The Internet Appendix to accompany

The Endogeneity of Trading Volume in Stock and Bond Returns: An Instrumental Variable Approach

In this Appendix we present a critical review of the return-volume literature and report the results of supplementary robustness checks. The remainder of the Internet Appendix is organized as follows. In Appendix A, we present a critical review of the return-volume literature. Appendix B presents the results of endogeneity tests, instrument relevance tests, and exogeneity tests for our bond analysis.

Appendix A. A Review of the Literature

The relationship between returns (or price changes) and volume is well studied in the existing literature. A positive correlation between the absolute value of price changes and volume has been documented using transactions level (Epps and Epps, 1976; Smirlock and Starks, 1988), intra-daily (e.g., Jain and Joh, 1988; Foster and Viswanathan, 1993; Chan et al., 1996; Xu, Chen, and Wu, 2006), daily (e.g., Safvenblad, 2000; Lee and Rui (2002), intra-weekly (Chang, Pinegar, and Schachter, 1997), weekly (e.g., Downing and Zhang, 2004), and monthly (e.g., Lee and Swaminathan, 2000) data on individual stocks (e.g., Parisi and Acevedo, 2001), stock indices (e.g., Hiemstra and Jones, 1994), bonds (e.g., Downing and Zhang, 2004), currency futures (e.g., Grammatikos and Saunders, 1986; Mougoué and Aggarwal, 2011), commodity futures (Chang, Pinegar, and Schachter, 1997), T-bills futures (Tauchen and Pitts, 1983) and Bitcoin (Balcilar et al., 2017). Although most of the previous studies focus on the American market, several studies use data from international markets such as Singapore (Arrif and Lee, 1993), Finland (Martikainen et al., 1994), Canada (Smith et al., 1997), Sweden (Safvenblad, 2000), Chile (Parisi and Acevedo, 2001), Hong Kong (Henry and McKenzie, 2006), and Korea (Umutlu and Shackleton, 2015). Internet Appendix Table 1 provides a systematic summary of this literature.

Appendix B. Robustness Tests and Diagnostics

This section presents the results of endogeneity tests, instrument relevance tests, and exogeneity tests for our bond analysis.

B.1. Bond Analysis: Endogeneity tests results

Internet Appendix Table 2 shows the results of our test for the endogeneity of bond return and bond trading activity measures. Panel A reports the results of the Hausman chi-squared test, and shows evidence of the rejection of the null hypothesis for all three measures at the 1% significance level. The rejection of the null hypothesis implies that our various measures for bond trading activity are indeed endogenous to bond returns and thus validates the instrumental variable approach. Panel B reports the computed chi-square statistics of the Granger causality test with their marginal levels. The figures show evidence of significant bidirectional Granger causality between bond returns and both the weighted volume and the number of trades at the 1% significance level. The results also show evidence of unidirectional causality from total bond volume to bond returns. Panel C presents Pearson correlation coefficients among the bond return and the three measures of bond trading activity. The results of correlation analysis show that bond returns are significantly negatively correlated to the weighted bond volume measure and positively correlated to the number of bond transactions. The correlation between bond return and number of bonds traded is insignificant. Overall, the results in Internet Appendix Table 2 indicate that bond return and volume are determined simultaneously.

B.2. Bond Analysis: Testing the instruments relevance condition $\left(Cov\left(Z_{j,t}^{B},\ V_{j,t}^{B}\right) \neq 0\right)$

Internet Appendix Table 3 empirically validates our choice of instruments in our empirical specification for the bond analysis. In Panel A, we use different specifications for the three volume measures. Columns (1), (3), and (5) use our two instruments $(Age^{B}, Size^{B})$ only, while columns (2), (4), and (6) include the instruments and the control variables $(MKT, SMB, HML, TERM, DEF)$. Our results for our instrumental variables are all consistent with those reported in Alexander, Edwards, and Ferri (2000) and Hotchkiss and Jostava (2007). As expected, both our instruments appear to be significant determinants of trading in the corporate bond market. All the coefficients on $Size^{B}$ are significantly positive in all regressions and the impact is robust for the three bond trading measures. Further, the coefficients on Age^{B} are significantly negative in explaining the number of bonds traded, and the number of transactions. The results also show that $SMB, TERM,$ and DEF are significant determinants for the three bond volume measures. Further, an F-test for examining if our instrumental and control variables are jointly equal to zero is rejected at the 1% level.

