**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 to June 2019. 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 |

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 |

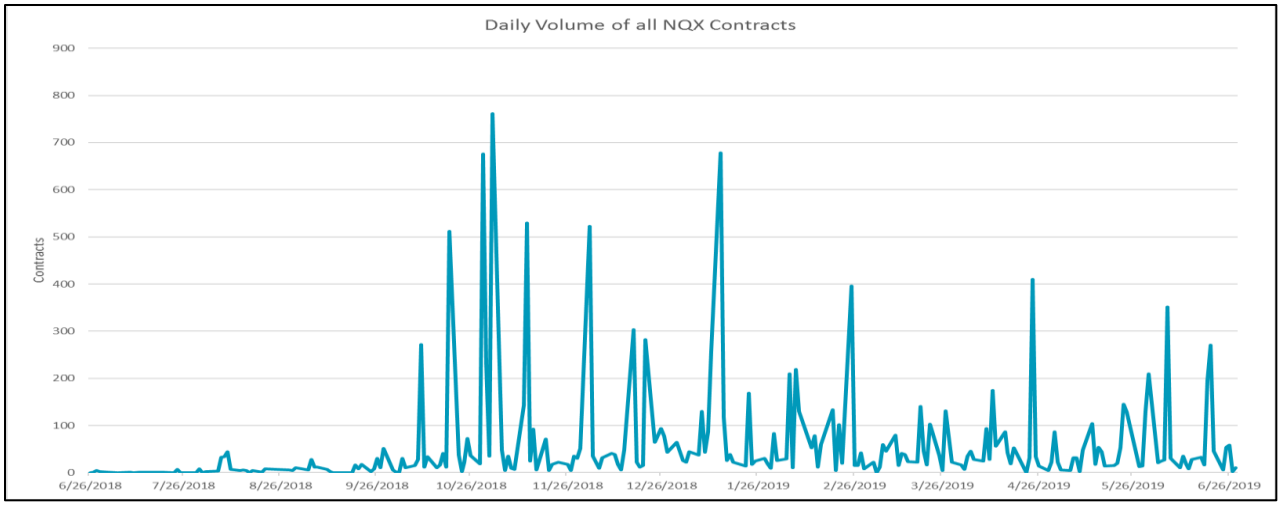
Daily Volume of Nasdaq-100 Components (millions of shares)

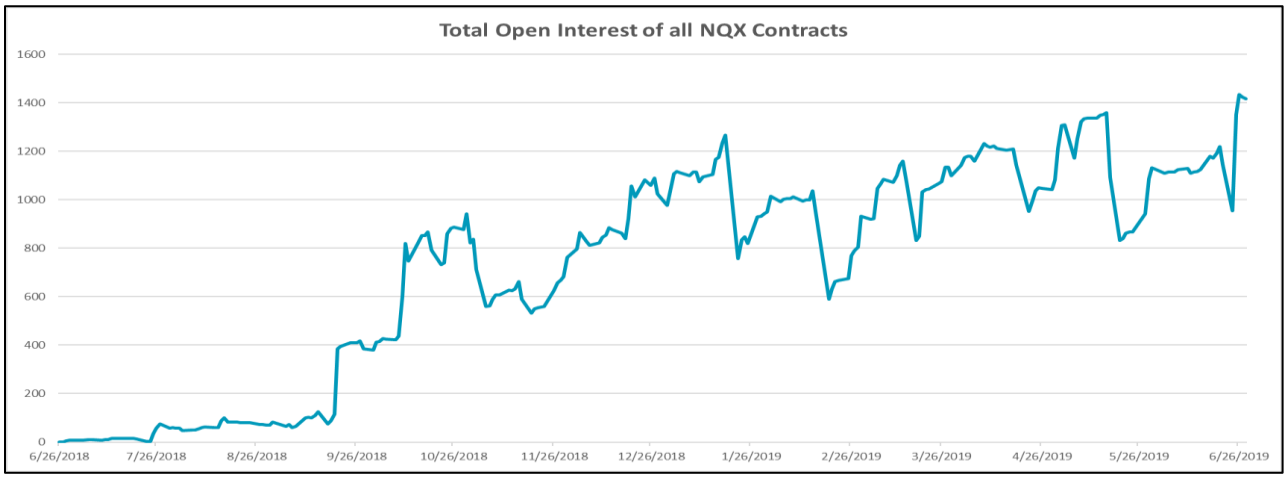
| Month | Days | Mean | Std. Dev. | Min. | Median | Max. |
|---|---|---|---|---|---|---|
| Jun-18 | 4 | 2,297 | 67 | 2,208 | 2,306 | 2,367 |
| Jul-18 | 21 | 1,999 | 325 | 1,185 | 1,906 | 2,629 |
| Aug-18 | 23 | 1,888 | 177 | 1,629 | 1,870 | 2,268 |
| Sep-18 | 19 | 2,195 | 458 | 1,843 | 2,106 | 3,978 |
| 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 |

