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DYNAMIC ASYMMETRIES IN BID-ASK RESPONSES TO INNOVATIONS IN THE TRADING PROCESS *

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Abstract

This paper proposes a flexible structural model of quote formation to jointly study the dynamics between buyer-initiated and seller-initiated trades and the posterior bid and ask quote revisions. The empirical reduced form counterpart is a vector error correction (VEC) model for bid and ask quotes, with the spread as the cointegrating vector, that extends the bivariate vector autoregresive (VAR) model introduced by Hasbrouck (1991a). The empirical results for several NYSE common stocks reveal that there are informational gains by not averaging the quote revision process through the quote midpoint. We find evidence of asymmetric behavior in the responses of both ask and bid prices to the innovations in the trading process. Under similar market conditions, the bid dynamics after an unexpected seller-initiated trade show significant deviations relative to the ask dynamics after a similar unexpected buyer-initiated trade.

Keywords: Market Microstructure; bid-ask quotes; VEC models; adverse-selection costs.

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I. Introduction

A fundamental topic of market microstructure is the process of price formation. A lot of theoretical and empirical work builds on the notion that trades convey information that updates the publicly known information set. The information inferred from a new trade is incorporated into the market's expectation about the "informationally-efficient" stock price, motivating the adjustment of posted quotes (e.g., Glosten and Harris, 1988, and Hasbrouck, 1988).

Structural models (e.g., Glosten and Milgrom, 1985; Glosten, 1987, and Hasbrouck, 1999) derive the market quotes as the result of adding a premium and subtracting a discount, usually of equal size, to the efficient price, achieving the ask and bid prices respectively. The magnitude of these amounts depend on certain market frictions (like price discreteness) and on the market making costs associated to the trading process, like inventory holding costs and adverse selection costs (see O'Hara, 1995 for a revision of this literature). These perturbations drive transaction prices away from the efficient price. Hence, quote variations induced by the innovations in the trading process have an information-related (permanent) component and a liquidity-related (transitory) component.

Hasbrouck (1991a) suggests a general econometric approach to model the dynamics of trades and trade price or quote midpoint revisions through a bivariate vector autoregressive (VAR) model.[1] This econometric reduced form approach covers many structural microstructure models as special cases (see Hasbrouck, 1996). The VAR model has been used to measure the informational content of trades (see Hasbrouck, 1991b), and also to separate the permanent and transitory price impacts of trades (see de Jong et al., 1996). Simple extensions allow assessing the role played by any trade feature or market condition on the quote adjustment subsequent to a trade (see Dufour and Engle, 2000).

An important feature of the bivariate VAR model is that quote behavior is averaged through the quote midpoint. This is not an inconvenient if ask and bid quote dynamics are assumed to be completely symmetric. Similarly, trade dynamics of purchases and sales are also averaged through the trade indicator equation. Therefore, the estimated impact of a given purchase follows the same path but with opposite sign to the impact of a similar seller-initiated trade.

Past empirical evidence suggest that this say "symmetry assumption" is not necessarily satisfied. Jang and Venkatesh (1991) evidenced that quote changes after a trade do not generally support the prediction of theoretical models (e.g., Stoll, 1989, and Glosten and Milgrom, 1985) that both ask and bid prices are revised in the same direction. Additionally, if both quotes are not adjusted downward or upward by the same amount following the trade, the quoted spread also changes and this will influence on the posterior dynamics of bid and ask quotes and on the total impact of the trade. This is a factor not considered in Hasbrouck's (1991a) model. Moreover, empirical works on block trading have shown that seller-initiated and buyer-initiated trades have different permanent and transitory effects on prices (e.g., Holthausen and Leftwich, 1987; Holthausen et al., 1990; Chan and Lakonishok, 1993; Griffiths et al., 2000) and different realized spreads (e.g., Huang and Stoll, 1996).[2] Biais et al. (1995), studying the order flow in the Paris Bourse, observed time asymmetries in ask and bid adjustments following trades. They also evidenced different induced cross-correlation in ask and bid quote revisions depending on whether quote adjustments where motivated by informative or liquidity reasons. These results lead them to conclude: (a) there should be additional information in analyzing ask and bid quotes jointly rather than averaging them using the quote midpoint. (b) Time series dynamics of quotes could be studied conditional on the type of orders observed in the market. Neither of this two proposals can be implemented with the bivariate VAR model.

This paper proposes a dynamic structural model of quote formation whose reduced form is shown to be a vector error correction (VEC) model. This model extends the Hasbrouck's (1991a) bivariate VAR model for ask and bid revisions after buyer-initiated and seller-initiated trades. Given that ask and bid prices have a common non-stationary long run component (the efficient stock price), their time series are cointegrated. The VEC model is the most commonly used efficient parameterization of vector autoregressive models with cointegrated variables (e.g., Engle and Granger, 1987, and Watson, 1994). In this case the cointegration relationship is known a priori, which lets setting a very general parameterization of the model.

Quote revisions induced by trade innovations are allowed to be non-linear due to several trade features (like volume, time since the last trade, and market of origin), market conditions (volatility, liquidity, and market demand and supply pressure) and trading-time regularities. The VEC model allows ask and bid revisions after a trade to follow different adjustment paths, and buyer and seller-initiated trades to be generated by idiosyncratic (but not independent) processes. These asymmetric dynamics are formally tested in the paper, revealing significant differences between the impact of a buyer-initiated trade on the ask quote and the impact of a similar seller-initiated trade on the bid quote, performed under an akin market environment. The paper concludes that there is an informational value-added in jointly modeling ask and bid quote dynamics rather than averaging them through the quote midpoint.

The paper proceeds as follows. Section II reviews the bivariate VAR model suggested by Hasbrouck (1991a). Section III introduces the structural model for bid and ask quotes and its reduced form: the VEC model. Section IV presents data, sample technique and defines variables. Section V reports the estimation and simulation results of the Hasbrouck's VAR model for the quote midpoint. Section VI summarizes and analyzes the estimation and simulation results of the VEC model for ask and bid quotes. Section VII formally tests for statistically significant differences in the mean adjustment of both the bid and the ask quotes to the trading process, using the VEC model. Finally, section VIII concludes.

II. The bivariate VAR model and extensions

Consider the following structural model. Let m_t be the efficient price, defined as the expected true value of the stock in some future terminal time κ (ψ_κ) given all the publicly available information set (ϕ_t)

$$m_t \equiv E(\psi_\kappa / \phi_t).$$

Assume this efficient price follows the following random walk process[3]

$$m_t = m_{t-1} + z v_{2,t} + v_{1,t},$$

where $v_{1,t}$ and $v_{2,t}$ are mutually and serially uncorrelated white noises. Let $v_{1,t}$ represent the revision of the public information set, and let $v_{2,t}$ be the innovation in the trading process. The parameter z measures the amount of private information conveyed by the trade innovation (adverse selection costs). The midpoint of the quoted bid-ask spread (q_t) is given by the efficient price plus a covariance stationary stochastic component (w_t) due to market frictions and inventory control issues

$$q_t = m_t + w_t = m_t + a(q_{t-1} - m_{t-1}) + bx_t,$$

with $a<1$ and $b>0$. The trade dynamics are given by the following equation,

$$x_t = -c(q_{t-1} - m_{t-1}) + v_{2,t},$$

where x_t equals 1 for buyer-initiated trades and –1 for seller-initiated trades. The parameter $c>0$ measures the impact of posted quotes on trading. In this model, trades have two interrelated and contemporaneous effects on prices: an informational (permanent) effect ($zv_{2,t}$) and a liquidity (transitory) effect (bx_t). Notice that a trade affects the efficient price only through its unexpected component. However, the effect on the stationary component depends on the full trade.

Hasbrouck (1991a,b) estimates the following vector autoregression (VAR) model to study the price impact of trade-related information, where $\Delta q_t = (q_t - q_{t-1})$ represents the revision in the quote midpoint after a trade at t (x_t). This empirical model includes as special cases the model presented above and other microstructure models (see Hasbrouck, 1996).

$$\begin{aligned} \Delta q_t &= \sum_{i=1}^{\infty} a_i \Delta q_{t-1} + \sum_{i=0}^{\infty} b_i x_{t-i} + v_{1,t} \\ x_t &= \sum_{i=1}^{\infty} c_i \Delta q_{t-1} + \sum_{i=1}^{\infty} d_i x_{t-i} + v_{2,t} \end{aligned} \tag{2.1}$$

Empirically, the model is truncated at 5 lags for all the explanatory variables and, assuming that $v_{1,t}$ and $v_{2,t}$ are jointly and serially uncorrelated, the VAR model is consistently estimated by OLS. The total impact of a trade in prices can be estimated from the vector moving average (VMA) representation of the VAR in (2.1)

$$\begin{bmatrix} \Delta q_t \\ x_t \end{bmatrix} = \begin{bmatrix} \theta_1(L) & \theta_2(L) \\ \theta_3(L) & \theta_4(L) \end{bmatrix} \begin{bmatrix} v_{1,t} \\ v_{2,t} \end{bmatrix},$$

where $\theta_j(L)$, $j=1$ to 4, are invertible polynomials in the lag operator L ($L^k y_t = y_{t-k}$). The coefficient $\theta_{2,k}$ in $\theta_2(L)$ measures the impact on the quote midpoint of an innovation in the trading process after k transactions. Therefore, the accumulated impact is measured by the sum of the coefficients of $\theta_2(L)$, usually known as the impulse-response function:

$$\alpha_{t+k}(v_{2,t}) = \sum_{i=0}^{k} \tilde{\theta}_{2,i} v_{2,t}.$$

The model (2.1) can be extended to allow trade coefficients to vary with trade characteristics. Hasbrouck (1991a) added trade volume and spread and Dufour and Engle (2000) considered time between consecutive transactions and dummies for the trading interval, all them interacting with x_t. They obtained that when trade volume and spread were larger and the time since the last trade was shorter, the accumulated quote revision after the trade was also larger. The VAR model, however, summarizes the quote dynamics using the quote midpoint, and the trade dynamics through the trade indicator x_t. Therefore, this model is not able to capture neither a possible asymmetric behavior of ask and bid quotes in their adjustment to the trade innovations nor deviations in the impact of buys and sells on posted quotes. Next section proposes and extension of the bivariate VAR model that allows buyer and seller-initiated trades to have their own idiosyncratic (although not independent) generating processes and to affect in a different way to the posted bid and ask quotes. Hence, ask and bid quotes revisions induced by the trading process are allowed to differ.

