

Tick Size Pilot Plan Threshold Analysis

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Abstract

This paper examines how the effects of the Tick Size Pilot vary with different stock characteristics in order to try and identify thresholds above or below which stocks experience improvements in market quality, including price discovery. We focus on three measures of market quality: the effective spread, variance ratios, and displayed limit order book depth. We match Test Group stocks to Control Group stocks based on the following pre-Pilot characteristics: quoted spreads, market capitalization, trading volume, price, limit order book depth, and volatility. We do not find clusters of stocks which systematically experienced improvements in market quality. Few stocks experience improvements in market quality and these stocks are not clearly identifiable based on pre-Pilot characteristics.

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1. Introduction

This paper follows up on the DERA “Tick Size Pilot Plan and Market Quality” white paper (the “market quality paper”) to examine how the effects of the Tick Size Pilot vary with different stock characteristics in order to try and identify clear thresholds above or below which stocks experience improvements in market quality, including price discovery.² The market quality paper shows that average market quality for Test Group stocks deteriorates relative to Control Group stocks during the Tick Size Pilot. We focus on three measures of market quality which display relatively high degrees of variation: the effective spread, variance ratios, and displayed limit order book depth. Each of these measures captures different dimensions of market quality.³ In order to examine variation in the effects of the tick size increase, we match Test Group stocks to the nearest ten Control Group stocks based on the following pre-Pilot characteristics: quoted spreads, market capitalization, trading volume, price, limit order book depth, and volatility.

We then look for clusters of stocks that experience improvements in market quality based on observable stock characteristics that could serve as a basis for segmenting stocks into groups that might benefit from different tick sizes. Although we find variation in the effects of the tick size increase on market quality, we do not find any variation associated with stock characteristics which would allow us to clearly identify clusters of stocks that experience improvements in market quality. Therefore, we are unable to identify clear thresholds above or below which stocks experience improvements in market quality. We interpret the evidence as suggesting that the limited improvements in market quality are essentially random with respect to observable stock characteristics. This finding is consistent with average deteriorations in market quality documented in the market quality paper.

2. Matching Methodology

In order to examine variation in the effects of increasing the minimum tick size, we construct a matched sample where we match each stock in the Test Groups with similar stocks in the Control Group.⁴ Specifically, for each Test Group stock, we pick, with replacement, the ten nearest Control Group stocks with the most similar characteristics to form our matched sample.

² The market quality paper also describes the details of the Tick Size Pilot Program and summarizes related literature. See Hu, E., P. Hughes, J. Ritter, P. Vegella and H. Zhang (2018), “Tick Size Pilot Plan and Market Quality”, White Paper, U.S. Securities and Exchange Commission, Division of Economic and Risk Analysis (available at: https://www.sec.gov/dera/staff-papers/white-papers/dera_wp_tick_size-market_quality).

³ See the market quality paper referenced in supra note 2 for a definition of these and other market quality variables.

⁴ The market quality paper only examines pooled averages across Test and Control Groups, which is a fair comparison because the Test and Control Groups are designed to be similar when compared to one another in aggregate. Because this paper is primarily concerned with how the effects of the tick size increase varies across stocks within the Test Groups, we ensure that any comparisons are made to a similar subset of control group stocks, by using a more rigorous matching methodology done at the individual-stock level.

Specifically, we match stocks based on the following pre-Pilot characteristics: quoted spreads, market capitalization, trading volume, price, limit order book depth, and volatility. We then compute the average change in the market quality measures for the Test Group stocks, relative to the matched Control Group stocks. See Appendix A for a more detailed description of the matching methodology.

3. Results

Table 1 provides descriptive statistics for the Test and Control Groups. Consistent with the previous market quality paper, we show that Test and Control Groups have similar characteristics. Table 2 provides descriptive statistics for the treatment effects.⁵ Consistent with the previous market quality paper, we show some evidence that the Test Group stocks experience a deterioration in market quality and price discovery. Specifically, the average treatment effect (Test Group vs. Control Group) shows an increase in the effective spread, variance ratios, and displayed limit order book depth. An increase in effective spread implies that trading costs increased; an increase in variance ratios implies that prices are noisier, i.e., less informative of fundamentals; an increase in displayed limit order book depth is usually a sign of improved liquidity—but in the previous market quality paper we show that this effect is largely mechanical, i.e., the depth comes from consolidating price levels and not from new displayed liquidity.

Figure 1 plots the treatment effects on the vertical axis, and the pre-Pilot dollar quoted spreads on the horizontal axis. The dots represent individual stock treatment effects, and we include a regression line to show the existence of a relation between the quoted spreads and the treatment effects, if any.⁶ The panels are in the following order: the effective spread, variance ratios, and displayed limit order book depth. We examine pre-Pilot quoted spreads because we expect that one important factor in determining the treatment effects is whether or not the quoting increment will be a binding constraint.⁷ Because we are plotting treatment effects that center around zero, we can divide the plot into two regions centered around zero on the vertical axis, with the > 0 region (top) representing an increase in effective spreads and variance ratios, and the < 0 region (bottom) representing a decrease in limit order book depth.

The majority of the stocks have low pre-Pilot dollar quoted spreads. A simple visual inspection shows no clear cluster or diagonal line that we can draw to identify the set of stocks that

⁵ The treatment effect is defined as the change in the market quality measure between the Pilot and pre-Pilot periods for the Test Group stock minus the average change in the corresponding matched Control Group stocks. See the market quality paper referenced in supra note 2 for a detailed discussion of treatment effects and the Difference-in-Difference methodology.

⁶ An increase in effective spreads and variance ratios can be interpreted as a deterioration in market quality and price discovery, respectively. An increase in limit order book can be interpreted as an improvement in market quality.

⁷ E.g., stocks that are already quoted in five cent increments or greater are less likely to be impacted by the Pilot.

experience improvements in market quality (lower effective spreads, lower variance ratios, higher limit order book depth). More formally, the red line models the conditional mean of the treatment effect using a generalized additive model with penalized cubic splines.⁸ In all three panels the lines are mostly flat, indicating that there is no systematic relationship between the pre-Pilot dollar quoted spread and our measures of market quality (e.g., higher or lower quoted spreads do not imply better or worse market quality). For example, across stocks with pre-Pilot quoted spreads between zero to one dollar—which represents the majority of stocks in the sample—there is very little change in the average treatment effects in terms of the magnitudes. Finally, although the lines do cross zero, there is not enough data to reasonably conclude that stocks above such a quoted spread threshold would *systematically* see improvements in market quality or price discovery.

Figure 2 repeats the same panels, but with the pre-Pilot dollar effective spread on the bottom axis, Figure 3 uses pre-Pilot market capitalization, Figure 4 uses pre-Pilot dollar trading volume, Figure 5 uses pre-Pilot stock price, Figure 6 uses the pre-Pilot volatility, and Figures 7 and 8 use the percentage of time the dollar quoted spread is greater than five cents during the pre-Pilot and Pilot periods, respectively. As with Figure 1, the red lines in Figures 2 through 8 are mostly flat indicating that there is no systematic relationship between the respective pre-Pilot stock characteristic and our measures of market quality.⁹

Figures 9 through 11 plot heat maps of the treatment effects based on pre-Pilot stock price and dollar trading volume. Stock price and dollar trading volume are two dimensions that would make for natural thresholds.¹⁰ Figure 9 shows that only a few low-volume stocks experience an improvement in effective spreads. Figure 10 shows that only a few stocks experience a significant improvement in displayed limit order book depth, but the variation does not seem to be systematically related to price or volume. Figure 11 shows that only a few stocks priced between \$50 and \$100 per share experience improvements in price discovery. Across all three figures, it is difficult to identify clear "clusters" of stocks for which we can say market quality has unambiguously improved.

⁸ For details on the estimation of generalized additive models, see Wood S.N. (2017), Generalized Additive Models: An Introduction with R (2nd edition). Chapman and Hall/CRC Press.

⁹ As a robustness check, we also examined variation in the treatment effects separately in each of the Test Groups. The results were qualitatively similar to the results presented in Figures 1-8.