Panel B in Internet Appendix Table 3 presents the Pearson correlation coefficients for the three measures of bond trading activity and the various instruments to further validate our choice of instruments. The results from the correlation analysis confirm those from Panel A, and show that both instrumental variables are significantly correlated with all three measures of bond trading activity.

B.3. Bond Analysis: Testing the instruments exogeneity condition $\left(Cov\left(Z_{j,t}^{B}, \epsilon_{2j,t}\right) = 0\right)$

Turning now to testing the second condition, our instruments for bond trading must be exogenous (unrelated) to bond returns. Internet Appendix Table 4 reports the results of four exogeneity tests for bonds analogous to those reported in Table 5 of the main paper for stocks. In Panel A, the results for the over-identification test clearly show that Hansen J-test fails to detect misspecification in our simultaneous system of Equation (9). All the statistics are insignificant, and this result is robust across the three volume measures.

In Panel B, the much higher incidence of statistically significant variables indicates that our instruments are not significantly related to bond returns, and as such, our simultaneous model measures only the effect of bond trading volume on bond return and not of the effect of the instrumental variables on bond return. Conversely, the coefficient estimates of regressing bond return on $PVOL^B, TTM^B, Rating^S$, and $S\&P$ are highly significant at 1% level, and this finding confirms our intuition for excluding these variables from our set of instruments.[1]

[1] The literature on the direction of the impact of the non-liquidity-based trading variables ($PVOL^B, TTM^B, Rating^B, S\&P$) on corporate bond trading is divided. For example, Harris and Raviv (1993) theorize that price volatility $PVOL^B$ reflects differences in opinions and thus induces more trading, and Alexander, Edwards, and Ferri (2000) empirically validate such a theoretical prediction. Conversely, Hotchkiss and Jostava (2007) find an opposite result. Our results in Panel B of Internet Appendix Table 4 shows that price volatility induces more bond trading, measured by the weighted volume and the number of bonds traded. We also observe that the coefficients on TTM^B are significantly negative at 1% level when volume is measured by weighted volume and the total number of bonds traded. This result is consistent with Hotchkiss and Jostava (2007). Moreover, Alexander, Edwards, and Ferri (2000) find that bonds with higher credit risk have higher volume, while Hotchkiss and Jostava (2007) find that higher credit risk induces less trading. Our results for the coefficients on $Rating^B$ suggest that credit rating has a significant negative impact on the weighted volume measure and the number of bond transactions, and a significant positive impact on the number of bonds traded. Our results also show that equity market conditions proxied by $S\&P$ are positively correlated with the number of bonds traded and the number of bond transactions. This result contrasts with Hotchkiss and Jostava (2007).

Panel C reports the results of our third exogeneity test that involves regressing current bond returns on future values of our instruments under the null hypothesis of exogeneity. We find that the fixed effect coefficients for the future values of bond age Age_{t+1}^{B} are insignificant in all regressions, while the future values of bond size $Size_{t+1}^{B}$ are significant. In the second specification which also includes the endogenous determinants of bond trading in columns (2), (4), and (6), the coefficient estimates for the future realizations of time to maturity TTM_{t+1}^{B} are significant.

Panel D reports the results of our last exogeneity test that involves regressing current levels of Age^{B} and $Size^{B}$ on lagged returns and lagged instrumental variables under the null hypothesis of strict exogeneity. The results show that the coefficients of regressing both instruments (Age^{B} and $Size^{B}$) on lagged returns are all insignificant at 5% level, while the coefficients of regressing $PVOL^{B}$, TTM^{B} and $Rating^{B}$ on lagged returns are all significant.