III. The structural model for bid-ask quotes and the empirical VEC representation

This section presents the VEC model for revisions in ask and bid quotes in response to buyer (BIT) and seller-initiated trades (SIT). The purpose is to jointly consider the dynamics of trades, ask and bid quotes with a general parameterization. The empirical model will allow for possible different adjustments of both quotes to the innovations in the trading process conditional on the type of trade observed. If quote dynamics of ask and bid quotes result fully symmetric, and the trade processes for BITs and SITs are identical, there will be no value added by modeling ask and bid quotes rather than the quote midpoint, and by summarizing the trade processes using the VAR trade indicator.

A. The structural model

Consider now the following dynamic structural model that allows for for asymmetries in bid and ask adjustments (nonlinear due to trade's features, market conditions and trading-time regularities) to trades. These asymmetries will be formally tested latter on in section VII. As in Hasbrouck's model, bid and ask quotes result from adding to the efficient price (m_t) a covariance stationary stochastic component (w_t). In this general model, however, the dynamics of these transitory components may be distinct for each quote (say $\Delta w_t^a \neq \Delta w_t^b$).

Hereafter, the superscript a will be indicative of "ask", b of "bid", B of "buys" and S of "sells".

The evolution of m_t is now given by (3.1). Three stochastic shocks affect the efficient price: $v_{1,t}$ are the innovations in public non-trade information; $v_{2,t}^B$ and $v_{2,t}^S$ are the updates in private information inferred from unexpected BITs and SITs respectively. Let $v_{1,t}$ be mutually and serially uncorrelated with $v_{2,t}^B$ and $v_{2,t}^S$. Although $v_{2,t}^B$ and $v_{2,t}^S$ are also serially uncorrelated, they could be mutually correlated. The parameters z^B and z^S measure the amount of private information carried by a given purchase and sale respectively

$$m_t = m_{t-1} + z^B v_{2,t}^B + z^S v_{2,t}^S + v_{1,t}. \tag{3.1}$$

The ask (a_t) and bid (b_t) price equations are obtained by adding and subtracting a time-varying premium or discount, respectively, to the efficient price m_t. These premiums and discounts are determined by trading and previous quotes, and their magnitudes and dynamics are allowed to differ. As Hasbrouck (1999) points out, the usual assumption of equal market making costs for bid and ask sides of the market is reasonable if the same quote setter is posting both prices. However, in most stock exchanges, as is the case of the NYSE, quotes reflect the interest of several traders that may be selectively offering liquidity in only one side of the market (see Kavajecz, 1999, and Chung et al., 1999). These alternative agents may be subject to different trading costs. Thus, Hasbrouck (2000) models the exposure costs for bid and ask quotes as two independent stochastic processes. The a_t and b_t evolutions are given by (3.2) and (3.3) imposing as in Hasbrouck's (1991a) model that $0<\alpha_m^a<1$ and $0<\alpha_m^b<1$. Therefore, if there is not trading, ask and bid quotes revert to the efficient price. The polynomial vectors $A_{x,t}(L)' = (A_{x,t}^B(L), A_{x,t}^S(L))$ and $B_{x,t}(L)' = (B_{x,t}^B(L), B_{x,t}^S(L))$ have time varying components that are finite order polynomials in the lag operator L. These polynomials capture the transitory effects of trading on ask and bid quotes. In this specification, as in Hasbrouck (2000), ask and bid market making costs are non-deterministic components that are allowed to differ, but in our case they could be mutually correlated.

$$a_t = m_t + \alpha_m^a (a_{t-t} - m_{t-1}) + A_{x,t}(L)' x_t + \alpha_a^{EC} (a_{t-1} - b_{t-1}) + \varepsilon_t^a \tag{3.2}$$

$$b_t = m_t + \alpha_m^b (m_{t-1} - b_{t-1}) + B_{x,t}(L)' x_t + \alpha_b^{EC} (a_{t-1} - b_{t-1}) + \varepsilon_t^b \tag{3.3}$$

The noise terms ε_t^a and ε_t^b are idiosyncratic errors of the ask and bid quotes, reflecting market frictions and model misspecifications. The vector $x_t' = (x_t^B, x_t^S)$ is the trade indicator, where x_t^B equals 1 for BITs and zero otherwise and x_t^S equals 1 for SITs and zero otherwise. The evolution of x_t^B and x_t^S is described in equations (3.4) and (3.5), with $\mu^B<0$ and $\mu^S<0$ defining downward sloping demand schedules. The terms $v_{2,t}^B$ and $v_{2,t}^S$ are the mutually correlated unexpected components of BITs and SITs, respectively.

$$x_t^B = \mu^B (a_{t-1} - m_{t-1}) + \pi^B (a_{t-1} - b_{t-1}) + v_{2,t}^B \tag{3.4}$$

$$x_t^S = \mu^S (m_{t-1} - b_{t-1}) + \pi^S (a_{t-1} - b_{t-1}) + v_{2,t}^S \tag{3.5}$$

The third term on the right hand side of equation (3.2) and (3.3) is decomposed in terms of BITs and SITs as follows,

$$A_{x,t}(L)' x_t = A_x^B(L) f_a^B(MC_t, D_t) x_t^B + A_x^S(L) f_a^S(MC_t, D_t) x_t^S$$

$$B_{x,t}(L)' x_t = B_x^B(L) f_b^B(MC_t, D_t) x_t^B + B_x^S(L) f_b^S(MC_t, D_t) x_t^S$$

where $A_x^B(L)$, $A_x^S(L)$, $B_x^B(L)$, and $B_x^S(L)$ are finite order polynomials in the lag operator L, having all roots outside the unit circle. The terns $f_i^B(MC_t, D_t)$ and $f_i^S(MC_t, D_t)$ $i \in \{a,b\}$ are functional forms of the vectors of variables MC_t and D_t. The vector MC_t includes a set of variables that characterize a trade and the environment surrounding that trade, and are specified latter on. The vector D_t represents dummies that control for trading-time regularities. These functions are linearly defined in equation (3.6) for $i \in \{a,b\}$ and $j \in \{B,S\}$. Linearity is imposed for simplicity reasons.

$$f_i^j(MC_t, D_t) = 1 + \sum_{k=1}^{n} \lambda_k^{i,j} MC_t^k + \sum_{h=1}^{n'} \gamma_h^{i,j} D_t^h \tag{3.6}$$

Finally, from equations (3.1)-(3.3), the a_t and b_t prices are non-stationary integrated of order one I(1) processes. Since the non-stationarity is generated by a common long-run component (m_t), the series must be cointegrated. Engle and Granger (1987), Stock and Watson (1988), Johansen (1991) and Escribano and Peña (1994) provide formal derivations of this result. Our model has the unusual advantage that the cointegration relationship, given in general by $\alpha_1 a_t + \alpha_2 b_t$, has a known cointegration vector $(\alpha_1, \alpha_2) = (1, -1)$. Hence, the cointegrating relationship has a clear interpretation since $\alpha_1 a_t + \alpha_2 b_t = a_t - b_t$ is the bid-ask spread (s_t), a stationary time series. The spread is, therefore, incorporated in the quote equations. Its coefficient will indicate how quotes revert to their common long-run component.

B. The empirical reduced-form: the vector error correction (VEC) model

The most common efficient parameterization of vector autoregressive (VAR) models with cointegrated variables is, from Granger's representation theorem of Engle and Granger (1987), the vector error correction (VEC) model,

$$\begin{pmatrix} 1 & 0 & A^{*}_{aB,t} & A^{*}_{aB,t} \\ 0 & 1 & A^{*}_{bB,t} & A^{*}_{bS,t} \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \Delta a_t \\ \Delta b_t \\ x^{B}_{t} \\ x^{S}_{t} \end{pmatrix} = \begin{pmatrix} \gamma_a^{EC} \\ \gamma_b^{EC} \\ \gamma_{0B} \\ \gamma_{0S} \end{pmatrix} s_{t-1} + \begin{pmatrix} A_{aa}(L) & A_{ab}(L) & A_{aB,t}(L) & A_{aS,t}(L) \\ A_{ba}(L) & A_{bb}(L) & A_{bB,t}(L) & A_{bS,t}(L) \\ A_{Ba}(L) & A_{Bb}(L) & A_{BB,t}(L) & A_{BS,t}(L) \\ A_{Sa}(L) & A_{Sb}(L) & A_{SB,t}(L) & A_{SS,t}(L) \end{pmatrix} \begin{pmatrix} \Delta a_{t-1} \\ \Delta b_{t-1} \\ x^{B}_{t-1} \\ x^{S}_{t-1} \end{pmatrix} + \begin{pmatrix} u_t^a \\ u_t^b \\ u_t^B \\ u_t^S \end{pmatrix} \quad (3.7)$$

where Δ=(1-L), that is, $\Delta a_t = (a_t - a_{t-1})$. The error correction terms $\gamma_a^{EC} s_{t-1}$ and $\gamma_b^{EC} s_{t-1}$ have coefficients restricted to be $(\gamma_a^{EC} - \gamma_b^{EC}) < 0$ in order to impose the cointegration restriction on the spread. The lag polynomials $A_{ij}(L)$ have all roots outside the unit circle for all i,j = {a,b,B,S}. The remaining lag polynomials $A_{ij,t}(L)$ are time varying and depend on the exogenous variables (MC_t) and the trading-time dummies (D_t). In particular, the following expression makes explicit the type of dependence

$$\mathrm{A}_{ij,t}(\mathrm{L})\, x_{t-1} = A_{ij}{}^{B}(L) f_{ij}{}^{B}(MC_{t-1}, D_{t-1}) x^{B}_{t-1} + A_{ij}{}^{S}(L) f_{ij}{}^{S}(MC_{t-1}, D_{t-1}) x^{S}_{t-1},$$

where the polynomials $A_{ij}^{B}(L)$ and $A_{ij}^{S}(L)$ have all the roots outside the unit circle for any i,j = {a,b,B,S}. Finally, $A^{*}_{ij,t} = -A_{ij,t}(0)$.

In error correction models, standard statistical inference can be used to test hypotheses about the parameters of variables that are I(0) even under the null hypothesis of no cointegration ($\gamma_i^{EC} = 0$). However, this is not the case when the variables are I(1) under the null hypothesis. Dolado and Lutkepohl (1996) and Toda and Yamamoto (1995) show that, by adding extra lags of the error correction terms (*Extended Error Correction Models*), for example ($a_{t-2} - b_{t-2}$), in usual error correction models standard inference can be conducted on the coefficients of the variables that are I(1) under the null hypothesis of no-cointegration. In our case the cointegrating vector is known a priori, making it certain that the error correction term (s_{t-1}) is going to be I(0). Then, all of the variables in our VEC (3.7) are I(0) and extensions are not strictly necessary. Nonetheless, well-specified empirical models must support any extended version. Arranz and Escribano (2000) showed that *extended error correction models* are robust to the presence of structural breaks under partial co-breaking. Co-breaks represent those situations characterized by having breaks (level shifts, changes in trend etc.) occurring simultaneously in some variables, so that certain linear combinations of those variables have no breaks. The common lung-run trend jointly with their discrete type of moves in the ask and the bid quotes time series makes a_t and b_t the perfect example of cointegrated variables that are candidate to be partially co-breaking. For example, in a given period, full co-breaking will occur whenever all the ask and bid quote revisions during the whole period are in the same direction and are of equal size.