¹⁰ Price and trading volume were also two of the dimensions, in addition to market capitalization, that were used in the stratified sampling to construct the Tick Size Pilot Control and Test Groups. See Order Approving the National Market System Plan to Implement a Tick Size Pilot Program ("Approval Order") by BATS Exchange, Inc., BATS Y-Exchange, Inc., Chicago Stock Exchange, Inc., EDGA Exchange, Inc., EDGX Exchange, Inc., Financial Industry Regulatory Authority, Inc., NASDAQ OMX BX, Inc., NASDAQ OMX PHLX LLC, The Nasdaq Stock Market LLC, New York Stock Exchange LLC, NYSE MKT LLC, and NYSE Arca, Inc., as Modified by the Commission, For a Two-Year Period, Securities Exchange Act Release No. 74892 (May 6, 2015).

4. Conclusion

Based upon visual inspection, we are unable to identify clear thresholds for several stock characteristics above or below which stocks experience an improvement in market quality. We interpret the evidence as suggesting that the improvement in market quality observed for a limited number of stocks is essentially random with respect to observable stock characteristics. Therefore, we do not recommend further statistical analysis in search of thresholds—e.g., cluster analysis, classification/regression tree analysis—as they are unlikely to discover meaningful variation in the treatment effects.

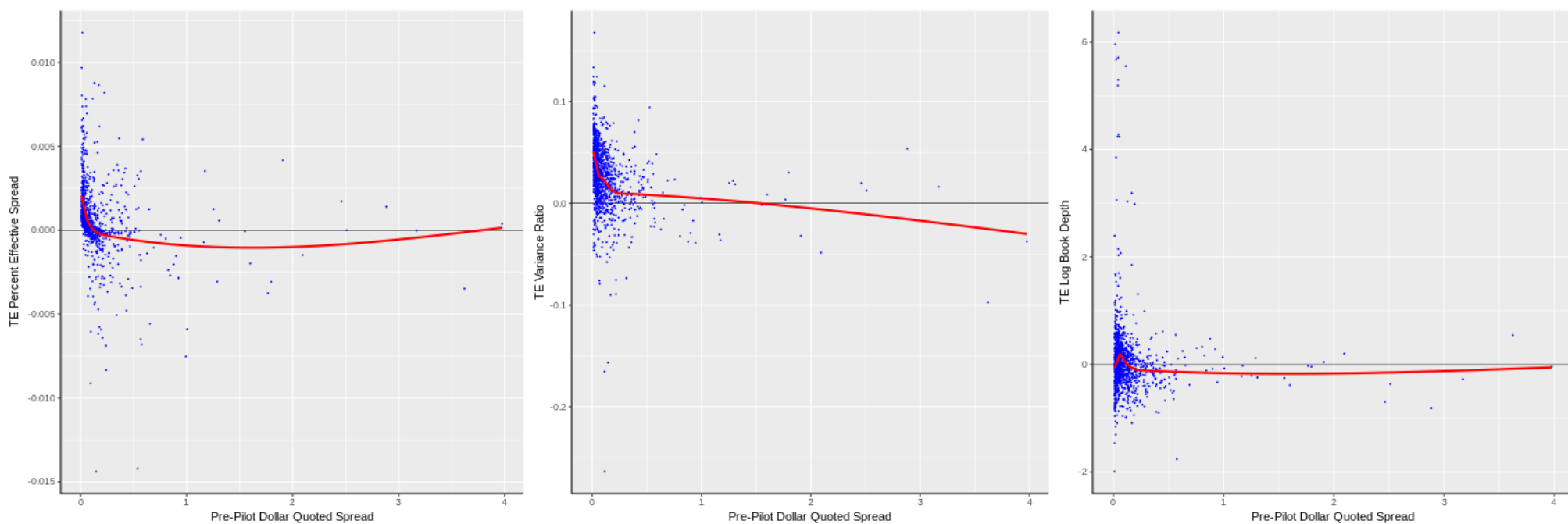


Figure 1: Treatment effects of market quality measures as a function of pre-Pilot dollar quoted spreads

This figure plots the treatment effects of market quality measures for stocks in the Test Groups in relation to each test stock’s average pre-Pilot dollar quoted spread. Each Test Group stock is matched with its ten nearest Control Group stocks using the methodology described in Appendix A. Treatment effects are calculated for each Test Group stock according to the following formula: $(T_{Pilot} - T_{Pre}) - (C_{Pilot} - C_{Pre})$, where T_{Pilot} and T_{Pre} are the average values of the market quality measure of the Test Group stock during the Pilot period (November 2016-February 2017) and pre-Pilot period (June 2016-September 2016), respectively, and C_{Pilot} and C_{Pre} are the average values of the market quality measure for the ten matched Control Group stocks during the Pilot period and pre-Pilot period, respectively. The market quality measures calculated for each stock are: percent effective spread (left panel), the variance ratio (middle panel), and log book depth (right panel). The horizontal axis is the value of the Test Group stock’s average pre-Pilot dollar quoted spread and the vertical axis is the value of the Test Group stock’s average treatment effect for the relevant market quality measure. The red line is the fitted values estimated from a generalized additive model with penalized cubic splines (see reference in supra note 8 for details). Please refer to Appendix B for detailed definitions of the variables.

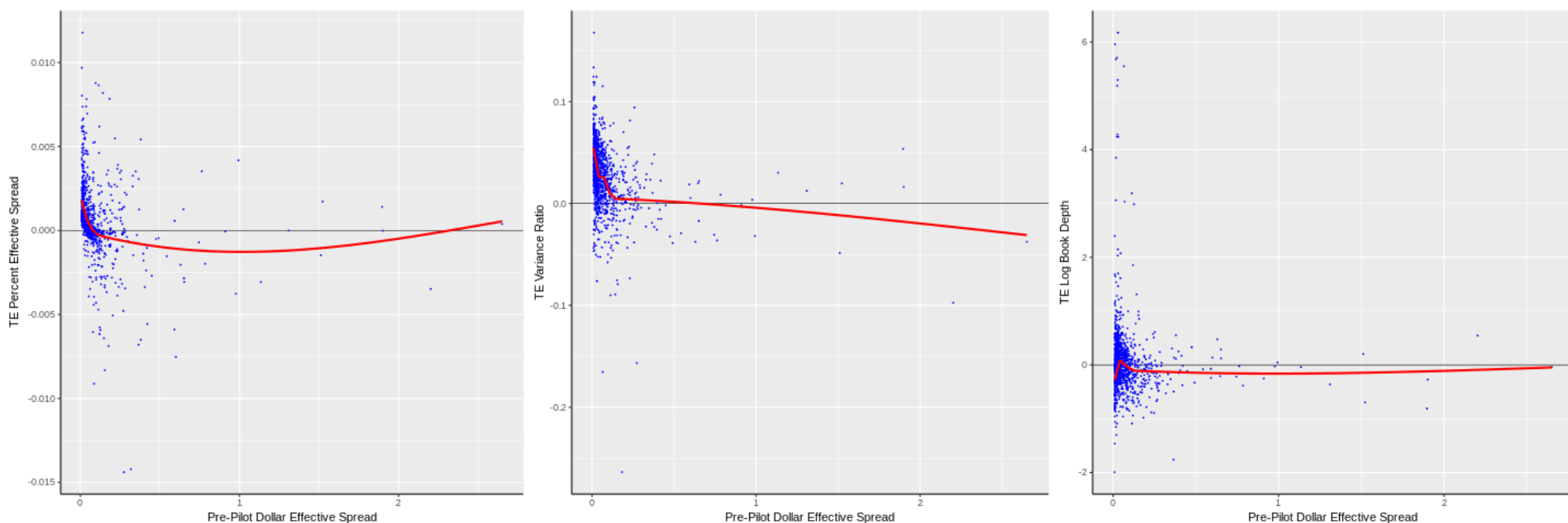


Figure 2: Treatment effects of market quality measures as a function of pre-Pilot dollar effective spread

This figure plots the treatment effects of market quality measures for stocks in the Test Groups in relation to each test stocks' average pre-Pilot dollar effective spread. Each Test Group stock is matched with its ten nearest Control Group stocks using the methodology described in Appendix A. Treatment effects are calculated for each Test Group stock according to the following formula: $(T_{Pilot} - T_{Pre}) - (C_{Pilot} - C_{Pre})$, where T_{Pilot} and T_{Pre} are the average values of the market quality measure of the Test Group stock during the Pilot period (November 2016-February 2017) and pre-Pilot period (June 2016-September 2016), respectively, and C_{Pilot} and C_{Pre} are the average values of the market quality measure for the ten matched Control Group stocks during the Pilot period and pre-Pilot period, respectively. The market quality measures calculated for each stock are: percent effective spread (left panel), the variance ratio (middle panel), and log book depth (right panel). The horizontal axis is the value of the Test Group stock's average pre-Pilot dollar effective spread and the vertical axis is the value of the Test Group stock's average treatment effect for the relevant market quality measure. The red line is the fitted values estimated from a generalized additive model with penalized cubic splines (see reference in supra note 8 for details). Please refer to Appendix B for detailed definitions of the variables.

