

## A. Internet Appendix

### Appendix A - List of TAQ Reporting Facilities

TABLE A1

#### Market Centers in TAQ

The table displays the market centers contained in the NYSE TAQ database. The list is from the “Daily TAQ Client Specification” document version 2.0, dated July 28, 2014.

<b>Code</b>	<b>Description</b>
A	NYSE MKT Stock Exchange
B	NASDAQ OMX BX Stock Exchange
C	National Stock Exchange
D	FINRA
I	International Securities Exchange
J	Direct Edge A Stock Exchange
K	Direct Edge X Stock Exchange
M	Chicago Stock Exchange
N	New York Stock Exchange
P	NYSE Arca SM
S	Consolidated Tape System
T	NASDAQ Stock Exchange
W	CBOE Stock Exchange
X	NASDAQ OMX PSX Stock Exchange
Y	BATS Y-Exchange
Z	BATS Exchange

## B. Appendix B - OLS Panel: Additional Results

TABLE B1

### Calculating the Total Effects of Fragmentation

The table displays results from a post-estimation linear combination for the total effects of fragmentation for quintiles 1, 2, 4, and 5. We examine results from the panel regression in Table 5 which takes the form:

$$y_{i,t+1} = \alpha + \beta \text{Fragmentation}_{i,t} + \sum_{k \neq 3} \delta_k \text{Size}_k + \sum_{k \neq 3} \theta_k (\text{Fragmentation} \times \text{Size}_k) + FE_i + FE_t + \text{Controls}_{i,t} + \varepsilon_{i,t+1},$$

where  $y_{i,t+1}$  is either the *Volume Turnover*, *Average Trade Size*, *Effective Spread*, or *Variance Ratio*. *Quintile* is an indicator variable which equals 1 when a firm is in that size quintile, and zero otherwise, where quintile 5 is the largest firms. The sample for this analysis is daily firm-level TAQ variables from 2003-2016. Control variables are discussed in Section IV of the text, and we include firm and day fixed effects. Firms are sorted into market capitalization quintiles on day  $t - 1$ . All dependent variables are log-transformed to address skewness. Standard errors are clustered by firm and date. To calculate the total effect of fragmentation against the null hypothesis that the total effect is zero, we test the linear combination of *Fragmentation* (the average effect for the omitted category) plus the relative effect of fragmentation for each quintile. \*\*\*, \*\*, \* indicates significance at the 1%, 5%, and 10% levels.

Quintile	Turnover	Avg. Trade Size	Eff. Spread	Var. Ratio
1	0.15***	0.01	0.07***	0.11***
2	0.18***	-0.28***	-0.15***	0.04***
4	0.29***	-0.58***	0.05***	-0.60***
5	0.35***	-1.02***	0.07**	-0.29***

TABLE B2

**Panel Regression of Pick-off Risk and Fragmentation**

The table displays results from an OLS panel regression of the form:

$$y_{i,t+1} = \alpha + \beta \text{Frag}_{i,t} + \delta \times \text{Volatility}_{i,t} + \theta \text{Frag} \times \text{Volatility}_{i,t} + \text{Controls}_{i,t} + \varepsilon_{i,t+1}$$

where  $y_{i,t+1}$  is either the *Volume Turnover*, *Average Trade Size*, *Effective Spread*, or *Variance Ratio*. *Quintile* is an indicator variable which equals 1 when a firm is in that size quintile, and zero otherwise, where quintile 5 is the largest firms. The sample for this analysis is daily firm-level TAQ variables from 2003-2016. Control variables are discussed in Section IV of the text, and we include firm and day fixed effects. Yamamoto (2014) finds pick-off risk is positively related to volatility, so we proxy for potential pick-off risk by using trade-based intraday volatility - taken from WRDS DTAQ IID. Intraday volatility is interacted with fragmentation and  $\theta$  is the main variable of interest. Firms are sorted into market capitalization quintiles on day  $t - 1$ . All dependent variables are log-transformed to address skewness. Standard errors, clustered by firm and date, are shown below the estimates. \*\*\*, \*\*, \* indicates significance at the 1%, 5%, and 10% levels.

Explanatory Variables	Dependent Variable =			
	Turnover 1	Avg. Trade Size 2	Eff. Spread 3	Var. Ratio 4
Fragmentation	0.257*** (0.007)	-0.523*** (0.011)	0.053*** (0.014)	-0.209*** (0.012)
Fragmentation $\times$ Volatility	-145.287*** (8.580)	382.168*** (12.654)	163.420*** (17.204)	223.657*** (11.859)
Quintile 1	-0.152*** (0.008)	0.009 (0.010)	0.568*** (0.018)	0.143*** (0.010)
Quintile 2	-0.097*** (0.005)	-0.014*** (0.005)	0.270*** (0.010)	0.152*** (0.006)
Quintile 4	0.064*** (0.006)	0.111*** (0.005)	-0.188*** (0.010)	-0.281*** (0.008)
Quintile 5	0.048*** (0.009)	0.242*** (0.009)	-0.353*** (0.017)	-0.508*** (0.014)
Return Volatility	-33.369*** (3.895)	-216.228*** (6.952)	244.623*** (8.578)	-126.952*** (5.713)
Leverage	4.726*** (0.130)	-0.026 (0.047)	5.985*** (0.186)	0.763*** (0.061)
Market-to-Book	0.114*** (0.018)	-0.078*** (0.020)	0.053* (0.032)	-0.061** (0.025)
Inverse Price	0.005 (0.003)	0.043*** (0.003)	0.033*** (0.005)	0.007** (0.003)
Intraday Volatility	-0.049*** (0.004)	0.346*** (0.005)	0.336*** (0.010)	0.075*** (0.005)
Volume Turnover		0.076*** (0.002)	-0.333*** (0.005)	-0.238*** (0.004)
Firm FE	YES	YES	YES	YES
Day FE	YES	YES	YES	YES
Observations	11,242,933	11,238,100	11,212,516	11,184,130
R <sup>2</sup>	0.525	0.607	0.882	0.517

## C. Appendix C - Instrumental Variables Approach

To round out our portfolio of empirical analyses and provide additional robustness to the results in the paper, we use the log of the number of market centers in the U.S. as an instrument to shock firm-level fragmentation. To do so, we use SEC data to compute the number of active market centers in the U.S. at each point in time. In response to a Freedom of Information Act request, the SEC released a series of reports with the names of active market centers and the dates on which they became active or inactive. We compile these reports to count the total number of venues available for equity trading every day. This number includes exchanges, electronic communication networks, and alternative trading systems.<sup>21</sup>

Specifically, we examine two-stage least squares regressions (2SLS) of the form:

$$Fragmentation_{i,t} = \phi + \eta(\# \text{ Markets})_t + Controls_{i,t} + \nu_{i,t}$$

$$y_{i,t+1} = \alpha + \beta \widehat{Fragmentation}_{i,t} + Controls_{i,t} + \varepsilon_{i,t+1},$$

where  $y_{i,t+1}$  is either a measure of trading volume turnover, average trade size, liquidity, or price efficiency for asset  $i$  on day  $t + 1$  and  $Controls$  include the same variables as in the panel regressions.

The first stage regression uses time-series variation in the log of the total number of U.S.

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<sup>21</sup>We remove trading venues which are clearly non-equity trading venues (i.e., those which reference bonds, fixed income, options, etc., in their name). We do not differentiate between fragmentation across dark pools and “lit” markets. While this is an important issue, we focus on total fragmentation. See Kwan et al. (2015), among others, for a more complete discussion of the effects of light versus dark venue trading.

market centers ( $\# Markets$ ) to predict fragmentation in each asset, while the second stage regression uses the fitted value of fragmentation as the key variable of interest.<sup>22</sup> In addition, we include firm and year fixed effects. Since our instrument is captured using time series variation, year fixed effects are discrete enough to take a general time trend out of the outcome variables while still allowing the instrument to create sufficient variation in fragmentation.