Extended error correction parameterizations of VAR models with cointegrated variables, like (3.8), could be formally justified using the Smith-MacMillan decomposition introduced by Engle and Yoo (1987). In appendix A, we give a simple explicit derivation of (3.8) from the structural model of previous subsection.

$$\begin{pmatrix} 1 & 0 & A^*_{aB,t} & A^*_{aB,t} \\ 0 & 1 & A^*_{bB,t} & A^*_{bS,t} \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \Delta a_t \\ \Delta b_t \\ x^B{}_t \\ x^S{}_t \end{pmatrix} = \begin{pmatrix} \gamma_a^{EC}(L) \\ \gamma_b^{EC}(L) \\ \gamma_B(L) \\ \gamma_S(L) \end{pmatrix} s_{t-1} + \begin{pmatrix} A_{aa}(L) & A_{ab}(L) & A_{aB,t}(L) & A_{aS,t}(L) \\ A_{ba}(L) & A_{bb}(L) & A_{bB,t}(L) & A_{bS,t}(L) \\ A_{Ba}(L) & A_{Bb}(L) & A_{BB,t}(L) & A_{BS,t}(L) \\ A_{Sa}(L) & A_{Sb}(L) & A_{SB,t}(L) & A_{SS,t}(L) \end{pmatrix} \begin{pmatrix} \Delta a_{t-1} \\ \Delta b_{t-1} \\ x^B{}_{t-1} \\ x^S{}_{t-1} \end{pmatrix} + \begin{pmatrix} u_t^a \\ u_t^b \\ u_t^B \\ u_t^S \end{pmatrix} \quad (3.8)$$

The individual error terms u_t^i in (3.8), for i={a, b, B, S}, are assumed to be independent and identically distributed random variables with zero mean and constant variance but they are not mutually independent or mutually uncorrelated (see Appendix A). Therefore, the system of equations (3.8) is a clear example of seemingly unrelated regression equations which can be efficiently estimated by SURE (see Zellner, 1962). When all of the equations have the same regressors, estimating the system by SURE reduces to estimate it equation by equation by OLS. However, for this result to hold the empirical estimated equations must actually have the same explanatory variables and the same lags of each of them, and this is a very unlikely event. In fact, as we will see in the empirical section, the dynamics of the quote-trading process imply that the system has different explanatory variables in each of the equations. Therefore, all equations should be simultaneously estimated by SURE to get efficiency.

Finally, it is possible to obtain an equation for the spread changes (Δs_t) by simply subtracting the first two equations of (3.8)

$$\Delta s_t = \alpha_s^{EC}(L)s_{t-1} + A_{sa}(L)\Delta a_{t-1} + A_{sb}(L)\Delta b_{t-1} + A_{sB,t}(L)x_t^B + A_{sS,t}(L)x_t^S + u_t^s . \qquad (3.9)$$

The first coefficient of $\alpha_s^{EC}(L)$, say $\alpha_{s,1}^{EC}$, must be less than 0 in order for the spread to be I(0) and the ask and bid variables cointegrated. Next sections proceed with the estimation of the VEC model in (3.8).

IV. Data and methodology

A. Data

The empirical analysis is performed using transaction and quote data for IBM obtained from the TAQ (*Trade and Quote*) database corresponding to all the 62 trading days from January to March 1996. Additionally, a sample of 150 common stocks is sampled from the population of 2574 NYSE-listed common stocks in January-1996 using Systematic Sampling based on market capitalization (see Som, 1996). From this sample, the 10 stocks with the largest mean trade frequencies were taken for comparative purposes (see Appendix B). Trades from the primary market (NYSE) and regional markets are considered. However, we only keep NYSE quotes because, accordingly with Hasbrouck (1991a,b) and Dufour and Engle (2000), regional quotes only follow with some delay those of the primary market. Trades not codified as "regular trades" have been discarded. Trades performed at the same market, at the same price, and with the same time stamp are treated as just one trade. All quote and trade registers previous to the opening quote or posterior to the 16:00, the official closing time, are dropped. The overnight changes in quotes are treated as missing values. Quotes with bid-ask spreads lower than or equal to zero or quoted depth equal to zero have also been eliminated. When prices and quotes must be considered together, the so-called "five seconds rule" (see Lee and Ready, 1991) has been applied. This rule assigns to each trade the first quote stamped at least five seconds before the trade itself. After these adjustments, more than 130.000 observations still remain for each data series of IBM.

B. Variables

Following previous empirical studies, a trade is classified as buyer (seller) initiated when the price is closer to the ask (bid) than to the bid (ask). The trade indicator in the VAR model, x_t, equals 1 BITs and –1 for SITs. The trade indicator in the VEC model, x_t^B (x_t^S), equals 1 for buyer (seller) initiated trades and zero otherwise. For trades with execution price equal to the quote midpoint (around 24% of the trades) all previous indicators are equal to zero. A change in quotes is computed as the difference between the quote associated to the trade at t+1 and the quote associated with trade at t: $\Delta a_t=(a_t-a_{t-1})$, $\Delta b_t=(b_t-b_{t-1})$ or $\Delta q_t=(q_t-q_{t-1})$. Eight trading-time dummies are constructed: one for trades during the first half-hour of trading, five for each trading hour between 10:00 a.m. and 15:00 p.m. and, finally, the last trading hour has been divided in two half-hour intervals.

Theoretical and empirical microstructure literature suggest several trade characteristics and market conditions to be considered for being included in MC_t. We have chosen the following ones: the trade volume (vol_t), e.g. Easley and O'Hara (1987). The time in seconds since the last trade ($tlast_t$), e.g. Easley and O'Hara (1992). A dummy variable that equals zero if the trade is from the NYSE, or one if it comes from the regional markets (reg_t), e.g. Bessembinder and Kaufman (1997). Liquidity, measured by both quoted depth ($depth_t$), e.g. Kyle (1985), and the posted spread (s_t), e.g. Glosten and Milgrom (1985a). The ratio of depth at the ask to depth at the bid as an indicator of the market current pressure to buy or sell ($pres_t$), as far as we know not previously considered. Finally, a measure of recent volatility ($risk_t$), see Bollerslev and Melvin (1994), computed as the sum of the square changes of the quote midpoint $\sum_{k=1}^{z}(\Delta q_k)^2$ in the five minutes interval previous to the trade.[4]

V. Estimation of the VAR model

In order to establish consistency with earlier work and to test the significance of some of the variables in MC_t, we first estimate an extended version of the bivariate VAR model of Hasbrouck (1991a). For each of the variables MC_t^k, the model in (5.1) has been estimated by OLS controlling for trading-time regularities (D_t^h), for h=1,...,8. All dummies except that of the trading interval 12:00-13:00 (D_t^4) were initially considered, also interacting with lagged values of the trade indicator. However, F tests showed that only dummies interacting with the contemporaneous trade indicator are jointly significant.

$$\begin{aligned} \Delta q_t &= \sum_{i=1}^{5} a_i \Delta q_{t-1} + \sum_{i=0}^{5} \left[\alpha_i^q + \beta_i^q MC_{t-i}^k\right] x_{t-i} + \sum_{h \neq 4} \lambda_h^q D_{t-i}^h x_t + v_{1,t} \\ x_t &= \sum_{i=1}^{5} c_i \Delta q_{t-1} + \sum_{i=1}^{5} \left[\alpha_i^x + \beta_i^x MC_{t-i}^k\right] x_{t-i} + \sum_{h \neq 4} \lambda_h^q D_{t-i}^h x_{t-1} + v_{2,t} \end{aligned} \tag{5.1}$$

Table I shows the summation of the coefficients of all lags of MC_t^k and also the results of testing the null hypotheses $H_0^q : \sum_{i=0}^{5} \beta_i^q = 0$ and $H_0^q : \sum_{i=1}^{5} \beta_i^x = 0$. For those variables already tested in previous studies (see Hasbrouck, 1991a, and Engle and Dufour, 2000), results for the quote revision equation are consistent: the larger the trade volume and the shorter the time since last trade, the larger the accumulated impact of the trade in quotes. Moreover, results indicate that trades from the regional markets have a lower impact on quote revisions. These results are consistent with larger trades conveying more information (e.g. Easley and O'Hara, 1987), time since the last trade indicating low information arrival (e.g., Easley and O'Hara, 1992) and new information flowing from the primary market to the regional markets and not on the contrary (e.g., Blume and Goldstein, 1997). More liquidity (measured by both lower spread and larger depth) reduces the impact of trades on quotes, a result that conforms with poorer liquidity conditions reflecting a higher risk of informational asymmetries (e.g., Lee et al., 1993). Finally, larger volatility increases the impact of a new buy trade, which is consistent with adverse selection costs arguments (e.g., French and Roll, 1986). Results for the control sample (not reported) are similar. For the trade equation, the strong positive autocorrelation of signed trades, already evidenced in previous work, is affected by all the variables considered but trade volume, not significant when the other variables are taken into account, and $tlast_t$ that is never significant. For the control sample, however, vol_t and $tlast_t$ are significant in 90% and 50% of the sample respectively.[5]

Using the model (5.1) for IBM, we simulate the accumulated effect on quotes of an unexpected BIT ($v_{2,t} = 1$) 25 steps into the future, conditional on different current levels of MC_t^k: $I_q^{25}(v_{2,t} / MC_{\text{ref}}^k)$. The unexpected trade is assumed to occur after a steady-state period defined by $x_{t-1} = \cdots = x_{t-5} = 0$ and $\Delta q_{t-1} = \ldots = \Delta q_{t-5} = 0$, Three levels of MC_t^k are considered: "small", "medium" and "large", obtained from the 25%, 75% and 95% percentiles of the empirical distribution of MC_t^k. For reg_t we simply compare the effects of a trade at the regional market versus a trade at the primary market. It is also assumed that MC_t^k follows a general probabilistic process, exogenous to the model in (5.1). The MC_t^k generating process is approximated by a linear autoregressive AR(p) model, with p to be determined empirically. The trade is assumed to occur at the control trading-time period ($D_t^h = 0$ for all $h \neq 4$). The simulation proceeds through the following steps:

(1) The AR(p) generating process of MC_t^k is estimated by General Least Squares (GLS) and controlling for deterministic trading-time patterns, where the finally chosen p is obtained from a general to particular procedure starting with $p = 7$.

$$MC_t^k = \sum_{i=1}^{p} \phi_i^k MC_{t-i}^k + \sum_{h=1}^{8} \varphi_h^k D_t^h + \varepsilon_t^k \tag{5.2}$$

(2) Once estimated, (5.2) is used to predict the future values of MC_t^j needed to proceed with the simulation. It is assumed that $\varepsilon_t^k \sim N(\mu_k, \sigma_k^2)$, where μ_k and σ_k^2 are estimated through the mean and variance of the GLS residuals of the estimated model (5.2). The initial conditions MC_{t-i}^k for i=1,...,p are obtained as the mean of the values of MC_t^k corresponding to the p trade periods preceding all trades satisfying $D_t^4 = 1$ and $MC_t^k = MC_{ref}^k$. The term MC_{ref}^k is the reference value of the variable (either "small", "medium" or "large").