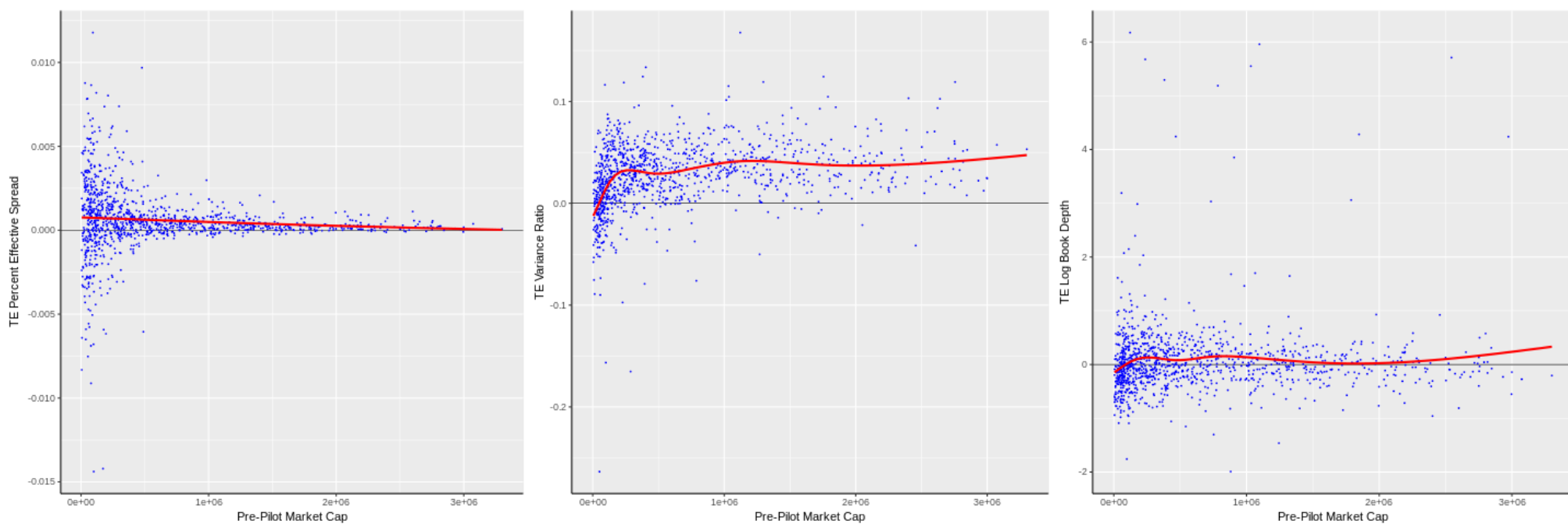


Figure 3: Treatment effects of market quality measures as a function of pre-Pilot market capitalization

This figure plots the treatment effects of market quality measures for stocks in the Test Groups in relation to each test stocks' average pre-Pilot market capitalization. Each Test Group stock is matched with its ten nearest Control Group stocks using the methodology described in Appendix A. Treatment effects are calculated for each Test Group stock according to the following formula: $(T_{Pilot} - T_{Pre}) - (C_{Pilot} - C_{Pre})$, where T_{Pilot} and T_{Pre} are the average values of the market quality measure of the Test Group stock during the Pilot period (November 2016-February 2017) and pre-Pilot period (June 2016-September 2016), respectively, and C_{Pilot} and C_{Pre} are the average values of the market quality measure for the ten matched Control Group stocks during the Pilot period and pre-Pilot period, respectively. The market quality measures calculated for each stock are: percent effective spread (left panel), the variance ratio (middle panel), and log book depth (right panel). The horizontal axis is the value of the Test Group stock's average pre-Pilot market capitalization and the vertical axis is the value of the Test Group stock's average treatment effect for the relevant market quality measure. The red line is the fitted values estimated from a generalized additive model with penalized cubic splines (see reference in supra note 8 for details). Please refer to Appendix B for detailed definitions of the variables.

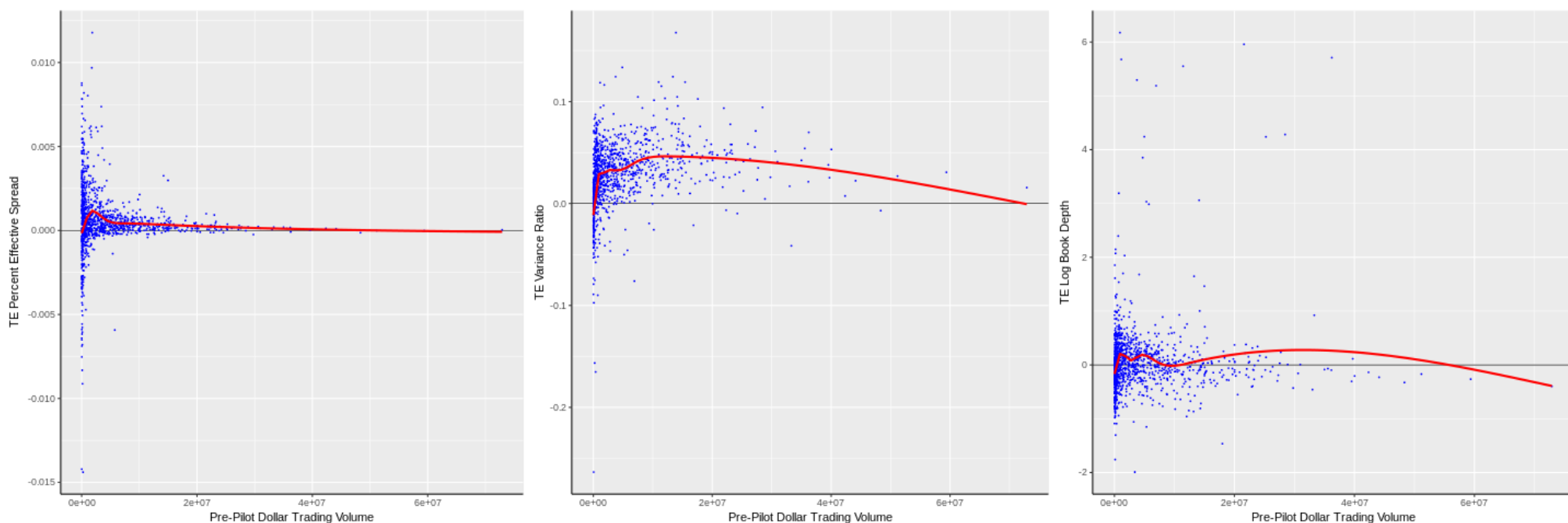


Figure 4: Treatment effects of market quality measures as a function of pre-Pilot dollar trading volume

This figure plots the treatment effects of market quality measures for stocks in the Test Groups in relation to each test stocks' average pre-Pilot dollar trading volume. Each Test Group stock is matched with its ten nearest Control Group stocks using the methodology described in Appendix A. Treatment effects are calculated for each Test Group stock according to the following formula: $(T_{Pilot} - T_{Pre}) - (C_{Pilot} - C_{Pre})$, where T_{Pilot} and T_{Pre} are the average values of the market quality measure of the Test Group stock during the Pilot period (November 2016-February 2017) and pre-Pilot period (June 2016-September 2016), respectively, and C_{Pilot} and C_{Pre} are the average values of the market quality measure for the ten matched Control Group stocks during the Pilot period and pre-Pilot period, respectively. The market quality measures calculated for each stock are: percent effective spread (left panel), the variance ratio (middle panel), and log book depth (right panel). The horizontal axis is the value of the Test Group stock's average pre-Pilot dollar trading volume and the vertical axis is the value of the Test Group stock's average treatment effect for the relevant market quality measure. The red line is the fitted values estimated from a generalized additive model with penalized cubic splines (see reference in supra note 8 for details). Please refer to Appendix B for detailed definitions of the variables.

