**Sample 1** starts with all components of the Nasdaq-100 index, with the universe of candidate control stocks drawn from all other non-components. Many of the control stocks are in the S&P500. This sample results in 94 pairs of stocks. Due to the minimum matching criteria described in the Data Memorandum, the matched pairs sample does not contain all the of 96 Nasdaq-100 components used in the summary data shown above.

**Sample 2** again starts with all components of the Nasdaq-100 index, but the universe of candidate controls excludes components of the S&P500. An advantage of this sample is that the control stocks, not being in one of the large indexes, are less likely to be part of index option settlements on Friday closes. A drawback is that the universe of control stocks excludes the very large market capitalizations characteristic of the top components of the Nasdaq-100, the exceptions being foreign stocks not in the S&P500. This sample has 93 pairs of stocks, as one additional Nasdaq-100 component was unable to be matched, given the minimum matching criteria described in the Data Memorandum.

**Sample 3** starts with Nasdaq-100 components that are not in the S&P500, which number 15 (after excluding the additions and deletions). The candidate control stocks are those stocks in both the Nasdaq-100 and S&P500. This sample, with 14 pairs, includes some control stocks that are in the Nasdaq-100, but tend to be larger.

**Sample 4** likewise starts with the 14 Nasdaq-100 components that are not in the S&P500. The candidate control stocks are drawn from stocks not in the Nasdaq-100 or the S&P500.

These four sample provide a complementary look at the potential impacts of the NQX introduction. The analyses presented below were carried out identically on all four samples.

#### High-Frequency Volatility

A set of high-frequency price volatility measures are computed during the last half-hour of equity trading on expiration Fridays (i.e., from 3:30 – close), and the first half-hour (9:30-10:00) on the following Monday (or Tuesday if Monday was a holiday). Each half-hour is divided into time buckets of 30-seconds, 1 minute, and 5 minutes in duration. For each time bucket the price return is calculated as the logarithmic difference between the prevailing last-sale price at the end of the bucket to that of the start of the bucket. The standard deviation of these returns is computed for each stock on each day. The pre-period and post-period averages of the standard deviations were then computed for each stock. The high/low range for each time bucket is calculated as the difference between the high and low prices divided by the average of the high and low price. The average range was computed for each stock on each day, and then averaged again over the pre- and post-periods for each stock. For both metrics, the final price of the last time bucket was taken as the primary market closing price.

Table 1 below presents results for these high-frequency volatility measures. The results were computed using the regression framework discussed above. The table presents the estimated coefficient of the interaction term ( $\beta_4$ ) which is the estimate of interest. The table also shows the associated t-statistic for the estimated coefficient. The t-statistic allows for determination of the statistical significance of the estimate. In particular, the t-statistic can be used to test the hypothesis that the coefficient is different than zero (i.e. that there was no pilot impact). The

higher the magnitude of the t-statistic the more likely that the hypothesis of no impact can be rejected. The table identifies results that are statistically significant at varying levels using the following notation shown next to the t-statistic as follows: ‘\*’ = 10%, ‘\*\*’ = 5%, ‘\*\*\*’ = 1%.