(3) We compute the impulse-response function of (5.1) 25 steps into the future using the corresponding 25 predicted values of MC_t^k in step (2). This gives a realization of the impulse-response function $\tilde{I}_q^{25}(v_{2,t} / MC_{\text{ref}}^k)$ for a given MC_t^k path.

(4) Steps (2) and (3) are repeated 10,000 times. The 10,000 conditional expected values of all the impulse-response realizations for each step z (z=1,...,25) are averaged to get the final mean impulse-response function.

Table I reports the difference in the total impact on the quote midpoint of an unexpected unit purchase when MC_t^j is "medium" versus "small", $I_q^{25}(v_{2,t} / MC_{\text{med}}^k) - I_q^{25}(v_{2,t} / MC_{\text{small}}^k)$, and "large" versus "small", $I_q^{25}(v_{2,t} / MC_{\text{large}}^k) - I_q^{25}(v_{2,t} / MC_{\text{small}}^k)$, expressed in percentage points to $I_q^{25}(v_{2,t} / MC_{\text{small}}^k)$. Reference values appear in parenthesis. Estimations corroborate previous results and show that for some variables like vol_t, s_t, $tlast_t$, and $risk_t$ there are important differences in the impact of the unexpected purchase depending on whether their reference level is "small", "medium" or "large". For example, the impact of a purchase on the quote midpoint duplicates with an increase in the spread equal to one tick. Additionally an unexpected purchase from the primary market has a 152% larger accumulated quote impact that the same trade coming from the regional markets.[6]

VI. Estimation of the VEC model

A. Estimation of the basic trade/quote revision model for bid and ask quotes

This subsection proceeds with the estimation of the simplest version of the VEC in (3.8) by imposing the restriction that $f_i^j(MC_t, D_t) = 1$ for all i and j, see (6.1). The polynomials in L are all truncated at 5 lags and the system is estimated by SURE, using the Feasible Generalized Least-Squares (FGLS) algorithm described in Green (1997, pp. 674-688).

$$\begin{aligned}
\Delta a_t &= \sum_{i=1}^5 \alpha_i^{a,a} \Delta a_{t-i} + \sum_{i=1}^5 \beta_i^{b,a} \Delta b_{t-i} + \sum_{i=0}^5 \delta_i^{B,a} x_{t-i}^B + \sum_{i=0}^5 \delta_i^{S,a} x_{t-i}^S + \sum_{i=1}^5 \eta_i^a s_{t-i} + u_t^a \\
\Delta b_t &= \sum_{i=1}^5 \alpha_i^{a,b} \Delta a_{t-i} + \sum_{i=1}^5 \beta_i^{b,b} \Delta b_{t-i} + \sum_{i=0}^5 \delta_i^{B,b} x_{t-i}^B + \sum_{i=0}^5 \delta_i^{S,b} x_{t-i}^S + \sum_{i=1}^5 \eta_i^b s_{t-i} + u_t^b \\
x_t^B &= \sum_{i=1}^5 \alpha_i^{a,B} \Delta a_{t-i} + \sum_{i=1}^5 \beta_i^{b,B} \Delta b_{t-i} + \sum_{i=1}^5 \delta_i^{B,B} x_{t-i}^B + \sum_{i=1}^5 \delta_i^{S,B} x_{t-i}^S + \sum_{i=1}^5 \eta_i^B s_{t-i} + u_t^B \\
x_t^S &= \sum_{i=1}^5 \alpha_i^{a,S} \Delta a_{t-i} + \sum_{i=1}^5 \beta_i^{b,S} \Delta b_{t-i} + \sum_{i=1}^5 \delta_i^{B,S} x_{t-i}^B + \sum_{i=1}^5 \delta_i^{S,S} x_{t-i}^S + \sum_{i=1}^5 \eta_i^S s_{t-i} + u_t^S
\end{aligned} \tag{6.1}$$

Preliminary Wald tests on the null that the coefficients of all lags of each explanatory variable in (6.1) are jointly zero, indicate that the following nulls

$$\sum_{i=1}^5 \beta_i^{b,a} = 0, \; \sum_{i=1}^5 \alpha_i^{a,b} = 0, \; \sum_{i=1}^5 \beta_i^{b,B} = 0 \text{ and } \sum_{i=1}^5 \alpha_i^{a,S} = 0, \tag{6.2}$$

cannot be rejected, either for IBM or for most of the stocks in the control sample. Table II reports the estimated model (6.1) for IBM imposing all previous restrictions. The correlation matrix of residuals report that corr($\tilde{u}_t^a, \tilde{u}_t^b$)=0.4362 and corr($\tilde{u}_t^S, \tilde{u}_t^B$)=-0.6804. All the other cross-equation correlation coefficients are not significantly different from zero. Therefore, the coefficients of (6.1) cannot be efficiently estimated equation by equation.

The coefficients of x_t^B and x_t^S on the Δa_t and Δb_t equations are in concordance with the non-dynamic evidence in Jang and Venkatesh (1991). After a BIT both quotes tend to increase but, on average, the ask is raised \$0.0075 and the bid is raised \$0.004 immediately subsequent to the trade. Similarly, after a SIT both quotes tend to be downward revised but, on average, the immediate decrease in the ask quote is -\$0.00438 and in the bid is -\$0.00739 (see Figure 1).

The coefficients of s_t reveal that wide quoted spreads induce posterior adjustments in quotes. Moreover, this adjustment tends to decrease the current posted spread: the ask decreases and the bid increases. Therefore, the model evidences two simultaneous but opposite effects on the dynamics of the ask and bid revision time-series: cross-serial positive correlation due to informational trading effects, and cross-serial negative correlation due to the quotes reversion to narrow spread levels, as Biais et al. (1995) evidenced for the Paris Bourse. Empirical analyses summarizing the quote dynamics through the quote midpoint cannot, therefore, isolate these two opposite effects. Moreover, the bid and ask adjustment path towards long-run relationship, given by the coefficients of the error correction term, is not necessarily linear. Following Escribano and Granger (1998), we have substituted the linear error correction term in (6.1) by a non-linear one, a cubic polynomial on the contemporaneous spread $\eta_{1,1}^j s_{t-1} + \eta_{1,2}^j s_{t-1}^2 + \eta_{1,3}^j s_{t-1}^3$. All coefficients result significant, indicating that the quote adjustment after a trade is faster the wider the posted spread. However, we do not get too much improvement in terms of model adjustment.

Regarding the trade equations, the most important features revealed are that the sum of the coefficients of the lagged x_t^B and x_t^S indicate that purchases are more likely followed by new purchases and sales are more likely followed by additional sales, as was already shown in Hasbrouck (1991a). Additionally, there is a strong negative effect of trading costs. The current spread strongly diminishes the trading activity. Moreover, x_t^B (x_t^S) exhibits a strong negative (positive) correlation with changes in the ask (bid) price, consistent with the hypothesis of classical demand schedules. The results for the control sample (not reported) are similar to those previously seen for IBM.

Our next concern is to relax our first assumption and allow $f_i^j(MC_t, D_t) = 1 + \sum_{h \neq 4} \gamma_h^{i,j} D_t^h$ in order to incorporate the trading-time dummies into the model. The estimation results (not reported) indicate that, as in the VAR model, the deterministic dummies are only jointly significant when they interact with the contemporaneous trade indicators (x_t^B and x_t^S in the quote revision equations and x_{t-1}^B and x_{t-1}^S in the trade equations). Neither the significance nor the interpretation of the other variables is affected by the incorporation of these dummies.

B. Estimation of the extended trade /quote revision model for bid and ask quotes

For each variable MC_t^k, and given the results of previous subsection, the VEC in (3.8) is now estimated imposing the restrictions in (6.2), truncating all the polynomials at lag 5, and defining this time $f_i^j(MC_{t-r}^k, D_{t-r}) = 1 + \lambda_k^{i,j} MC_{t-r}^k$ for all $r \neq 0$ in the quote revision equations and $r \neq 1$ in the trade equations and $f_i^j(MC_{t-r}^k, D_{t-r}) = 1 + \lambda_k^{i,j} MC_{t-r}^k + \sum_{h\neq 4} \gamma_h^{i,j} D_{t-r}^h$ otherwise. That leads to the system (6.3).

$$
\begin{aligned}
\Delta a_t &= \alpha_5^{a,a}(L)\Delta a_{t-1} + \delta_5^{B,a}(L) f_a^B(MC_t^k, D_t) x_t^B + \delta_5^{S,a}(L) f_a^S(MC_t^k, D_t) x_t^S + \eta_5^a(L) s_{t-1} + u_t^a \\
\Delta b_t &= \beta_5^{b,b}(L)\Delta b_{t-1} + \delta_5^{B,b}(L) f_b^B(MC_t^k, D_t) x_t^B + \delta_5^{S,b}(L) f_b^S(MC_t^k, D_t) x_t^S + \eta_5^b(L) s_{t-1} + u_t^b \\
x_t^B &= \alpha_5^{a,B}(L)\Delta a_{t-1} + \delta_5^{B,B}(L) f_B^B(MC_{t-1}^k, D_{t-1}) x_{t-1}^B + \delta_5^{S,B}(L) f_B^S(MC_{t-1}^k, D_{t-1}) x_{t-1}^S + \eta_5^B(L) s_{t-1} + u_t^B \\
x_t^S &= \beta_5^{b,S}(L)\Delta b_{t-1} + \delta_5^{B,S}(L) f_S^B(MC_{t-1}^k, D_{t-1}) x_{t-1}^B + \delta_5^{S,S}(L) f_S^S(MC_{t-1}^k, D_{t-1}) x_{t-1}^S + \eta_5^S(L) s_{t-1} + u_t^S
\end{aligned}
\tag{6.3}
$$

Table III summarizes the results of estimating (6.3) by SURE for the IBM data. This table reports the sum of the coefficients of $MC_{t-r}^k x_{t-r}^B$ ($\sum_r \delta_r^{B,i} \lambda_r^{i,k}$) and $MC_{t-r}^k x_{t-r}^S$ ($\sum_r \delta_r^{S,i} \lambda_r^{i,k}$) that are statistically significant at the 5% level, for i={a, b, B, S} and all r between zero and five. The results of the F tests for the nulls $\sum_r \delta_r^{B,i} \lambda_r^{i,k} = 0$ and $\sum_r \delta_r^{S,i} \lambda_r^{i,k} = 0$ for all i are also recorded. For the Δa_t and Δb_t equations, results are consistent with arguing that larger trades and more volatile periods are associated with higher adverse selection costs (e.g., Easley and O'Hara, 1987; Glosten and Harris, 1988; Bollerslev and Melvin, 1996). Larger trade volume and more volatility increase the impact of the corresponding trade on quotes, either buyer or seller-initiated. Thus, the larger the volume of a BIT, the larger the upward adjustment of ask and bid prices. However, the overreaction of the ask to the volume of a BIT duplicates in mean terms that of the bid. Moreover, a BIT performed in a high-volatility period has a larger impact on the ask quote but no additional effect on the bid quote. A sale in a high-volatility period, however, increases its negative impact on both quotes. Therefore, the dynamics of the bid and ask revisions after an informative trade are not necessarily neither symmetric nor of equal size, and the sensibility of both quotes to variations in certain trade features may depend on whether it is a BIT or a SIT.