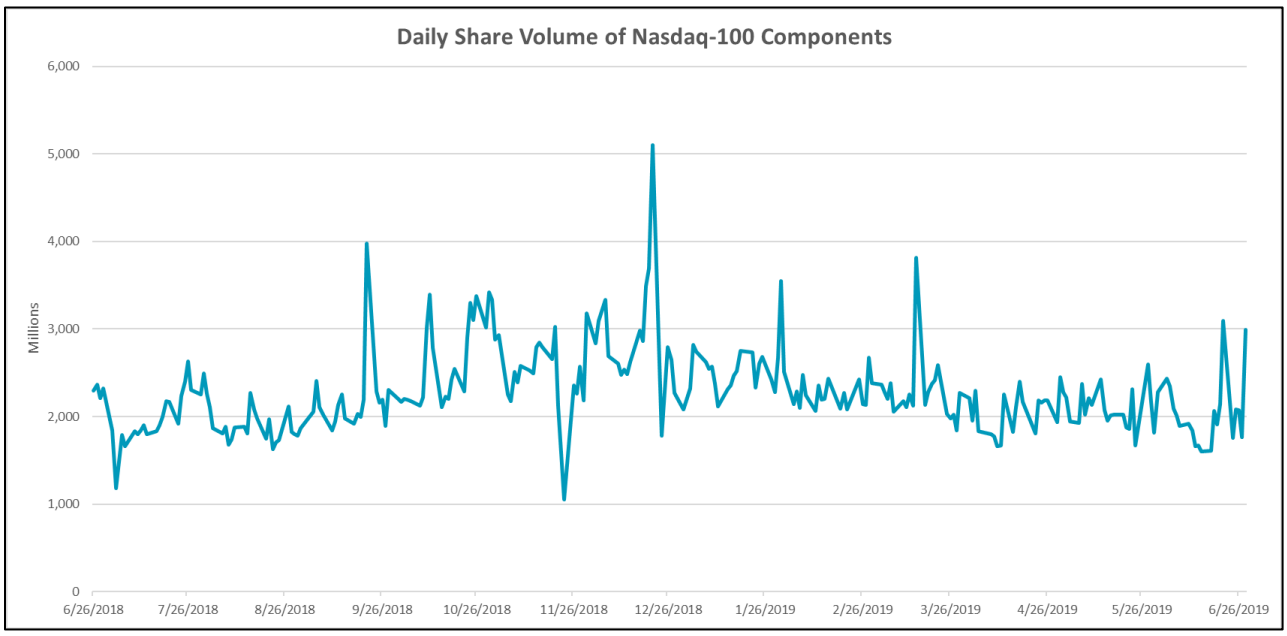
Daily VXN Close

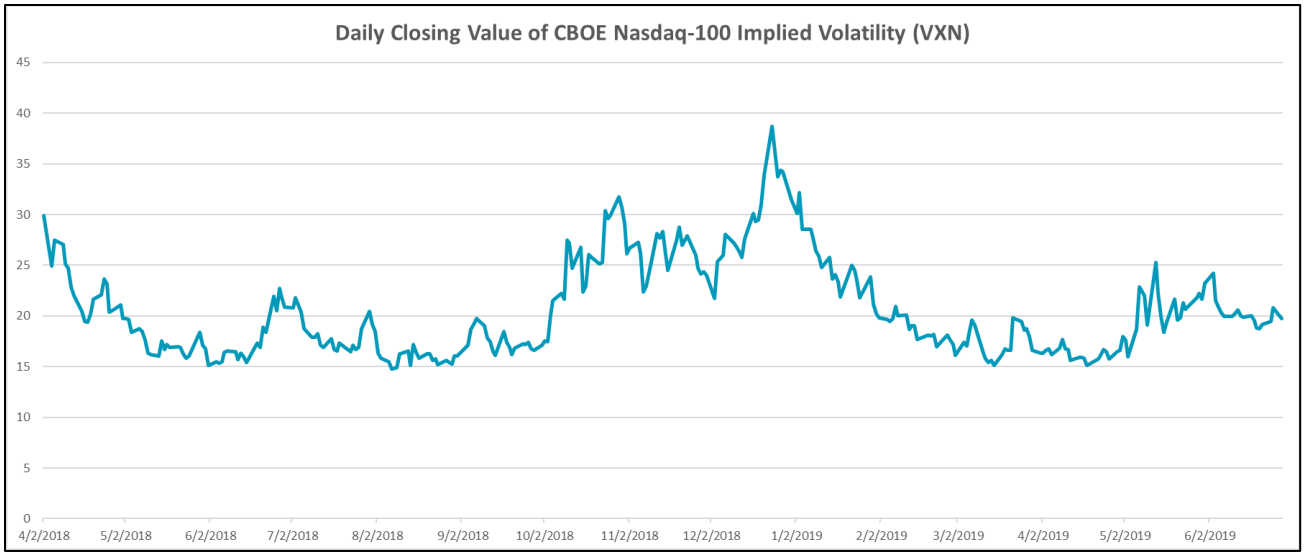
| Month | Days | Mean | Std. Dev. | Min. | Median | Max. |
|---|---|---|---|---|---|---|
| Apr-18 | 21 | 23.4 | 3.1 | 19.4 | 22.9 | 29.9 |
| May-18 | 22 | 17.4 | 1.2 | 15.8 | 17.0 | 19.8 |
| Jun-18 | 21 | 17.6 | 2.5 | 15.1 | 16.5 | 22.7 |
| Jul-18 | 21 | 18.1 | 1.6 | 16.5 | 17.7 | 21.8 |
| Aug-18 | 23 | 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 |

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


Daily Volume of all NQX Contracts
Contracts
900
800
700
600
500
400
300
200
100
0
6/26/2018
7/26/2018
8/26/2018
9/26/2018
10/26/2018
11/26/2018
12/26/2018
1/26/2019
2/26/2019
3/26/2019
4/26/2019
5/26/2019
6/26/2019


Total Open Interest of all NQX Contracts
1600
1400
1200
1000
800
600
400
200
0
6/26/2018
7/26/2018
8/26/2018
9/26/2018
10/26/2018
11/26/2018
12/26/2018
1/26/2019
2/26/2019
3/26/2019
4/26/2019
5/26/2019
6/26/2019


Daily Share Volume of Nasdaq-100 Components
Millions
6,000
5,000
4,000
3,000
2,000
1,000
0
6/26/2018
7/26/2018
8/26/2018
9/26/2018
10/26/2018
11/26/2018
12/26/2018
1/26/2019
2/26/2019
3/26/2019
4/26/2019
5/26/2019
6/26/2019




**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

| | 30-Second | | | 1-Minute | | |
|---|---|---|---|---|---|---|
| Month | 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 |
| **Total** | **2749** | **479** | **2916** | **2851** | **365** | **2928** |

| | 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 |
| **Total** | **2906** | **201** | **3037** | **2973** | **114** | **3057** |

**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 |

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 |

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 |

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 |

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 |

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 |

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 |

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 |

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 |

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 |

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 |

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 |

*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 July 2018 to the start of July 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:

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

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, $D_{Cntrl}$ 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 June 2019. Thus, stocks that were added or deleted from the index during the December 2018 rebalance were excluded from consideration. 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 96 pairs of stocks.