Motivated by the theoretical predictions, we then test for heterogeneous impacts from fragmentation using size quintiles. Specifically, we augment the 2SLS model to include size quintiles, and interactions between the size quintiles and the fitted value of fragmentation according to the model:<sup>23</sup>

(5)

$$\text{Fragmentation}_{i,t} = \phi + \eta(\# Markets_t) + \sum_{k \neq 3} \gamma_k \text{Size}_k + \sum_{k \neq 3} \mu_k (\# Markets_t \times \text{Size}_k) + \text{Controls}_{i,t} + \nu_{i,t}$$

$$(6) \quad y_{i,t+1} = \alpha + \beta \widehat{\text{Fragmentation}}_{i,t} + \sum_{k \neq 3} \delta_k \text{Size}_k + \sum_{k \neq 3} \theta_k (\widehat{\text{Frag}} \times \widehat{\text{Size}}_k) + \text{Controls}_{i,t} + \varepsilon_{i,t+1}$$

Formally, there are two requirements for a variable to be a valid instrument in a two-stage least squares regression: (1) the relevance condition and (2) the exclusion restriction. First, our instrument, the log of the total number of U.S. market centers, must be sufficiently correlated with

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<sup>22</sup>Using an augmented Dickey-Fuller test, we strongly reject the null of a unit root for our instrument. In other words, the log of the total number of U.S. market centers is stationary. The natural log transform also lends a natural interpretation in this setting in that it implies a decreasing marginal impact from each new market center.

<sup>23</sup>We instrument the interaction of fragmentation and size quintile by the interaction of the log of market centers and size quintile as discussed in Wooldridge (2010). Hence, the interactions and the unconditional instrument results in five first stage regressions to achieve the predicted values.

firm-level fragmentation. Second, the exclusion restriction requires the number of market centers to be uncorrelated with the true error of the endogenous data generating process. Simply put, the number of market centers must be correlated with fragmentation at the firm level, but must only affect the outcome variables through fragmentation. The assumption here requires that trading locations do not open or close because of the characteristics of individual assets. While the exclusion restriction is inherently untestable, the relevance condition is testable: accordingly, we examine the first-stage regression to test the relevance assumption for our instrument. As expected, the number of trading venues has a strong positive relation with the level of fragmentation and thus, we easily reject the null of a weak instrument.

TABLE C1

**First Stage Estimates from 2SLS Regressions**

We use the log of the total number of market centers in the U.S. at each point in time as an instrument according to the two-stage least squares model:

$$\text{Fragmentation}_{i,t} = \phi + \eta(\# \text{ Markets}_t) + \sum_{k \neq 3} \gamma_k \text{Size}_k + \sum_{k \neq 3} \mu_k (\# \text{ Markets}_t \times \text{Size}_k) + \text{Controls}_{i,t} + \nu_{i,t}$$

$$y_{i,t+1} = \alpha + \beta \widehat{\text{Fragmentation}}_{i,t} + \sum_{k \neq 3} \delta_k \text{Size}_k + \sum_{k \neq 3} \theta_k (\widehat{\text{Frag}} \times \text{Size}_k) + \text{Controls}_{i,t} + \varepsilon_{i,t+1},$$

The sample for this analysis contains daily firm-level variables from 2003-2016. Models (1) and (2) show first-stage regressions for the unconditional effect with and without controls, respectively. Models (3) and (4) repeat the process for the differential effects first-stage regressions. Control variables are discussed in Section IV of the text, and we include firm and year fixed effects as indicated at the bottom of the table. F-statistics associated with each regression are included at the bottom of the table. Standard errors, clustered by firm and date, are shown below the estimates. \*\*\*, \*\*, \* indicates significance at the 1%, 5%, and 10% levels.

Dependent Variable=	Fragmentation			
	1	2	3	4
Log(Market Centers)	0.032*** (0.003)	0.036*** (0.003)	0.037*** (0.003)	0.038*** (0.003)
Quintile 1		-0.037*** (0.003)	0.232*** (0.015)	0.213*** (0.015)
Quintile 2		-0.008*** (0.002)	0.095*** (0.011)	0.081*** (0.011)
Quintile 4		-0.016*** (0.002)	-0.113*** (0.011)	-0.107*** (0.012)
Quintile 5		-0.020*** (0.004)	-0.199*** (0.015)	-0.192*** (0.015)
Volume Turnover		0.037*** (0.001)		0.033*** (0.001)
Return Volatility		-0.247*** (0.020)		-0.206*** (0.019)
Leverage		0.050*** (0.008)		0.036*** (0.008)
Market-to-Book		-0.003*** (0.001)		0.000 (0.001)
Inverse Price		-0.004** (0.002)		-0.000 (0.001)
Log(Mkt Centers) × Quintile 1			-0.073*** (0.004)	-0.064*** (0.004)
Log(Mkt Centers) × Quintile 2			-0.029*** (0.002)	-0.023*** (0.003)
Log(Mkt Centers) × Quintile 4			0.026*** (0.003)	0.023*** (0.003)
Log(Mkt Centers) × Quintile 5			0.047*** (0.003)	0.043*** (0.004)
F-Stat	125.97	146.20	146.98	114.42
Firm FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Observations	18,329,434	16,807,472	18,329,434	16,807,472
R <sup>2</sup>	0.752	0.761	0.759	0.765

TABLE C2

**Second Stage Estimates from 2SLS Regression of Trading and Market Quality**

We use the log of the total number of market centers in the U.S. at each point in time as an instrument according to the two-stage least squares model:

$$\text{Fragmentation}_{i,t} = \phi + \eta(\# \text{ Markets}_t) + \text{Controls}_{i,t} + \nu_{i,t}$$

$$y_{i,t+1} = \alpha + \beta \widehat{\text{Fragmentation}}_{i,t} + \text{Controls}_{i,t} + \varepsilon_{i,t+1},$$

where  $y_{i,t+1}$  is either the *Volume Turnover*, *Average Trade Size*, *Effective Spread*, or *Variance Ratio*. *Quintile* is an indicator variable which equals 1 when a firm is in that size quintile, and zero otherwise, where quintile 5 is the largest firms. The sample for this analysis contains daily firm-level variables from 2003-2016. Control variables are discussed in Section IV of the text, and we include firm and year fixed effects. Firms are sorted into market capitalization quintiles on day  $t - 1$ . All dependent variables are log-transformed to address skewness. Standard errors, clustered by firm and date, are shown below the estimates. \*\*\*, \*\*, \* indicates significance at the 1%, 5%, and 10% levels.