**Table 1: High-Frequency Volatility**

		Sample							
		1		2		3		4	
Time Bucket	Metric	Coeff	t-stat	Coeff	t-stat	Coeff	t-stat	Coeff	t-stat
Friday Afternoon									
30-sec	Std Dev	-0.0013%	-0.685	-0.0013%	-0.685	-0.0013%	-0.685	-0.0013%	-0.685
1-min	Std Dev	-0.0030%	-1.235	-0.0030%	-1.235	-0.0030%	-1.235	-0.0030%	-1.235
5-min	Std Dev	-0.0078%	-1.585	-0.0078%	-1.585	-0.0078%	-1.585	-0.0078%	-1.585
30-sec	Hi/Lo	-0.0015%	-0.507	-0.0015%	-0.507	-0.0015%	-0.507	-0.0015%	-0.507
1-min	Hi/Lo	-0.0023%	-0.610	-0.0023%	-0.610	-0.0023%	-0.610	-0.0023%	-0.610
5-min	Hi/Lo	-0.0046%	-0.523	-0.0046%	-0.523	-0.0046%	-0.523	-0.0046%	-0.523
Monday Morning									
30-sec	Std Dev	-0.0022%	-0.327	-0.0022%	-0.327	-0.0022%	-0.327	-0.0022%	-0.327
1-min	Std Dev	-0.0027%	-0.310	-0.0027%	-0.310	-0.0027%	-0.310	-0.0027%	-0.310
5-min	Std Dev	-0.0116%	-0.660	-0.0116%	-0.660	-0.0116%	-0.660	-0.0116%	-0.660
30-sec	Hi/Lo	-0.0012%	-0.152	-0.0012%	-0.152	-0.0012%	-0.152	-0.0012%	-0.152
1-min	Hi/Lo	-0.0029%	-0.252	-0.0029%	-0.252	-0.0029%	-0.252	-0.0029%	-0.252
5-min	Hi/Lo	-0.0053%	-0.193	-0.0053%	-0.193	-0.0053%	-0.193	-0.0053%	-0.193

The estimated coefficients are uniformly negative, but in no case can any of the results be deemed statistically significant. The results provide no evidence that introduction of NQX was associated with increases in high-frequency volatility during time periods near contract expiration.

As called for in the Data Memorandum, a second complementary analysis is performed, in this case comparing each treatment stock with its matched-pairs control stock. For *each* treatment/control pair, a regression analysis was performed, but rather than using the pre- and post-period means of the metric in question, data from each expiration date is entered into the regression model. The regression model is similar to what was shown above, but is somewhat simpler:

$$y_{it} = \alpha + \beta_1 D_{Trt} + \beta_3 D_{Prd} + \beta_4 D_{Trt} \times D_{Prd}$$

where  $y_{it}$  represents the metric of interest for stock  $i$  (treatment or control) in time period  $t$ . The time periods refer to each expiration date in the sample. The variable  $D_{Trt}$  as before takes a value of 1 if the stock is a treatment stock, 0 otherwise. The variable  $D_{Prd}$  has a value of 1 if the date is after NQX introduction, 0 otherwise. Again, the estimate of interest is the coefficient  $\beta_4$  on the interaction term. Note that this estimate is often referred to as the ‘difference-in-difference.’

The return standard deviation and high/low range from one-minute time buckets are the metrics of interest. After running the regressions for each sample pair and each metric, cases in which the  $\beta_4$  coefficient was positive (a volatility increase) were noted. A count of these cases was made in which the increase was statistically significant at the 10%, 5%, and 1% levels. The same counts were made for cases with a negative coefficient (volatility decrease). Table 2 below presents these counts. For reference, recall the sizes of the four samples were 94, 93, 14, and 14, respectively.

**Table 2: Pairs-Level Analysis of 1-minute volatility metrics**

Sample	Metric	Date	Number of Increases			Number of Decreases		
			10%	5%	1%	10%	5%	1%
1	Std Dev	Fri	1	0	0	20	15	6
		Mon	9	6	2	14	11	1
	Hi/Lo	Fri	1	1	0	16	9	6
		Mon	8	5	2	16	12	4
2	Std Dev	Fri	3	2	0	14	9	6
		Mon	10	7	1	19	11	4
	Hi/Lo	Fri	3	1	0	17	9	2
		Mon	10	9	5	23	16	9
3	Std Dev	Fri	0	0	0	2	2	1
		Mon	1	0	0	1	1	1
	Hi/Lo	Fri	1	0	0	2	1	0
		Mon	1	1	0	3	2	1
4	Std Dev	Fri	1	0	0	2	2	2
		Mon	0	0	0	3	2	0
	Hi/Lo	Fri	0	0	0	2	1	1
		Mon	0	0	0	4	2	2

Generally the counts of statistically significant increases are small, but in all cases the decreases outnumber the increases. Overall, there is no evidence to suggest that introduction of NQX led to increases in short-horizon volatility during time close to expiration.