**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 95 pairs of stocks, as one 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 15 pairs, includes some control stocks that are in the Nasdaq-100, but tend to be larger.

**Sample 4** likewise starts with the 15 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 | -0.0002% | -0.107 | 0.0001% | 0.027 | -0.0016% | -0.321 | -0.0027% | -0.465 |
| 1-min | Std Dev | -0.0016% | -0.681 | -0.0009% | -0.322 | -0.0037% | -0.600 | -0.0050% | -0.728 |
| 5-min | Std Dev | -0.0008% | -0.182 | 0.0005% | 0.097 | -0.0079% | -0.657 | -0.0141% | -1.105 |
| 30-sec | Hi/Lo | -0.0006% | -0.220 | 0.0002% | 0.052 | 0.0006% | 0.060 | -0.0015% | -0.118 |
| 1-min | Hi/Lo | -0.0010% | -0.280 | 0.0004% | 0.101 | 0.0006% | 0.051 | -0.0021% | -0.156 |
| 5-min | Hi/Lo | -0.0024% | -0.284 | 0.0042% | 0.451 | -0.0006% | -0.033 | -0.0081% | -0.377 |
| Monday Morning | | | | | | | | | |
| 30-sec | Std Dev | -0.0014% | -0.225 | -0.0038% | -0.479 | 0.0069% | 0.422 | -0.0023% | -0.121 |
| 1-min | Std Dev | -0.0013% | -0.152 | -0.0048% | -0.460 | 0.0056% | 0.254 | -0.0044% | -0.171 |
| 5-min | Std Dev | -0.0022% | -0.125 | -0.0070% | -0.351 | 0.0098% | 0.214 | -0.0268% | -0.509 |
| 30-sec | Hi/Lo | 0.0015% | 0.190 | 0.0012% | 0.132 | 0.0057% | 0.247 | -0.0032% | -0.128 |
| 1-min | Hi/Lo | 0.0013% | 0.116 | 0.0005% | 0.035 | 0.0062% | 0.192 | -0.0083% | -0.235 |
| 5-min | Hi/Lo | 0.0079% | 0.298 | 0.0059% | 0.188 | 0.0162% | 0.225 | -0.0147% | -0.181 |

The estimated coefficients are of mixed sign, roughly evenly divided between positive and negative values. In no case can any of the results be deemed statistically significant. In other words, 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 96, 95, 15, and 15, respectively.

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

| | | | Number of Increases | | | Number of Decreases | | |
|---|---|---|---|---|---|---|---|---|
| Sample | Metric | Date | 10% | 5% | 1% | 10% | 5% | 1% |
| 1 | Std Dev | Fri | 0 | 0 | 0 | 4 | 0 | 0 |
| | | Mon | 6 | 3 | 2 | 9 | 7 | 1 |
| | Hi/Lo | Fri | 0 | 0 | 0 | 3 | 0 | 0 |
| | | Mon | 8 | 3 | 0 | 11 | 3 | 1 |
| 2 | Std Dev | Fri | 0 | 0 | 0 | 4 | 1 | 0 |
| | | Mon | 6 | 4 | 1 | 17 | 10 | 2 |
| | Hi/Lo | Fri | 0 | 0 | 0 | 1 | 0 | 0 |
| | | Mon | 13 | 2 | 1 | 16 | 10 | 7 |
| 3 | Std Dev | Fri | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Mon | 2 | 2 | 1 | 0 | 0 | 0 |
| | Hi/Lo | Fri | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Mon | 2 | 1 | 0 | 0 | 0 | 0 |
| 4 | Std Dev | Fri | 0 | 0 | 0 | 2 | 1 | 0 |
| | | Mon | 0 | 0 | 0 | 2 | 0 | 0 |
| | Hi/Lo | Fri | 0 | 0 | 0 | 1 | 0 | 0 |
| | | Mon | 0 | 0 | 0 | 3 | 3 | 0 |