Table 1: A survey of selected previous empirical studies on the price-changes-volume research

Study	Financial security	Estimation methodology used	Main findings	Addresses endogeneity?
Clark (1973)	Cotton futures	Linear regression (OLS)	Positive contemporaneous relation, but no causal relation from volume to returns	No
Epps and Epps (1976)	20 NYSE stocks	Linear regression (OLS)	Positive contemporaneous volume-volatility relation	No
Rogalski (1978)	10 stocks and their warrants	Linear Granger Causality	Positive contemporaneous, but no lagged relation	No
Tauchen and Pitts (1983)	90-day T-bills futures market	Linear regression (MLE)	Positive contemporaneous relation	No
Grammatikos and Saunders (1986)	Currency futures	Linear Granger Causality	Positive bidirectional causality relation	No
Jain and Joh (1988)	NYSE index	Linear regression and Granger causality	Positive contemporaneous and lagged relation	No
Smirlock and Starks (1988)	300 NYSE stocks	Linear Granger causality	Positive causal relation	No
Lamoureux and Lastrapes (1990)	20 CBOE stocks	GARCH (MLE)	Positive lagged volume-volatility relation	No
Gallant, Rossi, and Tauchen (1992)	S&P index and NYSE stocks	A semi-nonparametric estimation technique	Positive contemporaneous nonlinear correlation	No
Campbell, Grossman, and Wang (1993)	NYSE and AMEX indices	Non-linear regression	Large volume induces negative index return autocorrelations	No
Foster and Viswanathan (1993)	60 NYSE stocks	Linear regression (GMM)	High trading volume decreases return autocorrelation	No
Conrad, Hameed, and Niden (1994)	NASDAQ stocks	Volume-based portfolio strategies	Negative relation between lagged volume and returns in individual securities.	No
Hiemstra and Jones (1994)	DJIA index	Linear and Nonlinear Granger Causality	Nonlinear bidirectional causality between returns and volume	partially
Chan et al. (1996)	Foreign stocks listed on NYSE	Linear regression (GMM)	U-shaped patterns of volume and volatility	No
Chang, Pinegar, and Schachter (1997)	Commodity Futures	Linear regression (Newey–West)	Positive relation between intraday volume and volatility	No
Smith et al. (1997)	Toronto Stock Exchange	Linear regression (West)	Positive relation between intraday volume and volatility	No
Brooks (1998)	NYSE and DJIA indices	Non-linear Granger causality and GARCH	Bi-directional Granger-causality between volume and volatility	No
Chan and Fong (2000)	NYSE and Nasdaq stocks	Linear regression (OLS)	Positive relation between price volatility and volume	No
Chordia and Swaminathan (2000)	All firms in the NYSE/AMEX	Volume-based portfolio strategies	Trading volume is a significant determinant of lead-lag cross-autocorrelations in returns	No
Lee and Swaminathan (2000)	All firms in the NYSE/AMEX	Volume-based portfolio strategies	Low (high) volume firms earn higher (lower) future returns	No
Safvenblad (2000)	Stockholm Stock Exchange	Volume-based portfolio strategies	Positive relation between volatility and return autocorrelation due to higher volume	No
Gervais, Kaniel, and Mingelgrin (2001)	NYSE stocks	Volume-based portfolio strategies	Causal relation running from past returns to current volume	No

Table 1: A survey of selected previous empirical studies on the price-changes-volume research (continued)