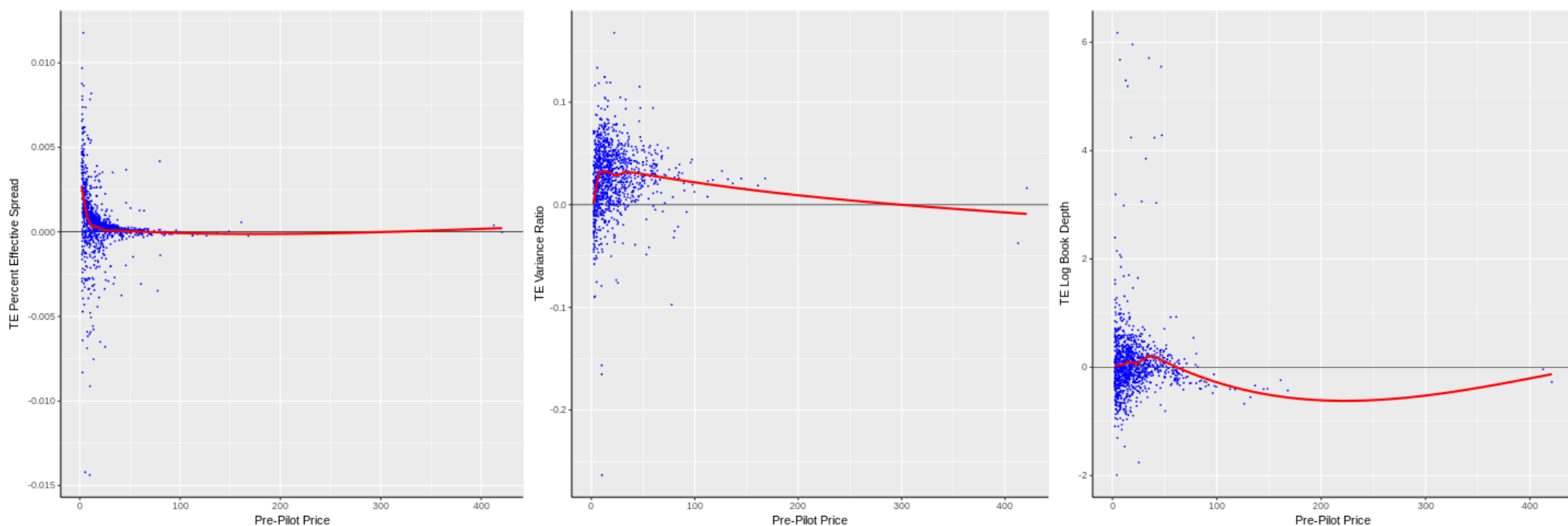


Figure 5: Treatment effects of market quality measures as a function of pre-Pilot price

This figure plots the treatment effects of market quality measures for stocks in the Test Groups in relation to each test stocks' average pre-Pilot price. Each Test Group stock is matched with its ten nearest Control Group stocks using the methodology described in Appendix A. Treatment effects are calculated for each Test Group stock according to the following formula: $(T_{Pilot} - T_{Pre}) - (C_{Pilot} - C_{Pre})$, where T_{Pilot} and T_{Pre} are the average values of the market quality measure of the Test Group stock during the Pilot period (November 2016-February 2017) and pre-Pilot period (June 2016-September 2016), respectively, and C_{Pilot} and C_{Pre} are the average values of the market quality measure for the ten matched Control Group stocks during the Pilot period and pre-Pilot period, respectively. The market quality measures calculated for each stock are: percent effective spread (left panel), the variance ratio (middle panel), and log book depth (right panel). The horizontal axis is the value of the Test Group stock's average pre-Pilot price and the vertical axis is the value of the Test Group stock's average treatment effect for the relevant market quality measure. The red line is the fitted values estimated from a generalized additive model with penalized cubic splines (see reference in supra note 8 for details). Please refer to Appendix B for detailed definitions of the variables.

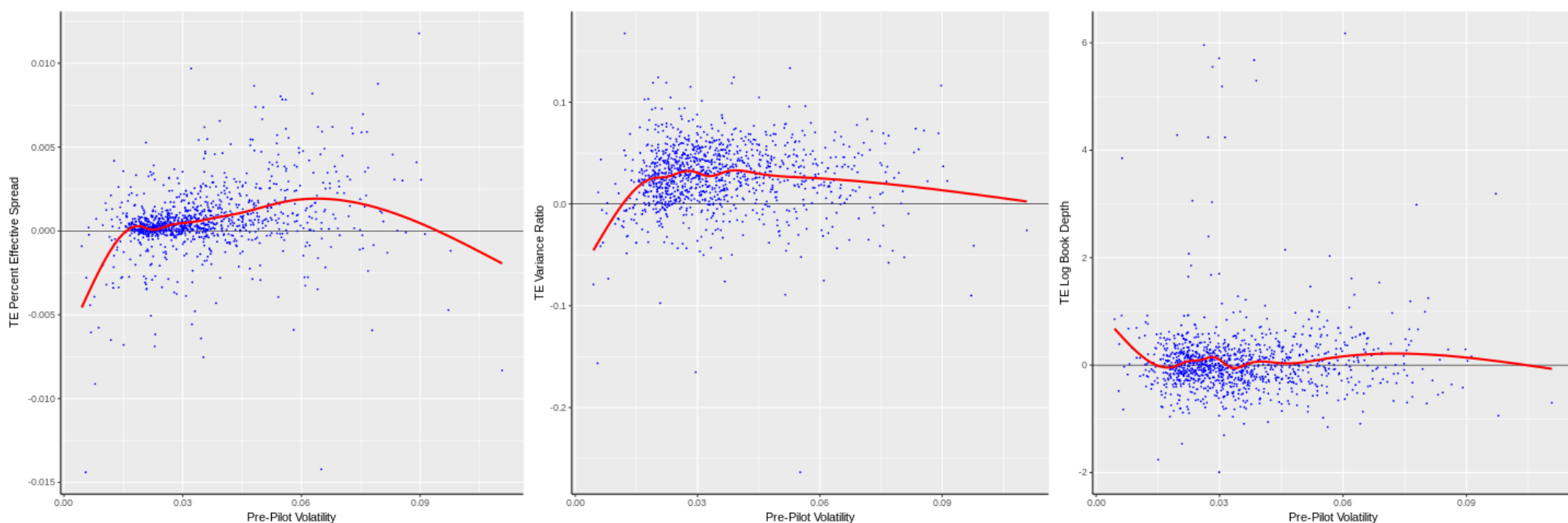


Figure 6: Treatment effects of market quality measures as a function of pre-Pilot volatility

This figure plots the treatment effects of market quality measures for stocks in the Test Groups in relation to each test stocks' average pre-Pilot volatility. Each Test Group stock is matched with its ten nearest Control Group stocks using the methodology described in Appendix A. Treatment effects are calculated for each Test Group stock according to the following formula: $(T_{Pilot} - T_{Pre}) - (C_{Pilot} - C_{Pre})$, where T_{Pilot} and T_{Pre} are the average values of the market quality measure of the Test Group stock during the Pilot period (November 2016-February 2017) and pre-Pilot period (June 2016-September 2016), respectively, and C_{Pilot} and C_{Pre} are the average values of the market quality measure for the ten matched Control Group stocks during the Pilot period and pre-Pilot period, respectively. The market quality measures calculated for each stock are: percent effective spread (left panel), the variance ratio (middle panel), and log book depth (right panel). The horizontal axis is the value of the Test Group stock's average pre-Pilot volatility and the vertical axis is the value of the Test Group stock's average treatment effect for the relevant market quality measure. The red line is the fitted values estimated from a generalized additive model with penalized cubic splines (see reference in supra note 8 for details). Please refer to Appendix B for detailed definitions of the variables.