Regional trades are less informative, a result that agrees with previous empirical evidence showing off-NYSE trading to bring narrower spreads (e.g., Ahn et al., 1995; Madhavan and Sofianos, 1998) and a possible "cream-skimming" of uninformed traders by off-NYSE market makers (e.g., Blume and Goldstein, 1997; Bessembinder and Kaufman, 1997). Time since the last trade also matters by reducing the impact of any trade (as predicted by Easley and O'Hara's 1992 model). However, the ask price seems more sensible to changes in this variable given a new purchase than the bid given a new sale. The role of trade features and market conditions in the final impact of a given trade is not essentially the same for BITs than for SITs. The depth-based measures considered show that larger depth at the ask (bid) ameliorates the impact on both quotes of a buyer (seller)-initiated trade. However, a larger pressure to sell than to buy ($pres_t$>1) enlarges the repercussion of a SIT. Therefore, certain transient market situations may produce differences in the permanent and transitory impacts of BITs and SITs.

From the control sample, it is observed that the significance of the MC_t^k variables increases with the stock's trading frequency. As the model is defined in trade-time, the short-term dynamics generated by the MC_t^k variables in ask and bid quotes should be better captured for the more frequently traded stocks. Significant relationships tend to coincide with those previously seen for IBM (see Appendix C), although there are some stock-specific features.

Regarding x_t^B and x_t^S equations, Table III shows that a trade, no matter what kind, in a high volatility period is less probability followed by a new trade. This result may reflect the fact that for IBM midpoint trades ($x_t^B = 0$ and $x_t^S = 0$) are more frequent during more volatile periods. The positive correlation between trades of the same kind evidenced in previous subsection is weaker for trades coming from the regional markets than for trades from the primary market, and it is stronger the larger the volume of the previous trades. This result suggests that the positive autocorrelation of signed trades may be explained, at least partially, by informational arguments: traders successively reacting to new information (e.g., Biais et al., 1995) or informed traders splitting their trades in order to reduce market impact (e.g., Easley and O'Hara, 1987, and He and Wang, 1995). The more informative a trade is the higher the probability of being followed by new trades of equal sign. According to the previously referenced empirical literature, these kind of trading schemes seem more probable to occur in the NYSE than in the off-NYSE markets. Finally, the larger the pressure to sell (*$pres_t$*) the higher the probability of observing a SIT. This result may reflect a trade-off between immediacy costs and some "waiting" or "non-execution" costs (e.g., Handa and Schwartz, 1996; Parlour, 1998, and Handa et al., 1996). Results for the control sample are very similar (see Appendix C).

C. Simulations of the VEC model.

This section reports the results of simulating (6.3) for IBM in order to evaluate the sensibility of market quotes to changes in the variables MC_t^k. The objective is to compare the accumulated effects on ask and bid quotes, 25 steps into the future, of an unexpected BIT ($v_{2,t}^B = 1$) and SIT ($v_{2,t}^S = 1$) after a steady-state period (defined in this case by $x_{t-1}^B = \cdots = x_{t-5}^B = 0$, $x_{t-1}^S = \cdots = x_{t-5}^S = 0$, $\Delta a_{t-1} = \ldots = \Delta a_{t-5} = 0$, $\Delta b_{t-1} = \ldots = \Delta b_{t-5} = 0$, and $s_{t-1} = \ldots = s_{t-5} = 0$) and depending on the current level of MC_t^k. This accumulated impact is represented by $I_i^{25}(v_{2,t}^j / MC_{\text{ref}}^k)$ where i={a,b} and j={B,S}. The three levels of MC_t^k considered are defined as in section IV and the simulation proceeds through the same steps, but replacing step #3 by #3' below. This new step takes into account that in the model (6.3) the spread must be actualized after each trade-time period *t*.

(3') Compute the impulse-response functions of (6.3) for both ask and bid quotes 25 steps into the future, using the corresponding predicted values of MC_t^k in step (2). The value of the spread is actualized in each step: $s_{t+h+1} = s_{t+h} + \Delta a_{t+h} - \Delta b_{t+h}$. This gives a realization of the impulse-response functions $I_a^{25}(v_{2,t}^j / MC_{\text{ref}}^k)$ and $I_b^{25}(v_{2,t}^j / MC_{\text{ref}}^k)$ for a given MC_t^k path. The term *j* is "*B*" or "*S*" depending on whether the initial unexpected trade is a BIT or a SIT.

Table IV reports the difference between the total impact on ask and bid quotes of an unexpected unit BIT/SIT when the exogenous variable MC_t^k is "medium" versus "small", $I_i^{25}(v_{2,t}^j / MC_{\text{med}}^k) - I_i^{25}(v_{2,t}^j / MC_{\text{small}}^k)$, and "large" versus "small",

$I_i^{25}(v_{2,t}^j / MC_{\text{large}}^k) - I_i^{25}(v_{2,t}^j / MC_{\text{small}}^k)$, both expressed in percentage points to $I_i^{25}(v_{2,t}^j / MC_{\text{small}}^k)$. Only those impacts that were significant in table III have been simulated. Reference values are those in Table I. Additional information consists of the maximum difference attained (in brackets) and the step at which this highest difference is achieved (in parenthesis). For example, the impact of a buy trade on the ask is positive, as was shown in Table II, and this effect increases the larger the trade volume, as was shown in Table III. Table IV additionally indicates that the impact after 25 trade-time periods is 31% larger for "large"-volume trades (8600 shares) than for "small"-volume trades (100 shares), and 6.5% larger for "medium"-volume trades (1900 shares) than for "small"-volume ones. Figure 2 shows the differences in the adjustment path of both quotes after a BIT depending on the trade size. In economic terms, these percentages denote differences of \$0.01171 and \$0.00248 twenty-five steps after the trade, respectively. However, the maximum differences (71% and 15% respectively) are achieved at the initial impact of the trade. Furthermore, the initial stronger impact of the unexpected purchase on the ask than on the bid (\$0.0059 for a "large"-volume trade) also produces an increase in the spread, inducing simultaneous adjustments on both quotes that partly compensate the accumulated positive impact of the trade.

Table IV shows important differences in the final impact of trades depending on the level of the MC_t^k variables. The ask reaction to a SIT and the bid response to a BIT are specially sensible to the MC_t^k level for all *k*. This result means that the probability of observing a symmetric adjustment of both quotes after a trade increases with the magnitude of the MC_t^k variables. Larger trade volume, less the time since the last trade, and/or higher volatility associated to a given SIT (BIT) increments the likelihood of observing a similar downward (upward) adjustment in both quotes, consistently with adverse selection costs models (e.g., Stoll, 1989; Easley and O'Hara, 1987 and 1992). The trade volume, the quoted depth, and the market of origin are especially relevant to determine the impact of BITs on the bid quote and SITs on the ask quote. The difference between the impact of a trade coming from the primary market and a trade from the regional markets is really large. A result that clearly reflects the lower informativeness of off-NYSE trades.

Reviewing all previous evidence, it can be concluded that a large part of the information about the trade-motivated quote dynamics revealed by the estimation of the VEC model, cannot be inferred from the corresponding VAR model estimated in section IV. There is, therefore, an important informational advantage by modeling the dynamics of bid and ask quotes jointly, without averaging them. Furthermore, the differences found in the magnitude and sensitivity of ask and bid quotes to the trade process suggest possible asymmetries in the mean behavior of bid and ask quotes. Section VI formally tests for these asymmetric dynamics.

D. Estimation of the model for the bid-ask spread changes

Table V summarizes the results of estimating by SURE the model for the spread changes (6.4) consisting of the last two equations in (6.3) and the difference between the first two[7]

$$\begin{aligned}
\Delta s_t &= \alpha_5^{s,a}(L)\Delta a_{t-1} + \alpha_5^{s,b}(L)\Delta b_{t-1} + \delta_5^{s,B}(L) f_a^B(MC_t^k, D_t) x_t^B + \delta_5^{s,S}(L) f_a^S(MC_t^k, D_t) x_t^S + \eta_5^s(L) s_{t-1} + u_t^s \\
x_t^B &= \alpha_5^{a,B}(L)\Delta a_{t-1} + \delta_5^{B,B}(L) f_B^B(MC_{t-1}^k, D_{t-1}) x_{t-1}^B + \delta_5^{S,B}(L) f_B^S(MC_{t-1}^k, D_{t-1}) x_{t-1}^S + \eta_5^B(L) s_{t-1} + u_t^B \\
x_t^S &= \beta_5^{b,S}(L)\Delta b_{t-1} + \delta_5^{B,S}(L) f_S^B(MC_{t-1}^k, D_{t-1}) x_{t-1}^B + \delta_5^{S,S}(L) f_S^S(MC_{t-1}^k, D_{t-1}) x_{t-1}^S + \eta_5^S(L) s_{t-1} + u_t^S
\end{aligned} \tag{6.4}$$

As in Table II, the estimated coefficients in Table V Panel A correspond to the restricted version of the model with $f_i^j(MC_t, D_t) = 1$ for all i and j. Spread changes have a strong negative dependence on its current level and are negatively related to the previous changes in the ask quote and positively related to the past changes in the bid quote. This pattern indicates a strong reversion of the spread to low levels for IBM. Panel B summarizes the estimation results of the unrestricted model. These results are consistent with those obtained for the VEC model (6.3). Larger trade volume and volatility increases the positive impact of any trade on the spread. However, more time since the last trade and larger quoted depth reduces the effect of the incoming trade on the immediacy costs level. Trades coming from the primary market have a larger effect on the bid-ask spread.