#### Low Frequency Volatility

Low-frequency volatility is measured on a daily basis. Daily close-to-close logarithmic returns are the primary input. For each stock, there were 103 pre-period returns, and 250 post-period returns. This section of the analysis compares each treatment stock to its matched-pair control stock, determining whether there was a statistically significant increase in the daily volatility of the treatment stock compared to that of its control. In other words, a difference-in-difference analysis is done on each matched pair. The volatility metric for a given stock/day is the squared value of the close-to-close return. The number of pairs in which the volatility increased is determined, at three different levels of statistical significance: 10%, 5%, and 1%. Likewise, the

number of pairs in which volatility decreased is determined at three levels of statistical significance. Table 3 below provides the results.

**Table 3: No. of Treatment Stocks with Increases/Decreases in Daily Volatility**

Sample	No. Pairs	Number of Increases			Number of Decreases		
		10%	5%	1%	10%	5%	1%
1	96	4	1	0	4	2	1
2	95	5	5	0	7	5	1
3	15	1	0	0	0	0	0
4	15	0	0	0	1	1	0

For each sample, there were only a relatively few number of pairs in which daily volatility increased relative to the control stock. Further, there were more pairs for which volatility decreased. In sum, there is no evidence that the introduction of NQX caused low-frequency volatility to increase.

As specified in the Data Memorandum, the realized volatility, measured using close-to-close return standard deviations, can be compared with values of the Cboe VXN index. The VXN is a *forward-looking* volatility measure that is derived from the observed values of index options based on the Nasdaq-100 index. It is calibrated to reflect the expected volatility of the index during the next 30 calendar days, expressed on an annualized basis. It should be noted that this volatility expectation is largely driven by macro factors impacting the stock market generally, as opposed to micro impacts associated with weekly index option expirations.

The comparison is done as follows. Daily closing value of VXN were obtained for each date in the sample. Daily averages were computed for the pre- and post-periods. For each of the stocks in Sample 1, the standard deviation of daily returns was computed, separately for the pre- and post-periods. To facilitate comparison with the VXN, the standard deviations were annualized by multiplying each by the square root of 252, the number of trading days in a year. Further, the values were multiplied by 100, so as to be expressed in percentages like the VXN.

For the Nasdaq-100 components, overall averages of these standard deviations were computed in two ways: a simple equally-weighted average, and an average weighted by the market capitalization of the stock during the pre-period. (The weighted average is motivated by the fact that the Nasdaq-100 is a market-cap weighted price index.) Finally, an equally-weighted average was computed for the Sample 1 control stocks. Table 4 shows the specified averages, as was as the ratio of the averages from the post-period to the pre-period.

**Table 4: Realized Volatility Compared with VXN**

Nasdaq-100 Components				
Time Period	VXN	Equal Weighted	Mkt Cap Weighted	Controls
Pre	19.4	27.1	24.5	27.0
Post	19.1	30.4	26.4	28.8
Ratio	0.98	1.12	1.08	1.07

The table indicates that the average closing value of the VXN was about the same in both periods. The realized volatility, however, was a bit higher in the post period, both for the Nasdaq 100 components as well as the control stocks.

### Reversals

A central question addressed in this report is whether the closing prices generated by Nasdaq on NQX settlement dates have been adversely impacted. A common way to measure the quality of price discovery at the close is through analysis of price reversals. A closing price reversal involves finding a pre-close price benchmark, the close price itself, and a post-close price benchmark. If, for example, the price of a stock was \$40 at 3:30 p.m. (pre-close), it closed up at \$41, then opened the next day down at \$39, one would say that a reversal had occurred. A reversal can go the other direction: a stock falling in the close, but rebounding the next day.

In a perfectly efficient market, closing price reversals should occur 50% of the time. The other 50% would be the opposite, often termed 'runs.' (An example of a run is a price increase into the close, followed by further increase the following day.) The 50/50 breakdown of reversals and runs is an implication of the 'random-walk' nature of efficient securities pricing.