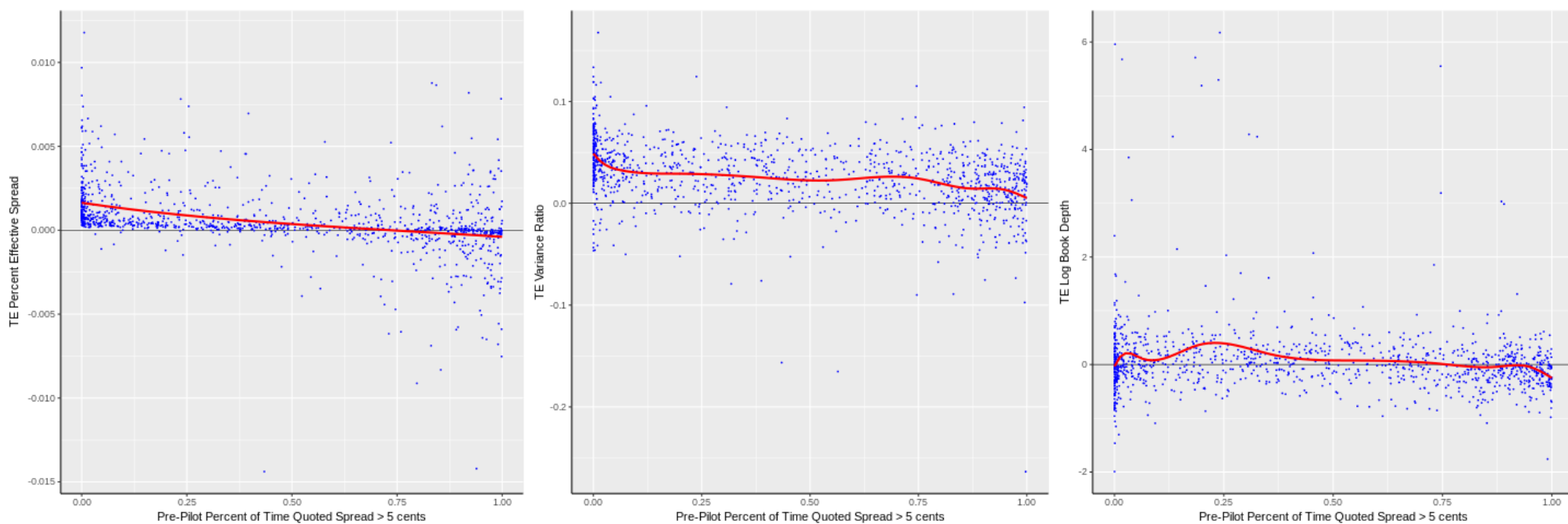


Figure 7: Treatment effects of market quality measures as a function of percent of time Pre-Pilot quoted spreads are greater than five cents

This figure plots the treatment effects of market quality measures for stocks in the Test Groups in relation to the percentage of time each stock’s quoted spreads were greater than five cents during the pre-Pilot period. Each Test Group stock is matched with its ten nearest Control Group stocks using the methodology described in Appendix A. Treatment effects are calculated for each Test Group stock according to the following formula: $(T_{Pilot} - T_{Pre}) - (C_{Pilot} - C_{Pre})$, where T_{Pilot} and T_{Pre} are the average values of the market quality measure of the Test Group stock during the Pilot period (November 2016-February 2017) and pre-Pilot period (June 2016-September 2016), respectively, and C_{Pilot} and C_{Pre} are the average values of the market quality measure for the ten matched Control Group stocks during the Pilot period and pre-Pilot period, respectively. The market quality measures calculated for each stock are: percent effective spread (left panel), the variance ratio (middle panel), and log book depth (right panel). The horizontal axis is the percentage of time each stock’s quoted spreads were greater than five cents during the pre-Pilot period and the vertical axis is the value of the Test Group stock’s average treatment effect for the relevant market quality measure. The red line is the fitted values estimated from a generalized additive model with penalized cubic splines (see reference in supra note 8 for details). Please refer to Appendix B for detailed definitions of the variables.

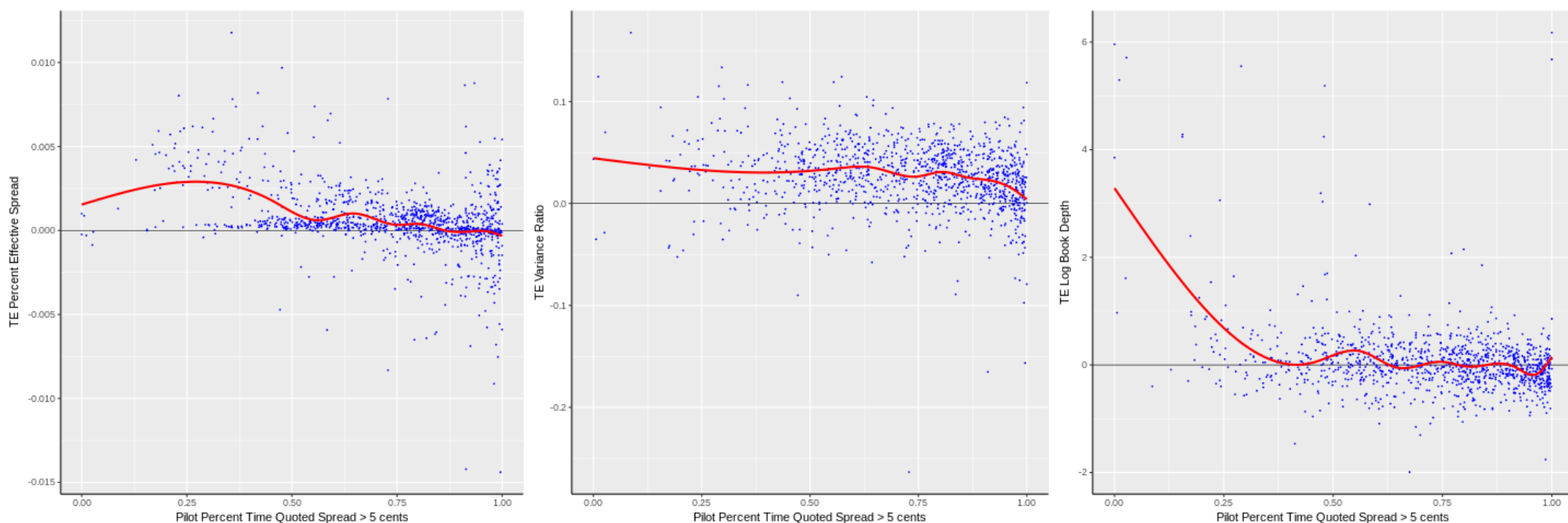


Figure 8: Treatment effects of market quality measures as a function of percent of time Pilot quoted spreads are greater than five cents

This figure plots the treatment effects of market quality measures for stocks in the Test Groups in relation to the percentage of time each stock’s quoted spreads were greater than five cents during the Pilot period. Each Test Group stock is matched with its ten nearest Control Group stocks using the methodology described in Appendix A. Treatment effects are calculated for each Test Group stock according to the following formula: $(T_{Pilot} - T_{Pre}) - (C_{Pilot} - C_{Pre})$, where T_{Pilot} and T_{Pre} are the average values of the market quality measure of the Test Group stock during the Pilot period (November 2016-February 2017) and pre-Pilot period (June 2016-September 2016), respectively, and C_{Pilot} and C_{Pre} are the average values of the market quality measure for the ten matched Control Group stocks during the Pilot period and pre-Pilot period, respectively. The market quality measures calculated for each stock are: percent effective spread (left panel), the variance ratio (middle panel), and log book depth (right panel). The horizontal axis is the percentage of time each stock’s quoted spreads were greater than five cents during the Pilot period and the vertical axis is the value of the Test Group stock’s average treatment effect for the relevant market quality measure. The red line is the fitted values estimated from a generalized additive model with penalized cubic splines (see reference in supra note 8 for details). Please refer to Appendix B for detailed definitions of the variables.