VII. Asymmetries in the dynamics of bid and ask quotes

Simulations in previous section suggest possible differences in the mean adjustment of bid and ask quotes to the trading process. This section formally tests these asymmetries using the VEC model. Concretely, two set of tests are performed The first one covers the restricted model given by (6.1) and (6.2) but including the trading-time dummy variables. The second set refers to the extended model (6.3) for each of the MC_t^k variables. In order to check for asymmetric effects of depth at the ask quote and depth at the bid quote, the last four hypotheses concern to the model (6.3) but including $deptha_t$ and $depthb_t$ together.

Given the estimation results in Table III, some asymmetries are obvious, and are clearly found to be significant. The effect of a BIT (SIT) on the ask (bid) quote is surely larger than its effect on the bid (ask) quote. Although a purchase tends to increase both quotes, reflecting a possible upward revision in the expected efficient price of the stock, the growth is not of equal size (as would be predicted by several microstructure models). For some stocks, the impact of a BIT (SIT) on the ask (bid) triplicates that on the bid (ask). Certainly, the initial larger impact on the ask quote may be the mix of a liquidity consuming (transitory) effect plus an informational (permanent) effect. Nonetheless, as transitory, the former effect cannot explain the differences found in the total impact of trades. The statistical analysis in this section concentrates on testing other kind of asymmetries not so obvious or expected: basically, the dynamics of the ask quote following a BIT and the dynamics of the bid following a similar SIT. The hypotheses tested, and the implications of rejecting them, are reported in Appendix D. Table VI shows the results of all these tests for IBM. This table reveals significant asymmetries in the mean dynamics of ask and bid quotes, even for the restricted VEC model.

For the restricted model results in Table VI indicate that the mean impact of an unexpected BIT on the ask quote differs from the mean impact of an unexpected SIT on the bid quote ($H^R_{q,1}$ rejected). A possible explanation of this asymmetry could be the quote evolution. During the time-period considered the IBM quotation increased from \$90.875 to \$109.75 (closing midpoint quotes), which could partly explain the larger impact of BITs. Through the control sample, however, we did not find a clear relationship between neither the stock's price trend nor the magnitude of the total quotation change during the period analyzed and the number and significance of the asymmetries found. For example, SLB and USS, both with augments of more than \$10, also reject $H^R_{q,1}$ in terms of a larger impact of BITs over the ask dynamics. However, CMB quotation inflated \$12.75 and GRN quotation decreased \$10.25, but did not show a statistically significant difference between the impact of BITs on the ask and SITs on the bid. Similarly, ask and bid's alignment in response to wide spreads is unlike ($H^R_{q,3}$ rejected) for IBM and 30% of the stocks in the control sample (this percentage increases when the test is performed only over the coefficient of the current spread). Again, although it seems that those stocks with the most striking upward (downward) trends show a faster bid (ask) immediate adjustment, the evidence is not unequivocal at all. BIT and SIT processes also show significant differences. The positive autocorrelation for sales is not equally stronger than for purchases ($H^R_{x,1}$ rejected) for IBM and 80% of the stocks in the control sample. This kind of asymmetry could be a symptom of overreaction of the market to certain kind of news. However, although for IBM a sequence of sells is more probable than a sequence of buys, the asymmetry is the opposite one for other stocks (e.g., GE, TXN). Once more, there is no clear relationship between the direction of this asymmetry and the stock price evolution. Therefore, it can be concluded that market trend is not enough to explain the asymmetries reported. The restricted model is fully asymmetric for TXN but fully symmetric for HM, however, both show a quotation increase around $3 during the three moths studied.

The results of the tests for the VEC (6.3) evidence that the variables selected to characterize trade features and market conditions have a different mean effect on both quotes, as the simulation results suggested. The nulls $H^E_{q,1}$ and $H^E_{q,2}$ are rejected for all MC^k_t, meaning that the sensitivity of the response of the ask quote to a trade innovation when market conditions and the trade features are changed, differs from that of the bid quote. For example, although for IBM the mean impact of a BIT on the ask is larger than the mean impact of a SIT on the bid, as the restricted model verified, the overreaction of both quotes to a change in the trade volume is larger for SITs than for BITs. On the contrary, the impact of a BIT on the ask quote depends more on the time since the previous trade than the impact of the corresponding SIT on the bid quote. These asymmetric findings are generally supported by the results of the control sample, particularly for $H^E_{q,1}$, although the imbalance for some MC^k_t (like $risk_t$) is not necessarily in the same direction than that found for IBM. The number of significant asymmetries is larger for the most frequently traded stocks (GE, TXN, GTE or ELY), suggesting that the short-term asymmetries are better captured the shorter the mean time between trades. Concerning the last set of hypotheses, $H^E_{q,3}$ and $H^E_{q,4}$ have been rejected for IBM, and also for 80% and 90% of the stocks in the control sample respectively. For IBM, the diminishing effect of $deptha_t$ over the impact of a BIT on the ask quote is weaker than the diminishing effect of an equivalent $depthb_t$ level over the impact of sales on the bid quote ($H^E_{q,3}$). Similarly, the impact of a SIT on the ask quote decreases due to $deptha_t$ in a larger amount than the impact of a BIT on the bid quote does due to a similar $depthb_t$ level ($H^E_{q,4}$). Therefore, even controlling by quoted depth, for IBM BITs have a larger impact on the ask quote than similar SITs on the bid. The trading processes also show some significant asymmetries, but are more stock specific.

It is difficult to find a reasonable explanation to all the asymmetries evidenced. The sign of a given asymmetry is not the same for all stocks, meaning that behind this phenomenon there could be stock-specific justifications. Block trading literature (e.g., Scholes, 1972; Kraus and Stoll, 1972; Holthausen et al., 1987 and 1990; Gemmil, 1996) expects BITs to have a larger impact than SITs, because (a) liquidity providers are less prone to take short than long positions. (b) The decision of selling one stock is restricted to a more reduced set of possible candidates (e.g., Chan and Lakonishok, 1993). This is the case for IBM but not for other stocks in our sample. It has been shown that the quote trend is not sufficient to explain the asymmetries found either. Other explanations are possible, however their analysis are out of the scope of the present work. What is really relevant for this work is that previous results reveal that ask and bid revisions to the innovations in the trading process may exhibit significant asymmetries. The dynamics induced by an unexpected BIT on the ask differ for some stocks in our sample from the dynamics provoked by a similar unexpected SIT on the bid, both occurring within a similar market environment. Therefore, the dynamic relationship between market quotes and the trading process is better characterized through the VEC model than through the VAR model. Therefore, there is an important value added in modeling bid and ask quotes simultaneously rather than averaging them through the quote midpoint or the trade price.

VIII. Conclusions

In this paper we introduce a structural model of quote formation that allows studying the dynamics of ask and bid quote revisions induced by the innovations in the trading process. We show that the empirical counterpart of the structural model is a vector error correction (VEC) representation that jointly specifies the dynamics of the ask and bid quote revisions and BIT and SIT processes. Therefore, our approach extends the bivariate vector autoregressive (VAR) model suggested by Hasbrouck (1991a) in at least five important aspects: (i) The VEC model incorporates the long-run cointegration relationship between the ask and bid quotes as a known cointegrating vector given by the spread. (ii) BITs and SITs have their own idiosyncratic, but mutually dependent, generating processes. (iii) Asymmetric behaviors in the responses of the ask and bid quotes to shocks in the trading processes are allowed. (iv) BITs and SITs are may have different impacts on the ask and bid quotes. (v) The empirical reduced-form is directly derived from the underlying dynamic structural model.

The empirical results obtained for several NYSE common stocks reveal important gains in information by not averaging the quote revision process through the quote midpoint. The mean dynamics of the ask and bid after an unexpected BIT and SIT, respectively, are not necessarily symmetric, nonetheless symmetry is more likely for more informative trades. But, in addition, the effect of a BIT on the ask is different than a similar SIT on the bid. The importance and significance of these asymmetries increase with the stock's trading frequency. These results do not support the usual hypotheses of most theoretical microstructure models of parallel adjustments of both quotes after a new trade and of symmetry in the ask and bid quotes with respect to the efficient stock price.

Footnotes

1. Other econometric approaches, parametric and semi-parametric respectively, to model the relationship between the trading process and the price changes are Hausman et al. (1992), that used ordered probit models, and Kempf and Korn (1999) that employed a neural networks type model.

2. The realized spread is defined as the difference between the trade price and a proxy for the efficient stock price in a convenient posterior time, far enough to guarantee that all the information conveyed by the trade has been incorporated into prices.

3. This paper follows the Hasbrouck's model original notation, m_t is the efficient price after the trade x_t and q_{t-1} is the quote associated to that trade. Therefore, x_t provokes a revision in the current efficient price equal to m_t - m_{t-1} and in the quotes equal to q_t - q_{t-1}. Similarly, $v_{1,t}$ is the update in public information that occurs between the revision in m_{t-1}, that is m_t - m_{t-1}, after the trade x_t.

4. $risk_t$ is not defined for trades performed during the first five minutes of trading. These cases are considered as missing values.

5. In case of autocorrelated disturbances FGLS provides no longer efficient estimators and the usual inference procedures are not appropriate. Usual statistical tests (White's Test, Goldfeld-Quand Test, Durbin-Watson Test, Breuch-Godfrey Test) performed on the FGLS residuals of (5.1) evidence very weak problems of residual autocorrelation.

6. The conditional expectation of x_t has to take values in the range of possible values of x_t during the simulation. This may not be the case for some extreme values of the explanatory variables. As was already done by de Jong et al. (1996) and Dufour and Engle (2000), we assume that this is a minor inconvenient.

7. Notice that this equation can be easily restated in terms of spread levels. Estimation results will not be altered except for the fist coefficient of the $\eta_5^s(L)$ polynomial, say η_0^s.