Study	Financial security	Estimation methodology used	Main findings	Addresses endogeneity?
Parisi and Acevedo (2001)	Chilean stock exchange	Volume-based portfolio strategies	Highly trade stocks experience price reversals	No
Lee and Rui (2002)	US, Japan, and UK exchanges	Linear regression (GMM) and GARCH	Positive contemporaneous relation, but no causal relation from volume to returns	No
Downing and Zhang (2004)	Municipal bonds	Linear regression (Fama-MacBeth)	Negative relation between average deal size and price volatility	No
Henry and McKenzie (2006)	21 stocks in Hong Kong	Multivariate GARCH	Nonlinear, bidirectional relationship between volume and volatility	Yes
Statman, Thorley, and Vorkink (2006)	NYSE/AMEX securities	VAR and impulse response function	Positive relation between volume and returns at both individual and aggregate levels	Yes
Xu, Chen, and Wu (2006)	30 DJIA stocks	VAR model	A positive bidirectional lagged relation between volume and volatility	No
Darrat, Zhong, and Cheng (2007)	NYSE stocks	Linear Granger Causality	Bi-directional Granger-causality between volume and volatility under public news	No
Chuang, Kuan, and Lin (2009)	US and Japan, stock exchanges	Linear Granger Causality	Volume has a positive causal effect on return volatility	No
Le and Zurbruegg (2010)	20 CBOE stocks	EGARCH (1,1)	Positive lagged relation between volume and volatility	No
Lin, Wang, and Wu (2011)	Corporate bonds	Linear regressions	Positive relation between expected corporate bond returns and volume	No
Mougoué and Aggarwal (2011)	Currency futures	Nonlinear Granger causality (GMM)	Negative (positive) contemporaneous (lead-lag) relation between volume and volatility	No
Sabbaghi (2011)	Equity indices for G5 countries	EGARCH model	Positive relation between return volatility and volume	No
Chuang, Hsiang-His, and Susmel (2012)	10 Asian stock markets	Multivariate-GARCH	A contemporaneous and causal relation between returns and volume	Yes
Kaniel, Ozoguz, and Starks (2014)	Stocks traded in 41 countries	Volume-based portfolio strategies	A causal relation running from past returns to current volume	No
Umutlu and Shackleton (2015)	Korean Stock Exchange	Linear regression (OLS)	A positive relation between return volatility and volume	No
Chakraborty and Kakani (2016)	4 emerging markets	Multivariate-GARCH	A bidirectional volume–volatility relationship	Yes
Balcilar et al. (2017)	Bitcoin	Nonlinear Granger causality-in-quantiles	Volume can predict return but not volatility	No

Table 2: Endogeneity Tests for Bond Return and Bond Trading Activity

This table presents the results of our tests for the endogeneity of bond return and bond trading activity measures. Panel A presents the results of Hausman's test of exogeneity. Under H_0 of no measurement error, OLS is efficient, while under H_1, 2SLS is consistent. Panel B shows the results of granger causality test. The null hypothesis of the Granger causality test is that the dependent variable is influenced only by itself, and not by the independent variable. The probability denotes the marginal significance level of the computed Chi-Square statistic used to test the zero restrictions implied by the null hypothesis of Granger noncausality. Panel C shows the results of the Pearson correlation matrix and the probability > $|r|$ under H_0: Rho = 0 between bond return and the three measures of bond trading activity. P-values are in parentheses.

Panel A: Hausman's Specification Test Results			
	$V^{B,WGHT}$	$V^{B,TOTAL}$	$V^{B,NUMTRD}$
Hausman Test Statistic	23248	16403	654.2
Pr>ChiSq	(<0.0001)	(<0.0001)	(<0.0001)

Panel B: Granger Causality Test Results			
	$V^{B,WGHT}$	$V^{B,TOTAL}$	$V^{B,NUMTRD}$
$V^B \xrightarrow{G.C} R^B$	13.95	158.35	13.31
	(0.0160)	(<0.0001)	(0.0206)
$R^B \xrightarrow{G.C} V^B$	66.21	92.39	32.62
	(<0.0001)	(0.5556)	(<0.0001)

Panel C: Correlation Matrix of Bond Return and Bond Trading Activity			
	$V^{B,WGHT}$	$V^{B,TOTAL}$	$V^{B,NUMTRD}$
R^B	-0.01383	-0.00352	0.00864
	(<0.0001)	(0.1518)	(0.0004)