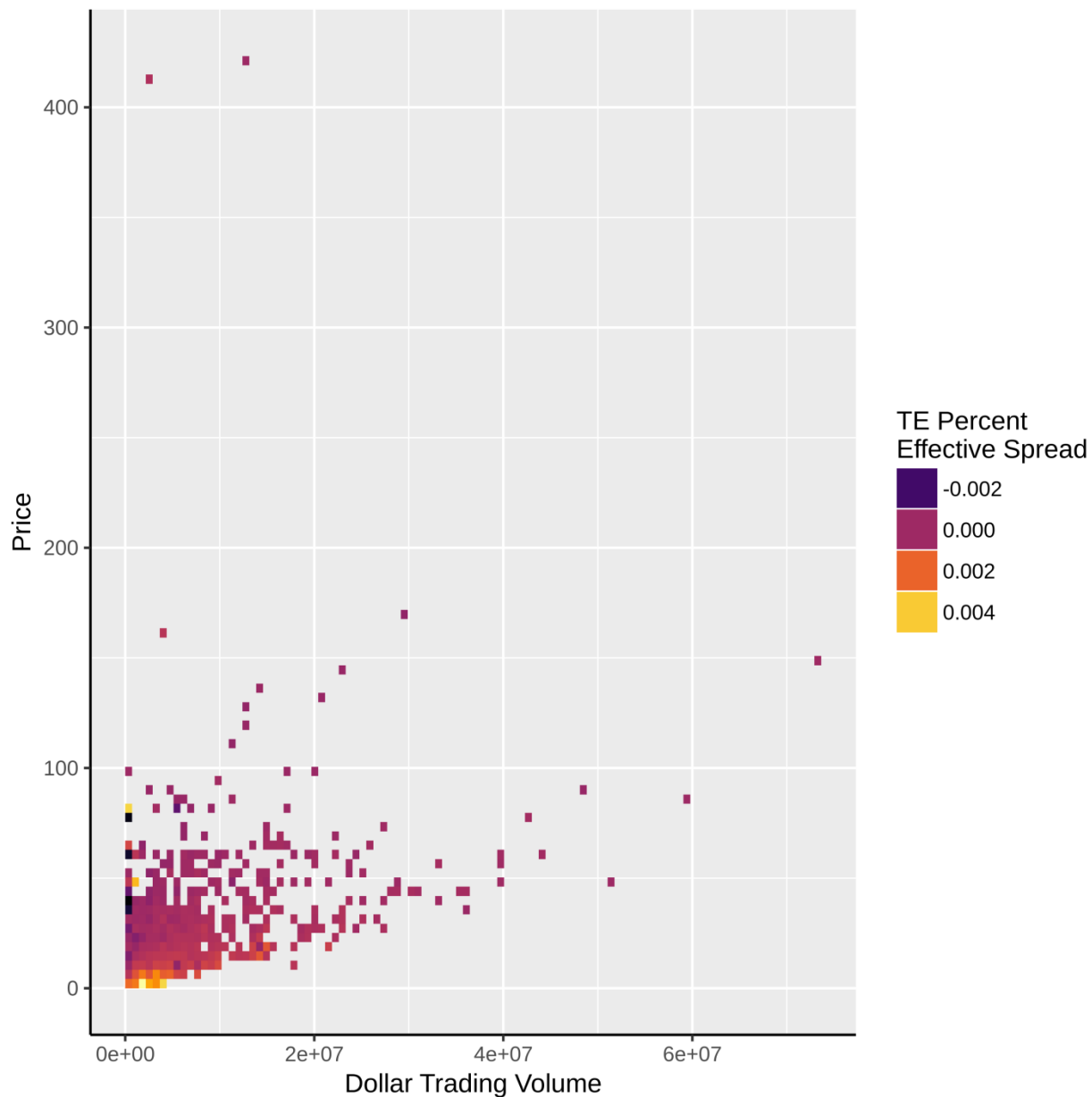


Figure 9: Heat Map of the treatment effect of percent effective spread as a function of dollar trading volume and price.

This heat map plots the treatment effect of the percent effective spread for stocks in the Test Groups in relation to each test stocks' average pre-Pilot dollar trading volume and price. Each Test Group stock is matched with its ten nearest Control Group stocks using the methodology described in Appendix A. The horizontal axis is the value of the Test Group stock's average pre-Pilot dollar trading volume and the vertical axis is the value of the Test Group stock's average pre-Pilot price. The colored area indicates the value of the treatment effect of percent effective spread for the Test Group stock in relation to the stock's corresponding dollar trading volume and price. A lower/higher treatment effect is indicated by a darker/lighter color in the colored bar, respectively. Please refer to Appendix B for detailed definitions of the variables.

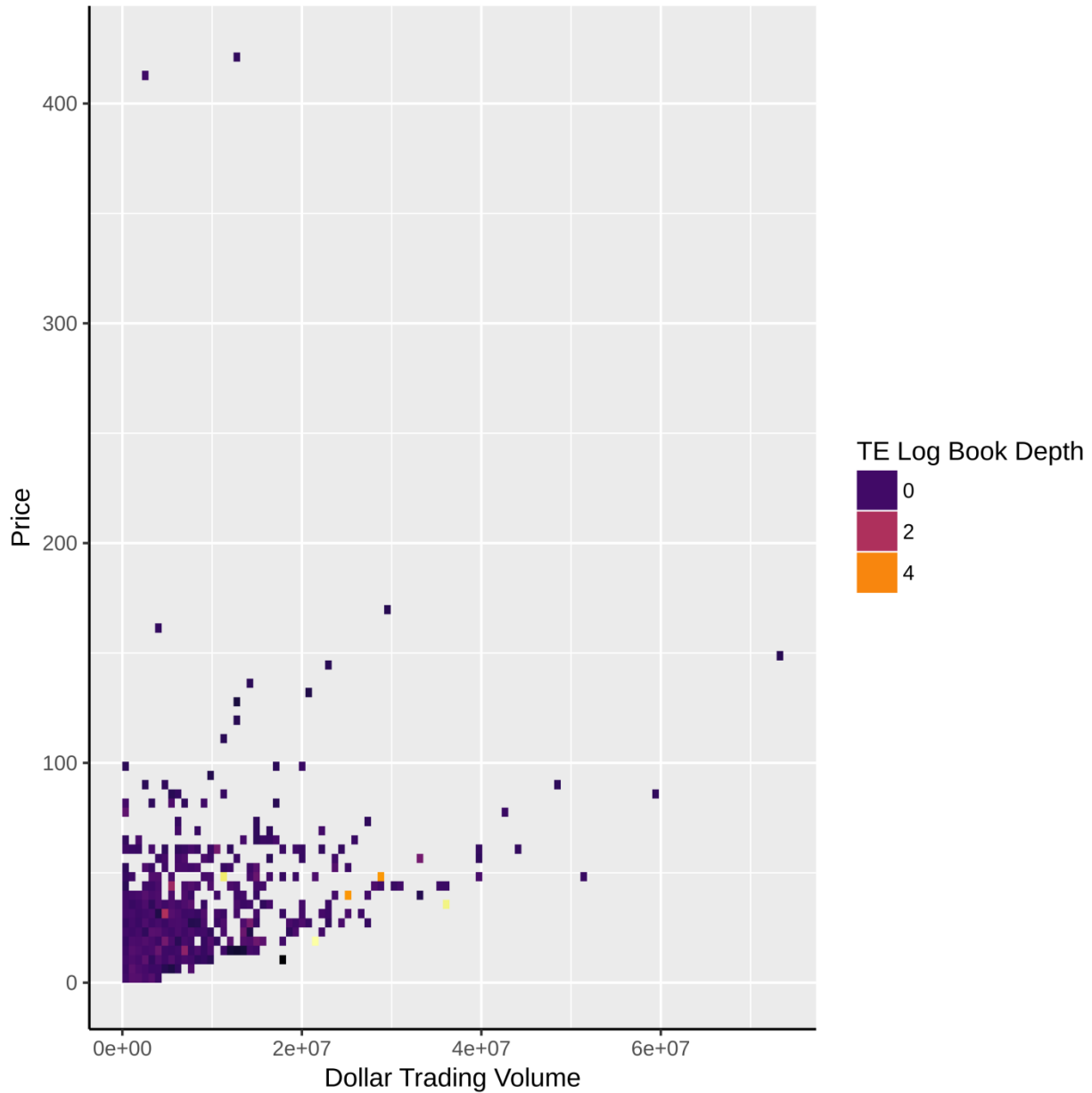


Figure 10: Heat map of the treatment effect of log book depth as a function of dollar trading volume and price.