Dep. Variable=	Turnover 1	Turnover 2	Avg. Trade Size 3	Avg. Trade Size 4	Eff. Spread 5	Eff. Spread 6	Var. Ratio 7	Var. Ratio 8
Fragmentation	-0.090 (0.186)	-0.391** (0.197)	-1.001*** (0.078)	-1.163*** (0.078)	0.305* (0.182)	-0.116 (0.097)	-0.211** (0.105)	-0.176* (0.103)
Quintile 1		-0.657*** (0.032)		0.012 (0.010)		0.509*** (0.019)		0.169*** (0.010)
Quintile 2		-0.362*** (0.018)		-0.003 (0.005)		0.238*** (0.010)		0.164*** (0.006)
Quintile 4		0.107*** (0.017)		0.083*** (0.005)		-0.157*** (0.011)		-0.293*** (0.009)
Quintile 5		0.019 (0.029)		0.205*** (0.009)		-0.293*** (0.018)		-0.534*** (0.014)
Return Volatility		10.710*** (0.327)		-0.661*** (0.057)		7.822*** (0.214)		0.176*** (0.066)
Leverage		0.186*** (0.067)		-0.096*** (0.020)		0.055 (0.034)		-0.063*** (0.024)
Market-to-Book		0.022** (0.010)		0.052*** (0.003)		0.020*** (0.005)		0.013*** (0.003)
Inverse Price		-0.230*** (0.015)		0.326*** (0.005)		0.359*** (0.010)		0.065*** (0.005)
Volume Turnover				0.117*** (0.005)		-0.352*** (0.007)		-0.231*** (0.006)
Firm FE	YES	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES	YES
Observations	12,612,253	11,513,838	12,612,253	11,513,838	12,561,452	11,467,927	12,515,205	11,428,430
R <sup>2</sup>	0.488	0.516	0.505	0.550	0.798	0.873	0.481	0.511



TABLE C3

### Second Stage Estimates from 2SLS Regression of the Differential Effects of Fragmentation

We use the log of the total number of market centers in the U.S. at each point in time as an instrument according to the two-stage least squares model:

$$\text{Fragmentation}_{i,t} = \phi + \eta(\# \text{ Markets}_t) + \sum_{k \neq 3} \gamma_k \text{Size}_k + \sum_{k \neq 3} \mu_k (\# \text{ Markets}_t \times \text{Size}_k) + \text{Controls}_{i,t} + \nu_{i,t}$$

$$y_{i,t+1} = \alpha + \beta \widehat{\text{Fragmentation}}_{i,t} + \sum_{k \neq 3} \delta_k \text{Size}_k + \sum_{k \neq 3} \theta_k (\widehat{\text{Frag}} \times \text{Size}_k) + \text{Controls}_{i,t} + \varepsilon_{i,t+1},$$

where  $y_{i,t+1}$  is either the *Volume Turnover*, *Average Trade Size*, *Effective Spread*, or *Variance Ratio*. *Quintile* is an indicator variable which equals 1 when a firm is in that size quintile, and zero otherwise, where quintile 5 is the largest firms. The sample for this analysis contains daily firm-level variables from 2003-2016. Control variables are discussed in Section IV of the text, and we include firm and year fixed effects. Firms are sorted into market capitalization quintiles on day  $t - 1$ . All dependent variables are log-transformed to address skewness. Standard errors, clustered by firm and date, are shown below the estimates. \*\*\*, \*\*, \* indicates significance at the 1%, 5%, and 10% levels.

Dep. Variable=	Turnover 1	Turnover 2	Avg. Trade Size 3	Avg. Trade Size 4	Eff. Spread 5	Eff. Spread 6	Var. Ratio 7	Var. Ratio 8
Fragmentation	-0.212*** (0.070)	-0.342*** (0.077)	-0.895*** (0.090)	-1.065*** (0.091)	0.013 (0.218)	-0.551*** (0.124)	-0.174 (0.125)	-0.189 (0.122)
Frag × Quintile 1	-0.172*** (0.039)	-0.220*** (0.040)	0.648*** (0.075)	0.273*** (0.065)	2.187*** (0.112)	1.301*** (0.088)	0.731*** (0.053)	0.529*** (0.046)
Frag × Quintile 2	-0.107*** (0.028)	-0.093*** (0.028)	0.300*** (0.046)	0.106*** (0.038)	0.794*** (0.080)	0.484*** (0.070)	0.463*** (0.045)	0.401*** (0.039)
Frag × Quintile 4	0.173*** (0.031)	0.169*** (0.032)	-0.248*** (0.042)	-0.078** (0.037)	-0.180** (0.081)	0.244*** (0.064)	-0.524*** (0.057)	-0.454*** (0.051)
Frag × Quintile 5	0.290*** (0.038)	0.293*** (0.040)	-0.711*** (0.054)	-0.493*** (0.050)	-0.275** (0.109)	0.392*** (0.081)	-0.267*** (0.071)	-0.108 (0.067)
Quintile 1	-0.118*** (0.021)	-0.070*** (0.021)	0.100** (0.041)	-0.090** (0.036)	0.241*** (0.060)	-0.173*** (0.051)	0.002 (0.029)	-0.083*** (0.026)
Quintile 2	-0.067*** (0.016)	-0.052*** (0.016)	0.005 (0.028)	-0.048** (0.023)	0.173*** (0.046)	-0.054 (0.043)	0.008 (0.026)	-0.058** (0.023)
Quintile 4	-0.025 (0.019)	-0.048** (0.020)	0.064** (0.027)	0.117*** (0.024)	-0.374*** (0.051)	-0.305*** (0.042)	-0.035 (0.036)	-0.011 (0.034)
Quintile 5	-0.096*** (0.025)	-0.148*** (0.027)	0.300*** (0.036)	0.500*** (0.033)	-0.726*** (0.071)	-0.535*** (0.054)	-0.464*** (0.047)	-0.466*** (0.046)
Return Volatility		4.315*** (0.123)		-0.692*** (0.056)		7.786*** (0.215)		0.151** (0.065)
Leverage		0.086*** (0.020)		-0.078*** (0.019)		0.067** (0.034)		-0.046* (0.024)
Market-to-Book		0.016*** (0.003)		0.052*** (0.003)		0.019*** (0.005)		0.013*** (0.003)
Inverse Price		-0.063*** (0.004)		0.311*** (0.005)		0.348*** (0.010)		0.051*** (0.005)
Volume Turnover				0.118*** (0.005)		-0.356*** (0.007)		-0.234*** (0.006)
Firm FE	YES	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES	YES
Observations	13,632,509	12,463,452	12,612,253	11,513,838	12,561,452	11,467,927	12,515,205	11,428,430
R <sup>2</sup>	0.435	0.466	0.540	0.564	0.822	0.871	0.498	0.513

TABLE C4

**Second Stage Estimates from 2SLS Regression of Pick-off Risk Interaction**

We use the log of the total number of market centers in the U.S. at each point in time as an instrument according to the two-stage least squares model:

$$\text{Fragmentation}_{i,t} = \phi + \eta(\# \text{ Markets}_t) + \gamma \times \text{Volatility}_{i,t} + \text{Controls}_{i,t} + \nu_{i,t}$$

$$y_{i,t+1} = \alpha + \beta \widehat{\text{Frag}}_{i,t} + \delta \times \text{Volatility}_{i,t} + \theta \widehat{\text{Frag}} \times \text{Volatility}_{i,t} + \text{Controls}_{i,t} + \varepsilon_{i,t+1}$$

where  $y_{i,t+1}$  is either the *Volume Turnover*, *Average Trade Size*, *Effective Spread*, or *Variance Ratio*. *Quintile* is an indicator variable which equals 1 when a firm is in that size quintile, and zero otherwise, where quintile 5 is the largest firms. The sample for this analysis contains daily firm-level variables from 2003-2016. Control variables are discussed in Section IV of the text, and we include firm and year fixed effects. Yamamoto (2014) finds pick-off risk is positively related to volatility, so we proxy for potential pick-off risk by using trade-based intraday volatility - taken from WRDS DTAQ IID. Intraday volatility is interacted with fragmentation in the first stage and we use the log of the number of market centers  $\times$  return volatility as an additional instrument. Firms are sorted into market capitalization quintiles on day  $t - 1$ . All dependent variables are log-transformed to address skewness. Standard errors, clustered by firm and date, are shown below the estimates. \*\*\*, \*\*, \* indicates significance at the 1%, 5%, and 10% levels.