Table 3: Testing the Relevance of Instruments for Bond Trading Variables

Panel A presents the results relating bond trading volume to our set of instrumental variables, using pooled OLS, as follows

$$V_{jt}^{B} = f(Age_{t-1}^{B}, Size_{t-1}^{B})$$

We perform the above test for three versions that differ in the dependent variable: $V_t^{B,WGHT}$ (the natural log of weighted monthly volume); $V_t^{B,TOTAL}$ (the natural log of total monthly volume); and $V_t^{B,NUMTRD}$ (the number of bond trades per month). In each of the three versions, we estimate two different specifications. The first specification includes the above instrument variables only, and the second specification expands the first specification to also include the control variables $(MKT_t, SMB_t, HML_t, TERM_t, DEF_t)$. The last three rows in Panel A presents the p-values of Wald test, LM test, and LR test under the restriction that the coefficients on the instruments are jointly equal to zero. Panel B shows the results of the Pearson correlation matrix and the probability > $|r|$ under H_0: Rho = 0 between the three measures of bond trading activity, the instrumental variables, and the control variables. *, **, and *** denotes significance at 10%, 5%, and 1% level, respectively.

Panel A: Regression Analysis

	$V^{B,WGHT}$		$V^{B,TOTAL}$		$V^{B,NUMTRD}$	
Age_{t-1}^{B}	0.0004***	0.0005***	-0.0045***	-0.0045***	-0.0138***	-0.0150***
$Size_{t-1}^{B}$	0.1463***	0.1472***	0.1366***	0.1356***	4.3438***	4.3013***
MKT_t		-0.12534		0.6693***		15.4842***
SMB_t		0.3816**		0.4783*		--16.000***
HML_t		-0.0999		-0.2611		-8.2579***
DEF_t		-0.9947**		3.9793***		-51.963***
$TERM_t$		-3.0733***		3.8709***		80.8357***
R-$square$	0.0299	0.0310	0.0124	0.0139	0.2298	0.2402
Wald Test	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
LM Test	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
LR Test	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***

Panel B: Correlation Analysis

	$V^{B,WGHT}$	$V^{B,TOTAL}$	$V^{B,NUMTRD}$
Age^{B}	0.0189***	-0.0434***	-0.0135***
$Size^{B}$	0.1728***	0.0939***	0.4783***
MKT	-0.0008	0.0171***	0.0609***
SMB	0.0021	0.0160***	-0.0058*
HML	0.00001	-0.0015	0.0038
DEF	-0.0142***	0.0245***	-0.0452***
$TERM$	-0.0259***	0.0255***	0.0881***

Table 4: Testing the Exogeneity of Instruments for Bond Trading Activity

This table presents the results of testing the exogeneity condition of the instruments $\left(i.e.,\ Cov\left(Z_{it}^{B}, \epsilon_{2jt}\right) = 0\right)$ using four empirical tests. Panel A reports the Hansen test J statistics for the over-identification test. Panel B shows the results of relating current bond trading volume and bond return to the lagged values of instrumental variables pooled OLS regression. Panel C shows the fixed effect estimation results of regressing current bond returns on the future values of trading activity and instrumental variables. Under the null hypothesis of strict exogeneity, future realizations of our instruments are unrelated to current bond returns. In Panels B and C, regressions (1) and (2) use $V^{B,WGHT}$ as the measure of trading activity; regressions (3) and (4) use $V^{B,TOTAL}$; and regressions (5) and (6) use $V^{B,NUMTRD}$. In each panel, we estimate two different specifications for the three measures of bond trading volume. The first specification includes our set of exogenous instruments $(Age^{B}, Size^{B})$ in columns (1), (3), and (5), and the second specification expands the instrumental variables to also include the endogenous instruments $(PVOL^{B}, TTM^{B}, Rating^{B}, S\&P)$ in columns (2), (4), and (6). Panel D reports the results of OLS regression of current values of instrumental variables on lagged values of bond return and instrumental variables. Under the null hypothesis of strict exogeneity, lagged bond returns are unrelated to current values of our instruments. *, **, and *** denotes significance at 10%, 5%, and 1% level, respectively.