For each of the four samples, price reversals are measured using four time horizons: 30-seconds, one minute, 5 minutes, and 30 minutes. For each horizon, the pre-close price benchmark is the prevailing last-sale price that amount of time before 4:00 (for example, 3:59 for the one-minute horizon.) The post-close benchmark is the prevailing last sale at the same amount of time after 9:30 (for example, 9:31). For a given horizon, the number of runs and reversals is counted for each stock in both the pre- and post-period. (Days in which there was no change in price either before or after the close were dropped from consideration.) The ratio of reversals to the sum of reversals plus runs was computed. Again, this ratio should be close to 50%. Therefore, the absolute difference between the ratio and 50% is the market quality metric. This metric is then analyzed in a regression framework for each of the samples, in which reversals of the treatment stocks are combined with reversals in the control stocks and reversals in the treatment stock on the day before expiration. As before the interaction of the treatment stock dummy variable and the pre/post dummy variable ( $\beta_4$ ) is the estimate of interest. Given the nature of the metric, a positive coefficient indicates a relative worsening of closing price efficiency relative to the control stocks. A negative coefficient means that the ratio has moved closer to 50%, an improvement in price discovery.

Table 5 presents the estimated coefficient of interest, along with the t-statistics that can be used to establish statistical significance. The level of the coefficients should be interpreted as follows. An estimate, say, of 0.03 means that the average ratio of price reversals moved away from 0.50 by that amount, for example moving from 0.47 pre to 0.44 post, or 0.53 pre to 0.56 post. An estimate, say, of -0.02 means that the average ratio of price reversals moved towards 0.50 by that amount, for example moving from 0.45 to 0.47.

**Table 5: Reversals Analysis**

Horizon	Sample							
	1		2		3		4	
	Coeff	t-stat	Coeff	t-stat	Coeff	t-stat	Coeff	t-stat
30-sec	0.0266	2.203**	0.0117	0.945	0.0111	0.369	0.0318	1.010
1-min	0.0062	0.537	0.0226	1.888*	-0.0263	-0.829	-0.0087	-0.259
5-min	0.0190	1.675*	0.0174	1.566	-0.0400	-1.523	-0.0188	-0.668
30-min	-0.0063	-0.510	-0.0049	-0.370	-0.0050	-0.167	0.0007	0.020

The coefficients are universally small in magnitude and of mixed sign: some positive, some negative. Only three are statistically significant.

Finally, as a complementary approach, analysis was done on the level of individual treatment/control pairs. Data from individual dates was used in the regression. The metric of interest was simply a 0/1 binary variable taking a value of 1 if a reversal occurred, 0 otherwise. This approach then simply looks for increases in reversals, rather than considering whether reversals and runs balance each other. For each pair, the estimated difference-in-difference coefficient was examined to determine whether it represented a statistically significant increase or decrease at three significance levels. Table 6 below provides counts of these outcomes.

**Table 6: Pairs Analysis of Increases in Reversals**

Sample	Horizon	Number of Increases			Number of Decreases		
		10%	5%	1%	10%	5%	1%
1	30-Min	3	1	1	4	1	1
	5-Min	1	0	0	6	1	0
	1-Min	0	0	0	4	3	0
	30-Secs	2	1	0	5	2	0
2	30-Min	6	2	1	3	0	0
	5-Min	0	0	0	4	2	0
	1-Min	2	0	0	3	2	0
	30-Secs	3	2	0	7	3	1
3	30-Min	0	0	0	0	0	0
	5-Min	0	0	0	0	0	0
	1-Min	1	1	0	1	0	0
	30-Secs	0	0	0	0	0	0
4	30-Min	1	0	0	0	0	0
	5-Min	0	0	0	0	0	0
	1-Min	1	0	0	0	0	0
	30-Secs	0	0	0	1	0	0

The number of statistically significant increases in reversals was small, and generally outnumbered by the number of decreases.

Overall, there is a lack of strong, consistent results suggesting that the introduction of NQX has caused a significant deterioration in the quality of the Nasdaq closing price process for Nasdaq-100 components.