<b>Dep. Variable=</b>	<b>Turnover</b>	<b>Avg. Trade Size</b>	<b>Eff. Spread</b>	<b>Var. Ratio</b>
	1	2	3	4
Fragmentation	-0.369*** (0.018)	-1.173*** (0.007)	-0.156*** (0.009)	-0.197* (0.102)
Fragmentation $\times$ Intraday Volatility	-1,253.810*** (23.325)	219.208*** (9.087)	604.944*** (11.030)	621.158*** (58.362)
Quintile 1	-0.633*** (0.002)	0.022*** (0.001)	0.516*** (0.001)	0.174*** (0.009)
Quintile 2	-0.369*** (0.002)	-0.005*** (0.001)	0.251*** (0.001)	0.164*** (0.006)
Quintile 4	0.128*** (0.002)	0.087*** (0.001)	-0.171*** (0.001)	-0.292*** (0.009)
Quintile 5	0.062*** (0.002)	0.210*** (0.001)	-0.318*** (0.001)	-0.531*** (0.014)
Intraday Volatility	20.203* (10.687)	-152.830*** (4.195)	52.206*** (5.093)	-314.392*** (26.114)
Return Volatility	11.851*** (0.022)	-0.481*** (0.008)	7.105*** (0.010)	0.217*** (0.068)
Leverage	0.206*** (0.005)	-0.084*** (0.002)	0.051*** (0.002)	-0.057** (0.024)
Market-to-Book	0.015*** (0.001)	0.051*** (0.000)	0.024*** (0.000)	0.013*** (0.003)
Inverse Price	-0.203*** (0.001)	0.326*** (0.000)	0.345*** (0.000)	0.064*** (0.005)
Volume Turnover		0.106*** (0.000)	-0.328*** (0.000)	-0.236*** (0.006)
Firm FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Observations	11,237,659	11,237,659	11,212,129	11,183,972
R <sup>2</sup>	0.512	0.574	0.878	0.507

TABLE C5

Intermarket Sweep Orders and Fragmentation

The table presents the results of two-stage instrumental variables regressions (IV) of inter-market sweep order (ISO) volume on fragmentation. For our instrumental variable, we use the log of the total number of market centers in the U.S. at each point in time according to the model:

$$\text{Fragmentation}_{i,t} = \phi + \eta(\# \text{ Markets}_t) + \sum_{k \neq 3} \gamma_k \text{Size}_k + \sum_{k \neq 3} \mu_k (\# \text{ Markets}_t \times \text{Size}_k) + \text{Controls}_{i,t} + \nu_{i,t}$$

$$y_{i,t+1} = \alpha + \beta \widehat{\text{Fragmentation}}_{i,t} + \sum_{k \neq 3} \delta_k \text{Size}_k + \sum_{k \neq 3} \theta_k (\widehat{\text{Frag}} \times \text{Size}_k) + \text{Controls}_{i,t} + \varepsilon_{i,t+1},$$

where  $y_{i,t+1}$  is a variable capturing the use of ISO trades from TAQ. *Quintile* is an indicator variable which equals 1 when a firm is in that size quintile, and zero otherwise, where quintile 5 is the largest firms. The sample for this analysis contains daily firm-level variables from 2007-2016. *Number of ISO Trades* is defined as the number of ISO trades, grouped together by the “parent” order, made for a firm within a day. *ISO Turnover* is the natural log of volume of ISO trades, scaled by shares outstanding. *Number of exchanges* is the number of exchanges at which the ISO was executed on, averaged across the day. The *percentage of depth* is the number of shares executed by the ISO order and scaled by the depth at the NBBO prior to the ISO order, then averaged across the day. *Price change* is the total price change comparing the “worst” price of the ISO as compared to the NBBO prior to execution, then averaged across the day. Hence, when Price Change is higher, the ISO pushed prices further from the NBBO to the detriment of the trader. Control variables are discussed in Section IV of the text, and we include firm and year fixed effects. Firms are sorted into market capitalization quintiles on day  $t - 1$  and then interacted with fragmentation in the first stage and we use the log of the number of market centers  $\times$  each market capitalization quintile as additional instruments. Standard errors clustered by firm and date are shown below the estimates. \*\*\*, \*\*, \* indicates significance at the 1%, 5%, and 10% levels.

Dep. Variable=	# of ISO Trades		ISO Turnover		# of Exchs.		% of Depth		Price Change	
	1	2	3	4	6	7	8	9	10	
Fragmentation	5.212*** (1.322)	5.059*** (1.347)	4.758*** (1.268)	3.979*** (1.308)	1.425*** (0.107)	1.045*** (0.104)	1.037*** (0.280)	0.681** (0.297)	0.146*** (0.047)	0.086** (0.044)
Frag $\times$ Quintile 1		-1.879*** (0.363)		1.325*** (0.321)		-0.435*** (0.045)		1.552*** (0.159)		0.036 (0.035)
Frag $\times$ Quintile 2		0.061 (0.255)		0.827*** (0.209)		-0.300*** (0.034)		0.065 (0.105)		0.009 (0.026)
Frag $\times$ Quintile 4		-0.113 (0.247)		0.012 (0.227)		0.259*** (0.030)		0.193** (0.093)		-0.004 (0.029)
Frag $\times$ Quintile 5		0.963*** (0.215)		1.600*** (0.193)		1.186*** (0.048)		0.519*** (0.115)		0.167** (0.081)
Quintile 1	-0.813*** (0.054)	0.239 (0.195)	-0.019 (0.049)	-0.855*** (0.168)	0.040*** (0.006)	0.279*** (0.026)	0.230*** (0.017)	-0.673*** (0.092)	0.015*** (0.005)	-0.009 (0.021)
Quintile 2	-0.380*** (0.021)	-0.413*** (0.157)	-0.063*** (0.018)	-0.619*** (0.126)	0.014*** (0.003)	0.200*** (0.022)	0.081*** (0.008)	0.023 (0.067)	0.006** (0.003)	-0.001 (0.017)
Quintile 4	0.305*** (0.013)	0.388** (0.173)	0.056*** (0.010)	0.064 (0.159)	0.003 (0.002)	-0.176*** (0.021)	0.040*** (0.007)	-0.091 (0.065)	-0.002 (0.003)	0.001 (0.020)
Quintile 5	0.578*** (0.022)	-0.133 (0.154)	0.096*** (0.016)	-1.069*** (0.138)	0.010*** (0.004)	-0.857*** (0.035)	0.132*** (0.012)	-0.242*** (0.082)	-0.001 (0.006)	-0.124** (0.059)
Volume Turnover	0.848*** (0.037)	0.875*** (0.043)	0.901*** (0.036)	0.896*** (0.041)	-0.001 (0.003)	0.018*** (0.003)	-0.001 (0.008)	-0.011 (0.010)	-0.002 (0.002)	-0.001 (0.002)
Return Volatility	-1.677*** (0.175)	-1.835*** (0.191)	-0.669*** (0.160)	-0.643*** (0.178)	-0.043 (0.027)	-0.157*** (0.023)	2.057*** (0.096)	2.115*** (0.101)	-0.115*** (0.021)	-0.121*** (0.021)
Leverage	-0.021 (0.045)	-0.051 (0.046)	0.160*** (0.029)	0.153*** (0.031)	0.076*** (0.010)	0.051*** (0.008)	0.046* (0.027)	0.050* (0.027)	-0.033*** (0.012)	-0.035*** (0.012)
Market-to-Book	0.034*** (0.008)	0.042*** (0.008)	-0.041*** (0.005)	-0.043*** (0.005)	-0.003** (0.001)	0.002* (0.001)	0.025*** (0.004)	0.021*** (0.004)	0.003* (0.002)	0.003* (0.002)
Price Inverse	0.076*** (0.018)	0.092*** (0.016)	-0.029** (0.015)	-0.032** (0.012)	0.014*** (0.002)	0.024*** (0.002)	-0.046*** (0.009)	-0.053*** (0.009)	0.001 (0.002)	0.002 (0.003)
Firm FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Number of observations	7,219,673	7,219,673	7,219,673	7,219,673	7,219,673	7,219,673	7,214,657	7,214,657	7,210,720	7,210,720
R <sup>2</sup>	0.869	0.880	0.587	0.582	0.095	0.445	0.132	0.103	0.479	0.481