Panel A (Test 1): Over-identification Test

	$V^{B,WGHT}$	$V^{B,TOTAL}$	$V^{B,NUMTRD}$
Overid. Stat.	0.12	0.45	0.86
p-value	0.9428	0.7992	0.6521

Panel B (Test 2): $V_{jt}^{B} = \gamma^{B} + \gamma_{1}^{B} Z_{jt-1}^{B} + \varepsilon_{jt}$; $R_{jt}^{B} = \delta_{j}^{B} + \delta_{1}^{B} Z_{jt-1}^{B} + \varepsilon_{jt}$

	$V^{B,WGHT}$		$V^{B,TOTAL}$		$V^{B,NUMTRD}$		R_{t}^{S}	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Age_{t-1}^{B}	0.0004***	-0.0004***	-0.0045***	-0.0039***	-0.0138***	-0.0169***	5.709E-6	0.00001*
$Size_{t-1}^{B}$	0.1463***	0.0790***	0.1366***	0.2214***	4.3438***	4.0935***	-0.00011	0.0003**
$PVOL_{t-1}^{B}$		0.3891***		2.6260***		-18.6082***		0.1943***
TTM_{t-1}^{B}		-0.0041***		-0.0184***		0.0150***		0.00006***
$Rating_{t-1}^{B}$		-0.4645***		0.4443***		-1.2490***		0.00004
$S\&P_{t-1}$		-0.1056***		0.6075***		9.41633***		0.1397***
R-square	0.0299	0.0657	0.0124	0.0494	0.2298	0.2378	0.0000	0.0379

Table 4: Testing the Exogeneity of Instruments for Bond Trading Activity (continued)

Panel C (Test 3): $R_{jt}^B = \delta^B + \delta_1^B Z_{jt}^B + \delta_2^B Z_{jt+1}^B + \delta_3^B V_{jt}^B + \delta_4^B V_{jt+1}^B + \varepsilon_{jt}$						
	(1)	(2)	(3)	(4)	(5)	(6)
Age_t^B	-2.63E-06	0.0000	0.0000	0.0000	0.0000	0.0000
$Size_t^B$	0.0096***	0.0109***	0.0098***	0.0110***	0.0100***	0.0116***
Age_{t+1}^B	-0.00001	0.0000	0.0000	0.0000	0.0000	0.0000
$Size_{t+1}^B$	-0.0063***	-0.0064***	-0.0063***	-0.0064**	-0.0072***	-0.0072***
$VOL_t^{B,WGHT}$	-0.0003*	-0.0003*				
$VOL_{t+1}^{B,WGHT}$	-0.0003**	-0.0003*				
$VOL_t^{B,TOTAL}$			-0.0002*	-0.0003*		
$VOL_{t+1}^{B,TOTAL}$			0.0001	0.0001		
$VOL_t^{B,NUMTRD}$					-0.0001	-0.0002**
$VOL_{t+1}^{B,NUMTRD}$					0.0003**	0.0003***
$PVOL_t^B$		0.0260***		0.0264***		0.0258***
TTM_t^B		0.0002***		0.0002***		0.0002***
$Rating_t^B$		0.0015		0.0017		0.0017
$S\&P_t$		0.1171***		0.1173***		0.1168***
$PVOL_{t+1}^B$		0.0025		0.0021		0.0017
TTM_{t+1}^B		-0.0002**		-0.0002**		-0.0002**
$Rating_{t+1}^B$		-0.0029		-0.0028		-0.0032
$S\&P_{t+1}$		-0.0033		-0.0031		-0.0039

Panel D (Test 4): $Z_{jt}^B = \mu^B + \mu_1^B R_{jt-1}^B + \mu_2^B Z_{jt-1}^B + \varepsilon_{jt}$				
	Age_t^S	$Size_t^B$		
R_{t-1}^S	-3.9471*	-0.1786		
	$PVOL_t^B$	TTM_t^B	$Rating_t^B$	$S\&P$
R_{t-1}^S	0.0056**	7.3389***	0.1294***	0.0059

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