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TABLE I
The VAR model

This table summarizes the estimation results of the extended Hasbrouck's VAR model for IBM,

$$\Delta q_t = \sum_{i=1}^{5} a_i \Delta q_{t-1} + \sum_{i=0}^{5} \left[\alpha_i^q + \beta_i^q MC_{t-i}^k\right] x_{t-i} + \sum_{h \neq 4} \lambda_h^q D_{t-i}^h x_t + v_{1,t} \qquad \text{(T.1)}$$

$$x_t = \sum_{i=1}^{5} c_i \Delta q_{t-1} + \sum_{i=1}^{5} \left[\alpha_i^x + \beta_i^x MC_{t-i}^k\right] x_{t-i} + \sum_{h \neq 4} \lambda_h^q D_{t-i}^h x_{t-1} + v_{2,t}$$

for the different variables considered to characterize the trade and the market conditions MC_t^k. The variables D_t^h are trading-time dummies, q_t is the quote midpoint and x_t is a trade indicator (-1=SIT, 1=BIT, 0=otherwise). Furthermore $\Delta q_t = (q_t - q_{t-1})$. Notice that q_{t-1} is the quote in existence when x_t occurs. The table reports the summation of the significant coefficients of MC_t^k for each of the two equations ($\sum_{i=0}^{5} \beta_i^q$ and $\sum_{i=1}^{5} \beta_i^x$) and also the results of the Wald Test (e.g., Davidson and MacKinnon, 1993) performed to test the null of global significance of these coefficients ($H_0^q : \sum_{i=0}^{5} \beta_i^q = 0$ and $H_0^x : \sum_{i=1}^{5} \beta_i^x = 0$). This table also reports the total quote impact of an unexpected buyer-initiated trade ($v_{2,t} = 1$) 25 steps into the future, estimated using (T.1), under different values of MC_t^k: "small", "medium" and "large", characterized by the 25%, 75% and 95% percentiles of the empirical distribution of MC_t^k, respectively. Values reported are $I_q^{25}(v_{2,t} / MC_{\text{large}}^k) - I_q^{25}(v_{2,t} / MC_{\text{small}}^k)$ and $I_q^{25}(v_{2,t} / MC_{\text{med}}^k) - I_q^{25}(v_{2,t} / MC_{\text{small}}^k)$, expressed in relative terms to $I_q^{25}(v_{2,t} / MC_{\text{small}}^k)$, where $I_q^{25}(v_{2,t} / MC_{\text{ref}}^k)$ represents the conditional accumulated quote impact. Reference values are in parenthesis.

(Coef.x1000)[†] MC_t^k	Δq_t $\sum_{i=0}^{5} \beta_i^q$	x_t $\sum_{i=1}^{5} \beta_i^x$	$I_q^{25}(v_{2,t} / MC_{\text{ref}}^k)$ Medium vs. Small MC_t^k (%)	Large vs. Small MC_t^k (%)
Vol_t	**0.00155***	0.0062	13.65 (1900 vs 100)	65.94 (8600 vs 100)
$Tlast_t$	**-0.112***	8.45	-2.84 (13 vs 3)	-9.96 (37 vs 3)
$Risk_t$	28.14	**-186.4***	7.51 (.05 vs .01)	24.28 (.12 vs .01)
Reg_t	**-17.85***	**-287.6***	152.15 (NYSE vs reg.)	
s_t	**41.2***	**441.7***	51.83 (.250 vs .125)	107.95 (.375 vs .125)
$Depth_t$	**-4.23e-05***	**0.00146***	-0.199 (300 vs 100)	-0.591 (600 vs 100)

[†] Format in bold means significant at the 5% level.

[*] Significant at the 5% level when all the variables are included in the model.

TABLE II
The basic VEC model

This table shows the coefficients of the VEC in (6.1) for IBM estimated by SURE and with the following restrictions:

$$\sum_{i=1}^{5}\beta_i^{b,a}=0,\ \sum_{i=1}^{5}\alpha_i^{a,b}=0,\ \sum_{i=1}^{5}\beta_i^{b,B}=0 \text{ and } \sum_{i=1}^{5}\alpha_i^{a,S}=0.$$

(Coef. x1000)*	Δa_t	Δb_t	x_t^B	x_t^S
Δa_{t-1}	**-21.2**		**-1710.5**	
Δa_{t-2}	**11.1**		**-914**	
Δa_{t-3}	**19.9**		**-300.9**	
Δa_{t-4}	**26.1**		20.7	
Δa_{t-5}	**27.4**		**190.6**	
Δb_{t-1}		**-9.7**		**1728.7**
Δb_{t-2}		**19.1**		**890.2**
Δb_{t-3}		**29.8**		**399.2**
Δb_{t-4}		**25.2**		-16.6
Δb_{t-5}		**29.6**		**-191.4**
x_t^B	**7.5**	**4.0**		
x_{t-1}^B	**7.0**	**3.1**	**265.3**	**50.1**
x_{t-2}^B	**3.9**	**0.7**	**168.9**	**29.3**
x_{t-3}^B	**3.3**	-0.1	**110.8**	**14.1**
x_{t-4}^B	**0.9**	**-2.2**	**83.6**	**22.2**
x_{t-5}^B	**1.9**	**-1.9**	**75.4**	**38.6**
x_t^S	**-4.4**	**-7.4**		
x_{t-1}^S	**-1.9**	**-4.9**	**51.6**	**260.7**
x_{t-2}^S	-0.4	**-3.2**	**26.2**	**171.4**
x_{t-3}^S	1.2	**-1.6**	**14.3**	**116.4**
x_{t-4}^S	**1.1**	**-1.8**	**17.7**	**94.8**
x_{t-5}^S	**3.0**	-0.6	**20.2**	**98.7**
s_{t-1}	**-75.5**	**69.8**	-703.5	**-813.7**
s_{t-2}	**-11.8**	**17.1**	**289.3**	**295.1**
s_{t-3}	1.6	-4.8	73.7	**163.4**
s_{t-4}	2.8	-5.6	74.8	**121.6**
s_{t-5}	**33.6**	**-27.5**	**365.4**	**390.9**
R^2	0.0726	0.0604	0.4586	0.5123

* Format in bold means significant at the 5% level.

TABLE III

The VEC model

This table summarizes the estimation results of the VEC model in (6.3) for each of the different variables considered to characterize trade and market conditions (MC_t^k) for IBM data. The summation of the significant coefficients of $MC_{t-r}^k x_{t-r}^B$ and $MC_{t-r}^k x_{t-r}^S$ for each equation are reported. The results of the Wald tests (e.g., Davidson and MacKinnon, 1993) performed to test the null of joint significance of these coefficients ($\sum_r \delta_r^{B,i} \lambda_r^{i,k} = 0$ and $\sum_r \delta_r^{S,i} \lambda_r^{i,k} = 0$) are also summarized.

(Coef.x1000) †	Δa_t		Δb_t		x_t^B		x_t^S	
MC_t^k	Buys	Sells	Buys	Sells	Buys	Sells	Buys	Sells
Vol_t	**0.00164***	**-0.00122***	**0.000832***	**-0.00277***	**0.00387**	**-0.00876***	**-0.00425***	**0.00298**
$Tlast_t$	**-0.1743***	-0.0343*	**-0.09207***	**0.0864***	0.6358	0.3534	**0.3853***	**0.8384***
$Risk_t$	**33.492***	**-10.33***	-3.798	**-22.75***	**-184.44**	**-98.01***	**-124.21***	**-314.6***
Reg_t	**-18.58***	**16.115***	**-14.09***	**21.767***	**-197.48***	**128.03***	**142.28***	**-180.19***
$Deptha_t$	**-0.011***	**-0.0122***	**-0.0127**	**0.00532***	**-0.1147***	**-0.1365***	**0.1662**	**0.147***
$Depthb_t$	-0.003	**0.01096***	**0.008***	**0.01915***	**0.2448***	**0.1485***	**-0.1662***	**-0.0976**
$Pres_t$	0.0688*	**-0.2762***	**-0.3801***	**-0.2974***	**-4.4015**	**-4.287***	**3.6143**	**2.8698**

† Format in bold means significant at the 5% level.

* Significant at the 5% level when all the variables are included in the model.

TABLE IV
Simulations of the VEC model

This table reports the results of simulating the model (6.3) for IBM. The accumulated effect 25 steps into the future on ask and bid quotes of an unexpected buyer-initiated trade ($v^B_{2,t}=1$) and seller-initiated trade ($v^S_{2,t}=1$) are compared conditional on the MC^k_t level. Three levels of MC^k_t are considered: "medium" (M), "large" (L) and "small" (S).† This panel reports the difference between the total impact of an unexpected trade when MC^k_t is L vs. S, i.e. $I^{25}_i(v^j_{2,t}/MC^k_{\text{large}})-I^{25}_i(v^j_{2,t}/MC^k_{\text{small}})$, and M vs. S, i.e. $I^{25}_i(v^j_{2,t}/MC^k_{\text{med}})-I^{25}_i(v^j_{2,t}/MC^k_{\text{small}})$ expressed in percentage points to $I^{25}_i(v^j_{2,t}/MC^k_{\text{small}})$. Additional information consists in the maximum difference achieved (in brackets) and the step at which it is attained (in parenthesis). We only report the impacts that are significantly different from zero (see Table III).

	Δa_t				Δb_t			
	Buy shock ($v^B_{2,t}=1$)		Sell shock ($v^S_{2,t}=1$)		Buy shock ($v^B_{2,t}=1$)		Sell shock ($v^S_{2,t}=1$)	
MC^k_t	L vs. S MC^k_t	M vs. S MC^k_t	L vs. S MC^k_t	M vs. S MC^k_t	L vs. S MC^k_t	M vs. S MC^k_t	L vs. S MC^k_t	M vs. S MC^k_t
Vol_t	30.99 [71.11] (1)	6.57 [15.06] (1)	530.87 [734.05] (14)	114.91 [157.84] (14)	89.73 [128.90] (6)	18.89 [27.15] (6)	65.22 [163.12] (2)	14.21 [34.55] (2)
$Tlast_t$	-8.38 [-28.29] (1)	-2.36 [-8.32] (1)			-21.38 [-28.21] (6)	-6.02 [-8.17] (6)	-0.46 [-30.47] (1)	-0.21 [-8.96] (1)
$Risk_t$	12.95 [32.74] (1)	3.67 [9.38] (1)	38.74 [56.34] (11)	12.72 [17.07] (11)			6.50 [60.58] (1)	2.22 [17.36] (1)
$Deptha_t$	-35.60 [-77.40] (1)	-10.94 [-24.75] (1)	532.22 [621.41] (16)	167.34 [192.81] (16)	-76.84 [-89.64] (5)	-23.95 [-28.95] (5)	40.99 [40.99] (25)	13.05 [13.05] (25)
$Depthb_t$			-94.54 [-98.19] (3)	-26.45 [-37.04] (6)	204.17 [204.17] (25)	53.66 [53.66] (25)	-38.48 [-90.61] (1)	-9.64 [-23.49] (1)
$Pres_t$			301.70 [334.93] (16)	69.15 [75.85] (16)	-28.38 [-77.60] (1)	-6.82 [-16.98] (1)	23.68 [74.54] (1)	5.47 [16.31] (1)
NY/Reg	112.55 [260.95] (1)		321.58 [131,006.42] (5)		232.96 [3047.72] (5)		83.12 [551.78] (1)	

†Reference values are those in Table I. For pre_t reference values are (10, 2.5, 0.4) for large, medium and small, respectively.