## D. Appendix D - Reduced Form IV Results

TABLE D1

### Reduced Form IV Results

The table presents the results of a reduced-form instrumental variables (IV) regression where we instrument for fragmentation using the log of the total number of market centers:

$$y_{i,t+1} = \alpha + \beta \# \text{Markets}_{i,t} + \sum_{k \neq 3} \delta_k \text{Size}_k + FE_i + FE_t + \text{Controls}_{i,t} + \varepsilon_{i,t+1},$$

where  $y_{i,t+1}$  is either the *Volume Turnover*, *Average Trade Size*, *Effective Spread*, or *Variance Ratio*. *Quintile* is an indicator variable which equals 1 when a firm is in that size quintile, and zero otherwise, where quintile 5 is the largest firms. The sample for this analysis contains daily firm-level variables from 2003-2016. Control variables are discussed in Section IV of the text, and we include firm and year fixed effects. Firms are sorted into market capitalization quintiles on day  $t - 1$ . All dependent variables are log-transformed to address skewness. Standard errors, clustered by firm and date, are shown below the estimates. \*\*\*, \*\*, \* indicates significance at the 1%, 5%, and 10% levels.

Dependent Variable=	Turnover 1	Turnover 2	Avg. Trade Size 3	Avg. Trade Size 4	Eff. Spread 5	Eff. Spread 6	Var. Ratio 7	Var. Ratio 8
Log(Market Centers)	-0.042 (0.087)	-0.184** (0.092)	-0.469*** (0.034)	-0.553*** (0.033)	0.143* (0.084)	-0.055 (0.047)	-0.099** (0.049)	-0.084* (0.049)
Quintile 1		-0.643*** (0.031)		0.032*** (0.010)		0.511*** (0.019)		0.172*** (0.010)
Quintile 2		-0.358*** (0.018)		-0.004 (0.006)		0.238*** (0.010)		0.163*** (0.006)
Quintile 4		0.114*** (0.016)		0.110*** (0.006)		-0.154*** (0.010)		-0.289*** (0.008)
Quintile 5		0.028 (0.028)		0.230*** (0.010)		-0.290*** (0.018)		-0.530*** (0.014)
Return Volatility		10.513*** (0.306)		-0.574*** (0.058)		7.830*** (0.215)		0.186*** (0.066)
Leverage		0.189*** (0.065)		-0.076*** (0.023)		0.057* (0.034)		-0.060** (0.025)
Market-to-Book		0.019** (0.009)		0.044*** (0.003)		0.019*** (0.005)		0.012*** (0.003)
Inverse Price		-0.220*** (0.014)		0.348*** (0.005)		0.361*** (0.010)		0.068*** (0.005)
Volume Turnover				0.060*** (0.003)		-0.357*** (0.005)		-0.240*** (0.004)
Firm FE	YES	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES	YES
Observations	12,612,253	11,513,838	12,612,253	11,513,838	12,561,452	11,467,927	12,515,205	11,428,430
R <sup>2</sup>	0.489	0.523	0.505	0.565	0.801	0.873	0.479	0.511

TABLE D2

## Reduced Form IV Differential Results

The table presents the results of a reduced-form instrumental variables (IV) regression where we instrument for fragmentation using the log of the total number of market centers:

$$y_{i,t+1} = \alpha + \beta \# \text{Markets}_{i,t} + \sum_{k \neq 3} \delta_k \text{Size}_k + \sum_{k \neq 3} \theta_k (\# \text{Markets} \times \text{Size}_k) + FE_i + FE_t + \text{Controls}_{i,t} + \varepsilon_{i,t+1},$$

where  $y_{i,t+1}$  is either the *Volume Turnover*, *Average Trade Size*, *Effective Spread*, or *Variance Ratio*. *Quintile* is an indicator variable which equals 1 when a firm is in that size quintile, and zero otherwise, where quintile 5 is the largest firms. The sample for this analysis contains daily firm-level variables from 2003-2016. Control variables are discussed in Section IV of the text, and we include firm and year fixed effects. Firms are sorted into market capitalization quintiles on day  $t - 1$ . All dependent variables are log-transformed to address skewness. Standard errors, clustered by firm and date, are shown below the estimates. \*\*\*, \*\*, \* indicates significance at the 1%, 5%, and 10% levels.

Dependent Variable=	Turnover 1	Turnover 2	Avg. Trade Size 3	Avg. Trade Size 4	Eff. Spread 5	Eff. Spread 6	Var. Ratio 7	Var. Ratio 8
Log( Market Centers)	-0.084 (0.090)	-0.182* (0.095)	-0.315*** (0.035)	-0.404*** (0.034)	0.082 (0.083)	-0.177*** (0.049)	-0.034 (0.051)	-0.047 (0.050)
Log(Mkt. Centers) × Quintile 1	-0.273*** (0.051)	-0.309*** (0.051)	0.234*** (0.024)	0.116*** (0.021)	0.656*** (0.031)	0.409*** (0.026)	0.228*** (0.016)	0.166*** (0.015)
Log(Mkt. Centers) × Quintile 2	0.003 (0.039)	0.032 (0.039)	0.119*** (0.016)	0.059*** (0.014)	0.251*** (0.024)	0.166*** (0.021)	0.150*** (0.014)	0.130*** (0.013)
Log(Mkt. Centers) × Quintile 4	0.079** (0.036)	0.024 (0.037)	-0.236*** (0.016)	-0.170*** (0.015)	-0.088*** (0.022)	0.039* (0.020)	-0.271*** (0.021)	-0.239*** (0.018)
Log(Mkt. Centers) × Quintile 5	0.223*** (0.049)	0.129** (0.051)	-0.642*** (0.021)	-0.540*** (0.020)	-0.167*** (0.030)	0.088*** (0.029)	-0.204*** (0.024)	-0.115*** (0.023)
Quintile 1	0.381* (0.222)	0.668*** (0.222)	-0.510*** (0.104)	-0.406*** (0.091)	-1.485*** (0.138)	-1.238*** (0.114)	-0.589*** (0.069)	-0.510*** (0.062)
Quintile 2	-0.477*** (0.171)	-0.509*** (0.170)	-0.306*** (0.070)	-0.227*** (0.061)	-0.448*** (0.104)	-0.469*** (0.092)	-0.368*** (0.062)	-0.382*** (0.055)
Quintile 4	-0.138 (0.158)	0.020 (0.161)	0.929*** (0.070)	0.818*** (0.064)	-0.108 (0.097)	-0.325*** (0.088)	0.809*** (0.089)	0.741*** (0.079)
Quintile 5	-0.748*** (0.217)	-0.518** (0.223)	2.625*** (0.093)	2.537*** (0.088)	-0.180 (0.133)	-0.676*** (0.126)	0.249** (0.106)	-0.041 (0.102)
Return Volatility		10.505*** (0.305)		-0.626*** (0.058)		7.769** (0.213)		0.148** (0.066)
Leverage		0.170*** (0.066)		-0.030 (0.021)		0.071** (0.033)		-0.037 (0.025)
Market-to-Book		0.019** (0.009)		0.043*** (0.003)		0.018*** (0.005)		0.011*** (0.003)
Inverse Price		-0.203*** (0.014)		0.313*** (0.005)		0.348*** (0.010)		0.049*** (0.005)
Volume Turnover				0.072*** (0.003)		-0.353*** (0.005)		-0.234*** (0.004)
Firm FE	YES	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES	YES
Observations	12,612,253	11,513,838	12,612,253	11,513,838	12,561,452	11,467,927	12,515,205	11,428,430
R <sup>2</sup>	0.500	0.524	0.543	0.576	0.841	0.874	0.499	0.512

## E. Appendix E - Regulation NMS Effects

TABLE E1

### Regulation NMS Effects on Trading Behavior and Market Quality

The table displays results from a simple pre-post regression around the implementation of Regulation NMS. *Turnover* is measured as daily volume scaled by the number of shares outstanding. *Effective spreads*, *average trade size*, and *variance ratios* are taken from WRDS TAQ Millisecond Intraday Indicators database. All dependent variables are log-transformed to adjust for skewness in the data. The point estimate is an indicator variable which takes the value of one after July 9, 2007, initial implementation of Regulation NMS. Hence, the point estimate is essentially the average difference in a small window before and after Regulation NMS. The sample for this analysis contains daily firm-level TAQ variables in 2007. Regression analysis includes firm fixed effects with standard errors clustered by firm and date shown below the estimates. \*\*\*, \*\*, \* indicates significance at the 1%, 5%, and 10% levels.