Generally the counts of statistically significant increases are small, and in most 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 212 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**

| | | Number of Increases | | | Number of Decreases | | |
|---|---|---|---|---|---|---|---|
| Sample | No. Pairs | 10% | 5% | 1% | 10% | 5% | 1% |
| 1 | 96 | 9 | 6 | 1 | 18 | 14 | 5 |
| 2 | 95 | 8 | 7 | 3 | 14 | 11 | 6 |
| 3 | 15 | 0 | 0 | 0 | 1 | 1 | 1 |
| 4 | 15 | 2 | 1 | 1 | 2 | 1 | 1 |

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**

| Nq-100 Components | | | | |
|---|---|---|---|---|
| Time Period | VXN | Equal Wghtd | Mkt Cap Wghted | Controls |
| Pre | 24.9 | 38.0 | 38.5 | 36.1 |
| Post | 18.4 | 28.8 | 25.6 | 26.4 |
| Ratio | 0.74 | 0.76 | 0.67 | 0.73 |

The table clearly indicates that both realized and expected volatility were much lower in the post-period. This is true for both 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**

| Sample | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | | 2 | | 3 | | 4 | |
| Horizon | Coeff | t-stat | Coeff | t-stat | Coeff | t-stat | Coeff | t-stat |
| 30-sec | 0.0217 | 1.799* | 0.0123 | 0.995 | -0.0093 | -0.315 | 0.0116 | 0.365 |
| 1-min | -0.0066 | -0.592 | 0.0064 | 0.571 | -0.0252 | -0.821 | -0.0077 | -0.235 |
| 5-min | 0.0255 | 2.254** | 0.0261 | 2.386** | -0.0680 | -2.471** | -0.0410 | -1.479 |
| 30-min | -0.0021 | -0.166 | 0.0031 | 0.233 | -0.0064 | -0.219 | 0.0053 | 0.162 |

The coefficients are universally small in magnitude and of mixed sign: some positive, some negative. Only three are statistically significant, all based on a 5-minute time horizon. Of these two are positive and one is negative.

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**

| | | Number of Increases | | | Number of Decreases | | |
|---|---|---|---|---|---|---|---|
| Sample | Horizon | 10% | 5% | 1% | 10% | 5% | 1% |
| 1 | 30-Min | 7 | 1 | 0 | 3 | 1 | 1 |
| | 5-Min | 1 | 0 | 0 | 5 | 3 | 0 |
| | 1-Min | 0 | 0 | 0 | 10 | 6 | 0 |
| | 30-Secs | 2 | 1 | 0 | 6 | 4 | 1 |
| 2 | 30-Min | 10 | 5 | 0 | 1 | 0 | 0 |
| | 5-Min | 0 | 0 | 0 | 4 | 2 | 0 |
| | 1-Min | 2 | 1 | 0 | 8 | 4 | 0 |
| | 30-Secs | 3 | 1 | 0 | 7 | 4 | 1 |
| 3 | 30-Min | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5-Min | 0 | 0 | 0 | 0 | 0 | 0 |
| | 1-Min | 0 | 0 | 0 | 0 | 0 | 0 |
| | 30-Secs | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 30-Min | 1 | 1 | 0 | 0 | 0 | 0 |
| | 5-Min | 0 | 0 | 0 | 1 | 1 | 0 |
| | 1-Min | 0 | 0 | 0 | 2 | 1 | 0 |
| | 30-Secs | 0 | 0 | 0 | 1 | 1 | 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 deterioration in the quality of the Nasdaq closing price process for Nasdaq-100 components.