This heat map plots the treatment effects of the log book depth for stocks in the Test Groups in relation to each test stocks' average pre-Pilot dollar trading volume and price. Each Test Group stock is matched with its ten nearest Control Group stocks using the methodology described in Appendix A. The horizontal axis is the value of the Test Group stock's average pre-Pilot dollar trading volume and the vertical axis is the value of the Test Group stock's average pre-Pilot price. The colored area indicates the value of the treatment effect of log book depth for the Test Group stock in relation to the stock's corresponding dollar trading volume and price. A lower/higher treatment effect is indicated by a darker/lighter color in the colored bar, respectively. Please refer to Appendix B for detailed definitions of the variables.

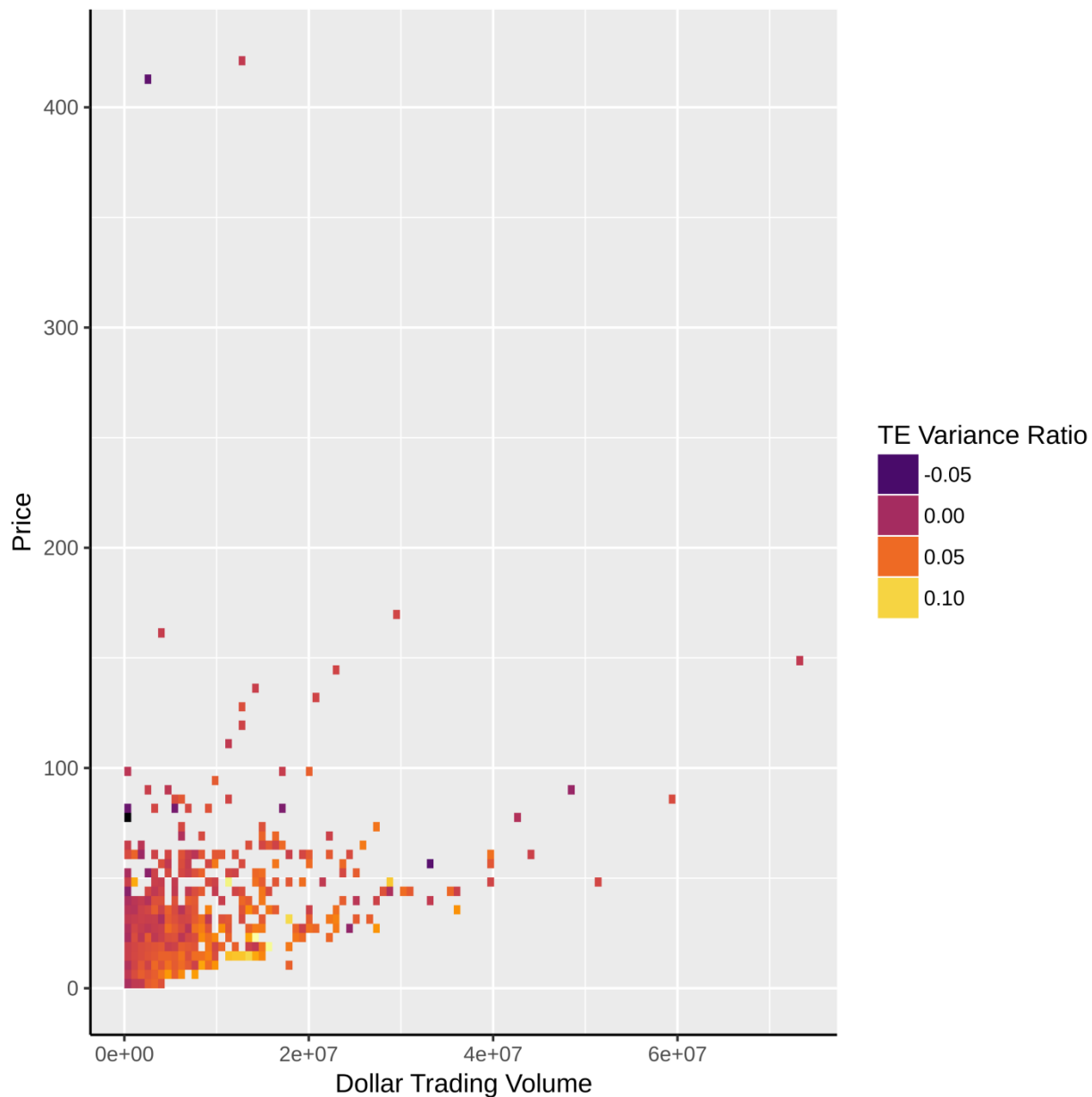


Figure 11: Heat map of the treatment effect of the variance ratio as a function of dollar trading volume and price.

This heat map plots the treatment effects of the variance ratio for stocks in the Test Groups in relation to each test stocks' average pre-Pilot dollar trading volume and price. Each Test Group stock is matched with its ten nearest Control Group stocks using the methodology described in Appendix A. The horizontal axis is the value of the Test Group stock's average pre-Pilot dollar trading volume and the vertical axis is the value of the Test Group stock's average pre-Pilot price. The colored area indicates the value of the treatment effect of the variance ratio for the Test Group stock in relation to the stock's corresponding dollar trading volume and price. A lower/higher treatment effect is indicated by a darker/lighter color in the colored bar, respectively. Please refer to Appendix B for detailed definitions of the variables.

Table 1: Descriptive Statistics

This table presents descriptive statistics for stocks in the Tick Size Pilot during the pre-Pilot (June 2016-September 2016) and Pilot (November 2016-February 2017) periods. Panel A presents descriptive statistics for stocks in the three Test Groups. Panel B presents descriptive statistics for stocks in the Control Group. Please refer to Appendix B for detailed definitions of the variables.

Panel A: Test Stock Descriptive Statistics (N = 1,160)

Variable	N	Mean	Std Dev	25th Pctl	Median	75th Pctl
pre-Pilot Dollar Quoted Spread	1,160	0.1410	0.2915	0.0332	0.0638	0.1404
pre-Pilot Percent Quoted Spread	1,160	0.0040	0.0055	0.0009	0.0019	0.0046
pre-Pilot Dollar Effective Spread	1,160	0.0857	0.1778	0.0211	0.0393	0.0848
pre-Pilot Percent Effective Spread	1,160	0.0026	0.0036	0.0005	0.0012	0.0031
pre-Pilot Market Capitalization	1,160	654,722	691,888	124,577	380,760	1,001,232
pre-Pilot Dollar Trading Volume	1,160	4,794,406	7,376,094	351,641	1,752,659	6,238,085
pre-Pilot Price	1,160	22.08	26.46	7.39	15.28	27.91
pre-Pilot Volatility	1,160	0.0346	0.0159	0.0229	0.0308	0.0425
pre-Pilot Book Depth	1,160	71,574	127,592	25,640	43,926	79,902
Percent Time pre-Pilot Quoted Spread greater than five cents	1,160	0.4581	0.3678	0.0665	0.4196	0.8414
Percent Time Pilot Quoted Spread greater than five cents	1,160	0.7295	0.2112	0.5862	0.7825	0.9103

Panel B: Control Stock Descriptive Statistics (N = 1,162)

Variable	N	Mean	Std Dev	25th Pctl	Median	75th Pctl
pre-Pilot Dollar Quoted Spread	1,162	0.1476	0.3074	0.0341	0.0630	0.1386
pre-Pilot Percent Quoted Spread	1,162	0.0041	0.0059	0.0010	0.0018	0.0048
pre-Pilot Dollar Effective Spread	1,162	0.0901	0.1878	0.0218	0.0386	0.0845
pre-Pilot Percent Effective Spread	1,162	0.0027	0.0038	0.0006	0.0011	0.0031
pre-Pilot Market Capitalization	1,162	657,795	699,187	139,852	370,599	927,665
pre-Pilot Dollar Trading Volume	1,162	4,613,796	7,096,807	367,981	1,802,246	5,811,051
pre-Pilot Price	1,162	21.77	24.60	7.71	14.82	27.65
pre-Pilot Volatility	1,162	0.0347	0.0163	0.0227	0.0307	0.0436
pre-Pilot Book Depth	1,162	69,297	132,774	25,387	42,412	75,593
Percent Time pre-Pilot Quoted Spread greater than five cents	1,162	0.4542	0.3650	0.0770	0.4137	0.8316
Percent Time Pilot Quoted Spread greater than five cents	1,162	0.4501	0.3657	0.0753	0.3995	0.8329