<b>Panel A: Trading Behavior and Market Quality</b>				
<b>Dep. Var=</b>	<b>Volume Turnover</b>	<b>Avg. Trade Size</b>	<b>Eff. Spread</b>	<b>Variance Ratio</b>
	1	2	3	4
Post Regulation NMS	0.106***	-0.076***	0.198***	-0.124***
	-0.026	-0.007	-0.015	-0.016
Constant	1.370***	5.459***	-6.380***	-1.282***
	-0.012	-0.005	-0.009	-0.009
Firm FE	YES	YES	YES	YES
Observations	978,283	978,283	977,587	975,465
R <sup>2</sup>	0.694	0.554	0.917	0.514

  

<b>Panel B: Relation between Reg NMS and Observed Fragmentation</b>	
<b>Dep. Var=</b>	1
	<b>Fragmentation</b>
Post Regulation NMS	0.037***
	-0.002
Constant	0.520***
	-0.002
Firm FE	YES
Observations	978,307
R <sup>2</sup>	0.378

TABLE E2

**Regulation NMS Differential Effects without Entropy Balancing**

The table displays results from a difference-in-differences regression around the implementation of Regulation NMS. The difference from Table 2 is that there is no entropy balancing in this regression. *Turnover* is measured as daily volume scaled by the number of shares outstanding. *Effective spreads*, *average trade size*, and *variance ratios* are taken from WRDS TAQ Millisecond Intraday Indicators database. All dependent variables are log-transformed to adjust for skewness in the data. The point estimate is the average differential treatment effect where treatment is an indicator for quintile 1 firms and *post* is an indicator that takes the value of one after the initial implementation of Regulation NMS on July 9, 2007. The sample is restricted to quintiles 1 and 5 only and contains daily firm-level TAQ data in 2007. Regression analysis includes day and firm fixed effects with standard errors clustered by firm and date shown below the estimates. \*\*\*, \*\*, \* indicates significance at the 1%, 5%, and 10% levels.

Dep. Var=	Volume Turnover 1	Avg. Trade Size 2	Eff. Spread 3	Variance Ratio 4
Point Estimate	-0.229*** (0.036)	0.142*** (0.013)	0.034 (0.023)	0.077*** (0.018)
Constant	1.336*** (0.007)	5.540*** (0.002)	-6.371*** (0.004)	-1.538*** (0.003)
Firm FE	YES	YES	YES	YES
Day FE	YES	YES	YES	YES
Observations	371,052	371,052	370,531	368,944
R <sup>2</sup>	0.702	0.586	0.950	0.557

TABLE E3

**Entropy Balancing Outcomes**

The table displays the levels of fragmentation before and after entropy balancing. Fragmentation is measured in the months leading up to the implementation of Regulation NMS, on July 9, 2007. “Treat” is an indicator variable that takes the value of one if firms are in quintile 1 of market capitalization. The sample is restricted to quintiles 1 and 5 only, where firms are sorted into market capitalization quintiles on the first trading day of 2007. Furthermore, firms are entropy balanced on the first three moments of the ex-ante distribution of fragmentation (both overall and lit exchanges only). The sample for this analysis contains daily firm-level TAQ variables in 2007.

	<b>Before Entropy Balancing</b>					
	Treat			Control		
	Mean	Std. Dev	Skewness	Mean	Std. Dev	Skewness
Fragmentation	0.4384	0.01539	-0.7279	0.5435	0.004313	-0.6575
Fragmentation (lit only)	0.2677	0.01293	0.1531	0.3952	0.004272	-0.2603

  

	<b>After Entropy Balancing</b>					
	Treat			Control		
	Mean	Std. Dev	Skewness	Mean	Std. Dev	Skewness
Fragmentation	0.4384	0.01539	-0.7279	0.4384	0.01539	-0.7279
Fragmentation (lit only)	0.2677	0.01293	0.1531	0.2677	0.01293	0.1532



## F. Appendix F - Alternate Fragmentation Measure

TABLE F1

### Panel Regression of the Effects of Alternate Fragmentation Measure

This table displays results from an OLS panel regression of the form:

$$y_{i,t+1} = \alpha + \beta \text{Off-Listing}_{i,t} + \text{Controls}_{i,t} + \varepsilon_{i,t+1}$$

where  $y_{i,t+1}$  is either the *Volume Turnover*, *Average Trade Size*, *Effective Spread*, or *Variance Ratio*. *Off-Listing Volume Share* is defined as the proportion of trading volume that occurs off the listing exchange, as defined in O'Hara and Ye (2011). The sample for this analysis contains daily firm-level variables from 2003-2016. *Quintile* is an indicator variable which equals 1 when a firm is in that size quintile, and zero otherwise and quintile 5 is the largest firms. Control variables are discussed in Section IV of the text, and we include firm and day fixed effects. Firms are sorted into market capitalization quintiles on day  $t - 1$ . All dependent variables are log-transformed to address skewness. Standard errors, clustered by firm and date, are shown below the estimates. \*\*\*, \*\*, \* indicates significance at the 1%, 5%, and 10% levels.

Dependent Variable=	Turnover 1	Turnover 2	Avg. Trade Size 3	Avg. Trade Size 4	Eff. Spread 5	Eff. Spread 6	Var. Ratio 7	Var. Ratio 8
Off-Listing Volume Share	0.162*** (0.006)	0.149*** (0.006)	-0.085*** (0.012)	-0.123*** (0.011)	0.010 (0.018)	0.059*** (0.012)	-0.111*** (0.011)	-0.065*** (0.008)
Quintile 1		-0.133*** (0.009)		-0.016 (0.012)		0.489*** (0.018)		0.111*** (0.010)
Quintile 2		-0.084*** (0.006)		-0.020*** (0.007)		0.229*** (0.010)		0.136*** (0.006)
Quintile 4		0.053*** (0.006)		0.121*** (0.006)		-0.162*** (0.010)		-0.272*** (0.009)
Quintile 5		0.031*** (0.010)		0.246*** (0.011)		-0.315*** (0.018)		-0.507*** (0.015)
Return Volatility		4.273*** (0.149)		0.057 (0.059)		6.488*** (0.231)		0.632*** (0.062)
Leverage		0.086*** (0.020)		-0.122*** (0.028)		0.048 (0.033)		-0.018 (0.026)
Market-to-Book		0.015*** (0.003)		0.044*** (0.004)		0.045*** (0.005)		0.006 (0.003)
Inverse Price		-0.075*** (0.005)		0.359*** (0.006)		0.397*** (0.010)		0.090*** (0.005)
Volume Turnover				0.051*** (0.003)		-0.347*** (0.005)		-0.241*** (0.004)
Firm FE	YES	YES	YES	YES	YES	YES	YES	YES
Day FE	YES	YES	YES	YES	YES	YES	YES	YES
Observations	9,739,629	8,976,954	9,731,821	8,969,686	9,695,878	8,936,578	9,660,387	8,906,145
R <sup>2</sup>	0.487	0.540	0.488	0.543	0.829	0.894	0.503	0.534

TABLE F2

### Panel Regression of the Differential Effects of Alternate Fragmentation Measure

The table displays results from an OLS panel regression of the form:

$$y_{i,t+1} = \alpha + \beta \text{Off-Listing}_{i,t} + \sum_{k \neq 3} \delta_k \text{Size}_k + \sum_{k \neq 3} \theta_k (\text{Off-Listing} \times \text{Size}_k) + \text{Controls}_{i,t} + \varepsilon_{i,t+1},$$

where  $y_{i,t+1}$  is either the *Volume Turnover*, *Average Trade Size*, *Effective Spread*, or *Variance Ratio*. *Off-Listing Volume Share* is defined as the proportion of trading volume that occurs off the listing exchange, as defined in O'Hara and Ye (2011). The sample for this analysis contains daily firm-level variables from 2003-2016. *Quintile* is an indicator variable which equals 1 when a firm is in that size quintile, and zero otherwise and quintile 5 is the largest firms. Control variables are discussed in Section IV of the text, and we include firm and day fixed effects. Firms are sorted into market capitalization quintiles on day  $t - 1$ . All dependent variables are log-transformed to address skewness. Standard errors, clustered by firm and date, are shown below the estimates. \*\*\*, \*\*, \* indicates significance at the 1%, 5%, and 10% levels.

Dependent Variable=	Turnover 1	Turnover 2	Avg. Trade Size 3	Avg. Trade Size 4	Eff. Spread 5	Eff. Spread 6	Var. Ratio 7	Var. Ratio 8
Off-Listing Volume Share	0.164*** (0.011)	0.136*** (0.011)	-0.099*** (0.016)	-0.141*** (0.015)	-0.040* (0.023)	0.043** (0.021)	-0.094*** (0.017)	-0.032** (0.015)
Off-Listing × Quintile 1	-0.124*** (0.013)	-0.116*** (0.012)	0.384*** (0.018)	0.346*** (0.017)	0.135*** (0.028)	-0.012 (0.024)	0.129*** (0.018)	0.068*** (0.016)
Off-Listing × Quintile 2	-0.091*** (0.011)	-0.075*** (0.011)	0.286*** (0.017)	0.251*** (0.015)	0.109*** (0.026)	0.010 (0.023)	0.149*** (0.017)	0.107*** (0.015)
Off-Listing × Quintile 4	0.150*** (0.014)	0.146*** (0.014)	-0.319*** (0.018)	-0.243*** (0.017)	-0.153*** (0.027)	0.044* (0.024)	-0.441*** (0.025)	-0.365*** (0.023)
Off-Listing × Quintile 5	0.248*** (0.016)	0.240*** (0.017)	-0.753*** (0.025)	-0.616*** (0.024)	-0.328*** (0.034)	0.060* (0.031)	-0.289*** (0.029)	-0.130*** (0.028)
Quintile 1	-0.117*** (0.010)	-0.085*** (0.011)	0.239*** (0.015)	-0.158*** (0.014)	1.252*** (0.024)	0.493*** (0.024)	0.301*** (0.013)	0.091*** (0.013)
Quintile 2	-0.070*** (0.008)	-0.051*** (0.008)	0.033*** (0.011)	-0.132*** (0.010)	0.567*** (0.018)	0.222*** (0.017)	0.187*** (0.011)	0.084*** (0.010)
Quintile 4	0.004 (0.009)	-0.014 (0.009)	0.083*** (0.011)	0.221*** (0.010)	-0.429*** (0.017)	-0.183*** (0.015)	-0.141*** (0.016)	-0.086*** (0.014)
Quintile 5	-0.045*** (0.013)	-0.086*** (0.012)	0.255*** (0.016)	0.543*** (0.016)	-0.773*** (0.026)	-0.345*** (0.023)	-0.506*** (0.023)	-0.443*** (0.021)
Return Volatility		4.261*** (0.147)		-0.151*** (0.056)		6.503*** (0.231)		0.570*** (0.061)
Leverage		0.072*** (0.019)		-0.090*** (0.025)		0.045 (0.033)		-0.007 (0.025)
Market-to-Book		0.014*** (0.003)		0.045*** (0.004)		0.045*** (0.005)		0.005 (0.003)
Inverse Price		-0.061*** (0.005)		0.327*** (0.006)		0.400*** (0.010)		0.080*** (0.005)
Volume Turnover				0.071*** (0.003)		-0.348*** (0.005)		-0.235*** (0.004)
Firm FE	YES	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES	YES
Observations	9,739,629	8,976,954	9,731,821	8,969,686	9,695,878	8,936,578	9,660,387	8,906,145
R <sup>2</sup>	0.502	0.545	0.526	0.558	0.865	0.894	0.521	0.535

TABLE F3

### Second Stage Estimates from 2SLS Regression of the Effects of Alternate Fragmentation Measure

We use the log of the total number of market centers in the U.S. at each point in time as an instrument according to the two-stage least squares model:

$$\text{Off-Listing Vol. Share}_{i,t} = \phi + \eta(\# \text{ Markets}_t) + \sum_{k \neq 3} \gamma_k \text{Size}_k + \text{Controls}_{i,t} + \nu_{i,t}$$

$$y_{i,t+1} = \alpha + \beta \widehat{\text{Off-Listing}}_{i,t} + \sum_{k \neq 3} \delta_k \text{Size}_k + \text{Controls}_{i,t} + \varepsilon_{i,t+1},$$

where  $y_{i,t+1}$  is either the *Volume Turnover*, *Average Trade Size*, *Effective Spread*, or *Variance Ratio*. *Off-Listing Volume Share* is defined as the proportion of trading volume that occurs off the listing exchange, as defined in O'Hara and Ye (2011). The sample for this analysis contains daily firm-level TAQ variables from 2003-2016. *Quintile* is an indicator variable which equals 1 when a firm is in that size quintile, and zero otherwise and quintile 5 is the largest firms. Control variables are discussed in Section IV of the text, and we include firm and year fixed effects. Firms are sorted into market capitalization quintiles on day  $t - 1$ . All dependent variables are log-transformed to address skewness. Standard errors, clustered by firm and date, are shown below the estimates. \*\*\*, \*\*, \* indicates significance at the 1%, 5%, and 10% levels.

Dependent Variable=	Turnover 1	Turnover 2	Avg. Trade Size 3	Avg. Trade Size 4	Eff. Spread 5	Eff. Spread 6	Var. Ratio 7	Var. Ratio 8
Off-Listing Volume Share	-0.222 (0.177)	-0.460** (0.186)	-1.007*** (0.079)	-1.200*** (0.081)	0.317* (0.179)	-0.261*** (0.087)	-0.122 (0.099)	-0.144 (0.096)
Quintile 1		-0.525*** (0.034)		0.082*** (0.015)		0.453*** (0.020)		0.145*** (0.012)
Quintile 2		-0.293*** (0.019)		0.033*** (0.008)		0.218*** (0.011)		0.151*** (0.008)
Quintile 4		0.072*** (0.018)		0.068*** (0.007)		-0.149*** (0.011)		-0.287*** (0.010)
Quintile 5		-0.016 (0.029)		0.192*** (0.012)		-0.276*** (0.019)		-0.533*** (0.015)
Return Volatility		10.562*** (0.349)		-0.552*** (0.076)		7.728*** (0.244)		0.088 (0.072)
Leverage		0.090 (0.064)		-0.138*** (0.030)		0.046 (0.033)		-0.018 (0.026)
Market-to-Book		0.050*** (0.011)		0.068*** (0.005)		0.038*** (0.006)		0.013*** (0.004)
Inverse Price		-0.259*** (0.015)		0.354*** (0.007)		0.417*** (0.010)		0.080*** (0.005)
Volume Turnover				0.094*** (0.005)		-0.338*** (0.006)		-0.237*** (0.005)
Firm FE	YES	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES	YES
Observations	9,731,237	8,969,326	9,731,237	8,969,326	9,695,288	8,936,219	9,660,051	8,905,738
R <sup>2</sup>	0.511	0.541	0.412	0.440	0.817	0.889	0.494	0.525