Table 2: Market Quality Changes

This table presents summary statistics for changes in market quality measures between the Pilot period (November 2016-February 2017) and pre-Pilot period (June 2016-September 2016) for stocks in the Tick Size Pilot. Changes in market quality are calculated for each stock as the average value of the market quality measure during the Pilot period minus the average value during the pre-Pilot period. Each Test Group stock is matched with its ten nearest Control Group stocks using the methodology described in Appendix A. Panel A shows the changes for stocks in the three Test Groups. Panel B shows the average change for the ten nearest Control Group stocks matched to each Test Group stock. Panel C shows the summary statistics for the treatment effects for Test Group stocks. Treatment effects are calculated for each Test Group stock according to the following formula: $(T_{Pilot} - T_{Pre}) - (C_{Pilot} - C_{Pre})$, where T_{Pilot} and T_{Pre} are the average values of the market quality measure of the Test Group stock during the Pilot period (November 2016-February 2017) and pre-Pilot period (June 2016-September 2016), respectively, and C_{Pilot} and C_{Pre} are the average values of the market quality measure for the ten matched Control Group stocks during the Pilot period and pre-Pilot period, respectively. Please refer to Appendix B for detailed definitions of the variables.

Panel A: Test Stock Market Quality Changes

Variable	N	Mean	Std Dev	25th Pctl	Median	75th Pctl
Change Percent Effective Spread	1160	0.000592	0.001854	-0.000024	0.000364	0.001060
Change Log Book Depth	1160	0.1918	0.6790	-0.1237	0.1007	0.3664
Change Variance Ratio	1158 ¹¹	-0.0875	0.0490	-0.1200	-0.0796	-0.0561

Panel B: Control Stock Market Quality Changes

Variable	N	Mean	Std Dev	25th Pctl	Median	75th Pctl
Change Percent Effective Spread	1160	-0.000002	0.000816	-0.000100	-0.000009	0.000050
Change Log Book Depth	1160	0.1259	0.1630	0.0316	0.1100	0.2030
Change Variance Ratio	1160	-0.1142	0.0263	-0.1343	-0.1108	-0.0965

Panel C: Market Quality Treatment Effects

Variable	N	Mean	Std Dev	25th Pctl	Median	75th Pctl
TE Percent Effective Spread	1160	0.000594	0.001969	-0.000007	0.000377	0.001150
TE Log Book Depth	1160	0.0659	0.6790	-0.2371	-0.0067	0.2348
TE Variance Ratio	1158	0.0267	0.0320	0.0096	0.0285	0.0456

¹¹ Two Test Group stocks are dropped in Panel A and C due to missing Variance Ratios during the Pilot period.

Appendix A: Matched Sample Construction

In order to examine variation in the treatment effects of increasing the minimum tick size, we construct a matched sample where we match each stock in the Test Groups with similar stocks in the Control Group.

More specifically, for each stock in the Test Groups we compute a distance measure between that stock and all stocks in the Control Group. The distance measure is calculated using the formula:

$$Distance_{t,c} = \sqrt{\sum_{i=1}^N (X_{i,t} - X_{i,c})^2},$$

where $X_{i,t}$ and $X_{i,c}$ are the i th characteristic of the Test Group stock, t , and the Control Group stock, c , it is being compared to. The stock characteristics used to calculate the distance measure are the standardized average values of the following variables for each Test and Control Group stock during the pre-Pilot period: dollar quoted spread, market capitalization, dollar trading volume, price, book depth, and volatility.

For each Test Group stock, we pick, with replacement, the ten nearest Control Group stocks with the shortest distance to serve as our corresponding matched control stocks. We then compute the average change in the market quality measures between the Pilot period (November 2016-February 2017) and pre-Pilot period (June 2016-September 2016) for the ten matched Control Group stocks. Treatment effects are calculated for each Test Group stock according to the following formula: $(T_{Pilot} - T_{Pre}) - (C_{Pilot} - C_{Pre})$, where T_{Pilot} and T_{Pre} are the average values of the market quality measure of the Test Group stock during the Pilot period (November 2016-February 2017) and pre-Pilot period (June 2016-September 2016), respectively, and C_{Pilot} and C_{Pre} are the average values of the market quality measure for the ten matched Control Group stocks during the Pilot period and pre-Pilot period, respectively. The market quality measures calculated for each stock are: percent effective spread, the variance ratio, and log book depth. Please refer to Appendix B for detailed definitions of the variables.

Appendix B: Data Sources, Sample Construction, and Definitions of Variables

This section provides a brief overview of our sample and the data sources we use for our analysis.

The sample used in our study includes 2,322 stocks in the Control Group and Test Groups of the Tick Size Pilot. Given that the Pilot came into effect following a staggered implementation schedule during October 2016,¹² we define the four months prior to October 2016 (i.e., June 2016 - September 2016) as the pre-Pilot period and the four months after October 2016 (i.e., November 2016 - February 2017) as the Pilot period.

In this study, we use publicly available data from the Market Information Data Analytics System (MIDAS), the NYSE's Daily Trade and Quote (TAQ) database, and the Center for Research in Security Prices (CRSP) database. The MIDAS database provides information on the displayed limit order book for each of the national securities exchanges. The TAQ database provides intraday transaction and quotation data for all NMS stocks traded on the national securities exchanges. The CRSP database provides information on stock characteristics as well as daily trading volume and prices. We use this data to construct the market quality measures and other variables used in our analysis. We filter the TAQ data following Holden and Jacobsen (2014). We winsorize the variables at 0.1% and 99.9% levels to remove outliers.

Below are descriptions of the variables we use in our analysis. For most of our analysis, we compute the average value of the variable for each stock over the pre-Pilot period and Pilot period, respectively.

Variables	Definition	Data Sources
Dollar Quoted Spread	Time-weighted daily average of the quoted bid-ask spread for a stock-day observation. The dollar quoted bid-ask spread is calculated using the difference between the NBO and the NBB.	TAQ data
Percent Quoted Spread	Time-weighted daily average of relative quoted bid-ask spread for a stock-day observation. The percent quoted bid-ask spread is calculated using the difference between the log of the NBO and the log of the NBB.	TAQ data

¹² See Appendix A of the market quality paper referenced in supra note 2.

Dollar Effective Spread	Share-weighted daily average of the effective bid-ask spread for a stock-day observation. The dollar effective bid-ask spread is defined as double the signed difference between the trade price and the NBBO midquote before the trade took place.	TAQ data
Percent Effective Spread	Share-weighted daily average of relative effective bid-ask spread for a stock-day observation. The percent effective bid-ask spread is defined as double the signed difference between the log trade price and the log NBBO midquote before the trade took place.	TAQ data
Book Depth	The stock day average of the cumulative dollar value of limit order book depth that is displayed across all exchanges within five cents of the NBBO.	MIDAS
Log Book Depth	The natural log (ln) of Book Depth.	MIDAS
Variance Ratio	This is a ratio of the variance of a stock's midpoint returns measured at different frequencies. A higher value indicates that the stock's price deviates further from the properties of a random walk and, therefore, prices are less efficient. ¹³	TAQ data
Dollar Trading Volume	The dollar trading volume of a stock on a given date. Defined as price times CRSP daily shares traded.	CRSP database
Volatility	Stock price volatility of a stock on a given date, defined as (daily high price – daily low price) / closing price.	CRSP database

¹³ This is the variance ratio measure defined in Appendix A of Comerton-Forde, Carole and Talis Putnins, 2015, "Dark Trading and Price Discovery," Journal of Financial Economics 118, 70-92.

Price	The daily closing price (or the average of closing bid and ask price if there was no closing trade) for a stock.	CRSP database
Market Capitalization (\$M)	The daily market capitalization, defined as closing price times the number of shares outstanding, for a stock.	CRSP database
Percent Time Quoted Spread greater than five cents	The percentage of time during the stock-day that the dollar quoted spread is greater than five cents.	MIDAS