TABLE F4

### Second Stage Estimates from 2SLS Regression of the Differential Effects of Alternate Fragmentation Measure

We use the log of the total number of market centers in the U.S. at each point in time as an instrument according to the two-stage least squares model:

$$\text{Off-Listing Vol. Share}_{i,t} = \phi + \eta(\# \text{ Markets}_t) + \sum_{k \neq 3} \gamma_k \text{Size}_k + \sum_{k \neq 3} \mu_k (\# \text{ Markets}_t \times \text{Size}_k) + \text{Controls}_{i,t} + \nu_{i,t}$$

$$y_{i,t+1} = \alpha + \beta \widehat{\text{Off-Listing}}_{i,t} + \sum_{k \neq 3} \delta_k \text{Size}_k + \sum_{k \neq 3} \theta_k (\widehat{\text{Off-Listing}} \times \text{Size}_k) + \text{Controls}_{i,t} + \varepsilon_{i,t+1},$$

where  $y_{i,t+1}$  is either the *Volume Turnover*, *Average Trade Size*, *Effective Spread*, or *Variance Ratio*. *Off-Listing Volume Share* is defined as the proportion of trading volume that occurs off the listing exchange, as defined in O'Hara and Ye (2011). The sample for this analysis contains daily firm-level TAQ variables from 2003-2016. *Quintile* is an indicator variable which equals 1 when a firm is in that size quintile, and zero otherwise, where quintile 5 is the largest firms. Control variables are discussed in Section IV of the text, and we include firm and year fixed effects. Firms are sorted into market capitalization quintiles on day  $t - 1$ . All dependent variables are log-transformed to address skewness. Standard errors, clustered by firm and date, are shown below the estimates. \*\*\*, \*\*, \* indicates significance at the 1%, 5%, and 10% levels.

Dependent Variable=	Turnover 1	Turnover 2	Avg. Trade Size 3	Avg. Trade Size 4	Eff. Spread 5	Eff. Spread 6	Var. Ratio 7	Var. Ratio 8
Off-Listing Volume Share	-0.342*** (0.074)	-0.472*** (0.084)	-0.983*** (0.094)	-1.171*** (0.098)	-0.188 (0.217)	-0.889*** (0.118)	-0.075 (0.120)	-0.135 (0.120)
Off-Listing × Quintile 1	-0.170*** (0.047)	-0.185*** (0.050)	0.738*** (0.077)	0.425*** (0.080)	2.323*** (0.128)	1.408*** (0.093)	0.675*** (0.055)	0.439*** (0.049)
Off-Listing × Quintile 2	-0.102*** (0.035)	-0.057 (0.036)	0.424*** (0.049)	0.266*** (0.048)	0.929*** (0.082)	0.612*** (0.073)	0.513*** (0.046)	0.427*** (0.041)
Off-Listing × Quintile 4	0.284*** (0.037)	0.299*** (0.040)	-0.328*** (0.046)	-0.138*** (0.045)	-0.149* (0.079)	0.379*** (0.067)	-0.687*** (0.058)	-0.590*** (0.054)
Off-Listing × Quintile 5	0.494*** (0.045)	0.521*** (0.050)	-0.732*** (0.064)	-0.499*** (0.064)	-0.148 (0.111)	0.672*** (0.082)	-0.380*** (0.071)	-0.177** (0.070)
Quintile 1	-0.072** (0.030)	-0.015 (0.030)	0.053 (0.049)	-0.124** (0.050)	-0.081 (0.085)	-0.357*** (0.058)	-0.030 (0.034)	-0.072** (0.029)
Quintile 2	-0.053** (0.021)	-0.047** (0.021)	-0.027 (0.029)	-0.095*** (0.028)	0.100** (0.047)	-0.110*** (0.042)	-0.023 (0.027)	-0.072*** (0.023)
Quintile 4	-0.078*** (0.022)	-0.112*** (0.023)	0.067** (0.027)	0.122*** (0.026)	-0.414*** (0.047)	-0.354*** (0.039)	-0.003 (0.034)	0.014 (0.032)
Quintile 5	-0.186*** (0.028)	-0.252*** (0.030)	0.238*** (0.039)	0.436*** (0.038)	-0.834*** (0.067)	-0.639*** (0.048)	-0.440*** (0.044)	-0.447*** (0.042)
Return Volatility		4.048*** (0.140)		-0.628*** (0.073)		7.733*** (0.246)		0.032 (0.071)
Leverage		0.056*** (0.021)		-0.107*** (0.029)		0.051 (0.035)		0.012 (0.025)
Market-to-Book		0.028*** (0.004)		0.066*** (0.005)		0.040*** (0.006)		0.010*** (0.004)
Inverse Price		-0.055*** (0.005)		0.326*** (0.008)		0.408*** (0.011)		0.055*** (0.005)
Volume Turnover				0.107*** (0.004)		-0.334*** (0.006)		-0.227*** (0.005)
Firm FE	YES	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES	YES
Observations	9,739,046	8,976,303	9,731,237	8,969,326	9,695,288	8,936,219	9,660,051	8,905,738
R <sup>2</sup>	0.442	0.464	0.470	0.472	0.830	0.884	0.508	0.524

## G. Appendix G - Augmented Dickey-Fuller Test

TABLE G1

### Augmented Dickey-Fuller test

The table displays the results from a Dickey-Fuller unit root test for the time series of the log-transformed number of market centers between 2003-2016. We follow Schwert's rule of thumb to begin with a number of lags =  $12 * \left(\frac{T}{100}\right)^{0.25}$ . Therefore, we start with 30 lags and move down to 20 lags such that the last included lag has a t-test statistic of at least 1.6. The results strongly reject the null hypothesis of a unit process with a p-value below 0.0001.

	Coefficient	Std. Error	t-statistic	p-value
L1.	-0.001	0.000	-4.92	0.000
LD.	-0.011	0.014	-0.80	0.422
L2D.	-0.007	0.014	-0.49	0.627
L3D.	-0.007	0.014	-0.49	0.627
L4D.	-0.007	0.014	-0.49	0.627
L5D.	-0.007	0.014	-0.49	0.627
L6D.	-0.007	0.014	-0.49	0.627
L7D.	-0.007	0.014	-0.49	0.627
L8D.	-0.007	0.014	-0.49	0.627
L9D.	-0.007	0.014	-0.49	0.627
L10D.	-0.007	0.014	-0.49	0.627
L11D.	-0.007	0.014	-0.49	0.627
L12D.	-0.007	0.014	-0.49	0.627
L13D.	-0.007	0.014	-0.49	0.627
L14D.	-0.007	0.014	-0.49	0.627
L15D.	-0.007	0.014	-0.49	0.627
L16D.	-0.007	0.014	-0.49	0.627
L17D.	-0.007	0.014	-0.49	0.627
L18D.	-0.007	0.014	-0.49	0.627
L19D.	0.009	0.014	0.62	0.532
L20D.	0.284	0.014	19.90	0.000
Constant	0.006	0.001	5.23	0.000

Augmented Dickey-Fuller Test for unit root				
	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
Z(t)	-4.92	-3.43	-2.86	-2.57
MacKinnon approximate p-value = 0.0000				