TABLE V
The model for the spread changes

Panel A shows the coefficients of the first equation of the spread changes model (T2) for IBM, estimated by SURE.

$$
\begin{aligned}
\Delta s_t &= \alpha_5^{s,a}(L)\Delta a_{t-1} + \alpha_5^{s,b}(L)\Delta b_{t-1} + \delta_5^{s,B}(L) f_a^B(MC_t^k, D_t)x_t^B + \delta_5^{s,S}(L) f_a^S(MC_t^k, D_t)x_t^S + \eta_5^s(L)s_{t-1} + u_t^s \\
x_t^B &= \alpha_5^{a,B}(L)\Delta a_{t-1} + \delta_5^{B,B}(L) f_B^B(MC_{t-1}^k, D_{t-1})x_{t-1}^B + \delta_5^{S,B}(L) f_B^S(MC_{t-1}^k, D_{t-1})x_{t-1}^S + \eta_5^B(L)s_{t-1} + u_t^B \\
x_t^S &= \beta_5^{b,S}(L)\Delta b_{t-1} + \delta_5^{B,S}(L) f_S^B(MC_{t-1}^k, D_{t-1})x_{t-1}^B + \delta_5^{S,S}(L) f_S^S(MC_{t-1}^k, D_{t-1})x_{t-1}^S + \eta_5^S(L)s_{t-1} + u_t^S
\end{aligned}
\qquad \text{(T2)}
$$

Panel B summarizes the estimation results of the unrestricted spread changes model for each of the variables characterizing trade features and market conditions. The summation of the significant coefficients of $MC_{t-r}^k x_{t-r}^B$ and $MC_{t-r}^k x_{t-r}^S$ for each equation is reported. The results of the Wald tests (e.g., Davidson and MacKinnon, 1993) performed for the null of joint significance of these coefficients ($\sum_r \delta_r^{B,i}\lambda_r^{i,k} = 0$ and $\sum_r \delta_r^{S,i}\lambda_r^{i,k} = 0$) are also summarized.

(Coef. x1000)*	Panel A		Panel B	
	Δs_t	MC_t^k	Buys	Sells
Δa_{t-1}	**-58.4**	Vol_t	**0.00081**	**0.00143**
Δa_{t-2}	**-28.8**			
Δa_{t-3}	**-42.4**	$Tlast_t$	**-0.0767**	**-0.1033**
Δa_{t-4}	-18.7			
Δa_{t-5}	**-28.9**	$Risk_t$	**39.3147**	**8.3122**
Δb_{t-1}	**46.9**			
Δb_{t-2}	20.8	Reg_t	**-4.0686**	**-4.4128**
Δb_{t-3}	**32.9**			
Δb_{t-4}	20.1	$Deptha_t$	**-0.00008**	**-0.00007**
Δb_{t-5}	27.6			
x_t^B	**2.8**	$Depthb_t$	**-0.00009**	**-0.00013**
x_{t-1}^B	**3.8**			
x_{t-2}^B	**3.2**	$Pres_t$	**0.1241**	0.0262
x_{t-3}^B	**3.5**			
x_{t-4}^B	**3.1**			
x_{t-5}^B	**3.9**			
x_t^S	**1.9**			
x_{t-1}^S	**2.9**			
x_{t-2}^S	**2.8**			
x_{t-3}^S	**2.8**			
x_{t-4}^S	**2.9**			
x_{t-5}^S	**3.7**			
s_{t-1}	**-110.1**			
s_{t-2}	-26.3			
s_{t-3}	28.4			
s_{t-4}	-8.6			
s_{t-5}	26.3			
R^2	0.0844			

*Format in bold means significant at the 5% level.

TABLE VI

Asymmetries in the short-term dynamics of bid and ask quotes

This table reports the results of the Wald tests (e.g., Davidson and MacKinnon, 1993) mentioned in Appendix D for IBM. "Rejected" means that the null hypothesis can be rejected at the 5% confidence level. If nothing is specified, the null hypothesis is acceptable at the same confidence level.

Restricted VEC model (Coef.x10^3)						
	$H^R_{q,1}:\sum_{i=0}^5 \delta_i^{B,a} = -\sum_{i=0}^5 \delta_i^{S,b}$	$H^R_{q,2}:\sum_{i=0}^5 \delta_i^{S,a} = -\sum_{i=0}^5 \delta_i^{B,b}$	$H^R_{q,3}:\sum_{i=0}^5 \eta_i^{a} = -\sum_{i=0}^5 \eta_i^{b}$	$H^R_{x,1}:\sum_{i=1}^5 \delta_i^{B,B} = \sum_{i=1}^5 \delta_i^{S,S}$	$H^R_{x,2}:\sum_{i=1}^5 \delta_i^{S,B} = \sum_{i=1}^5 \delta_i^{B,S}$	$H^R_{x,3}:\sum_{i=0}^5 \eta_i^{B} = \sum_{i=0}^5 \eta_i^{S}$
Test result:	Rejected	Rejected	Rejected	Rejected	Rejected	
Values	$\sum_{i=0}^5 \delta_i^{B,a} = 24.31$	$\sum_{i=0}^5 \delta_i^{S,a} = -0.551$	$\sum_{i=0}^5 \eta_i^{a} = -53.671$	$\sum_{i=1}^5 \delta_i^{B,B} = 704.181$	$\sum_{i=1}^5 \delta_i^{S,B} = 130.008$	$\sum_{i=0}^5 \eta_i^{B} = 93.3749$
	$\sum_{i=0}^5 \delta_i^{S,b} = -18.29$	$\sum_{i=0}^5 \delta_i^{B,b} = 3.822$	$\sum_{i=0}^5 \eta_i^{b} = 49.028$	$\sum_{i=1}^5 \delta_i^{S,S} = 742.158$	$\sum_{i=1}^5 \delta_i^{B,S} = 154.356$	$\sum_{i=0}^5 \eta_i^{S} = 157.486$

Extended VEC model: (6.3)*				
H_0	$H^E_{q,1}$: $\sum_{k=0}^5 \delta_k^{B,a}\lambda_k^{B,a} = -\sum_{k=0}^5 \delta_k^{S,b}\lambda_k^{S,b}$	$H^E_{q,2}$: $\sum_{k=0}^5 \delta_k^{S,a}\lambda_k^{S,a} = -\sum_{k=0}^5 \delta_k^{B,b}\lambda_k^{B,b}$	$H^E_{x,1}$: $\sum_{k=1}^5 \delta_k^{B,B}\lambda_k^{B,B} = -\sum_{k=1}^5 \delta_k^{S,S}\lambda_k^{S,S}$	$H^E_{x,2}$: $\sum_{k=1}^5 \delta_k^{S,B}\lambda_k^{S,B} = -\sum_{k=0}^5 \delta_k^{B,S}\lambda_k^{B,S}$
Vol_t	Rejected	Rejected		Rejected
$Tlast_t$	Rejected	Rejected		
$Risk_t$	Rejected	Rejected	Rejected	
Reg_t	Rejected	Rejected	Rejected	
$Pres_t$	Rejected	Rejected		

Extended VEC model (6.3) with *$deptha_t$* and *$depthb_t$* (Coef.x10^6)				
H_0	$H^E_{q,3}$: $\sum_{k=0}^5 \delta_{Da,k}^{B,a}\lambda_{Da,k}^{B,a} = -\sum_{k=0}^5 \delta_{Db,k}^{S,b}\lambda_{Db,k}^{S,b}$	$H^E_{q,4}$: $\sum_{k=0}^5 \delta_{Da,k}^{S,a}\lambda_{Da,k}^{S,a} = -\sum_{k=0}^5 \delta_{Db,k}^{B,b}\lambda_{Db,k}^{B,b}$	$H^E_{x,3}$: $\sum_{k=1}^5 \delta_{Da,k}^{B,B}\lambda_{Da,k}^{B,B} = \sum_{k=1}^5 \delta_{Db,k}^{S,S}\lambda_{Db,k}^{S,S}$	$H^E_{x,4}$: $\sum_{k=1}^5 \delta_{Da,k}^{S,B}\lambda_{Da,k}^{S,B} = \sum_{k=0}^5 \delta_{Db,k}^{B,S}\lambda_{Db,k}^{B,S}$
Test:	Rejected	Rejected		Rejected
Values:	$\sum_k \delta_{Da,k}^{B,a}\lambda_{Da,k}^{B,a} = -0.1272$	$\sum_k \delta_{Da,k}^{S,a}\lambda_{Da,k}^{S,a} = -0.046$	$\sum_k \delta_{Da,k}^{B,B}\lambda_{Da,k}^{B,B} = -1.34$	$\sum_k \delta_{Da,k}^{S,B}\lambda_{Da,k}^{S,B} = -1.46$
	$\sum_k \delta_{Db,k}^{S,b}\lambda_{Db,k}^{S,b} = 0.2277$	$\sum_k \delta_{Db,k}^{B,b}\lambda_{Db,k}^{B,b} = 0.168$	$\sum_k \delta_{Db,k}^{S,S}\lambda_{Db,k}^{S,S} = -1.283$	$\sum_k \delta_{Db,k}^{B,S}\lambda_{Db,k}^{B,S} = -1.82$

* The values of the coefficients are those in Table III.

FIGURE 1

Restricted VEC model for IBM: Response of quotes after an unexpected trade.

This figure shows the response of ask and bid quotes to an unexpected buyer and seller initiated trade according to the estimated VEC model for IBM.

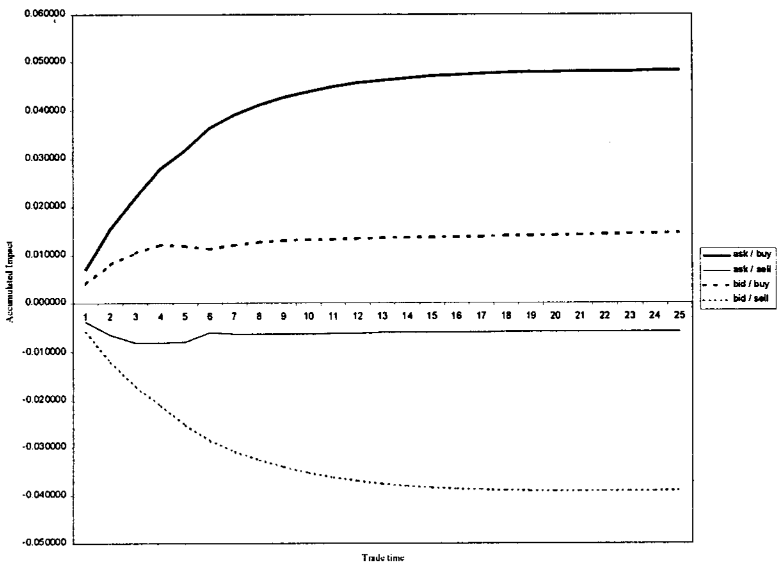
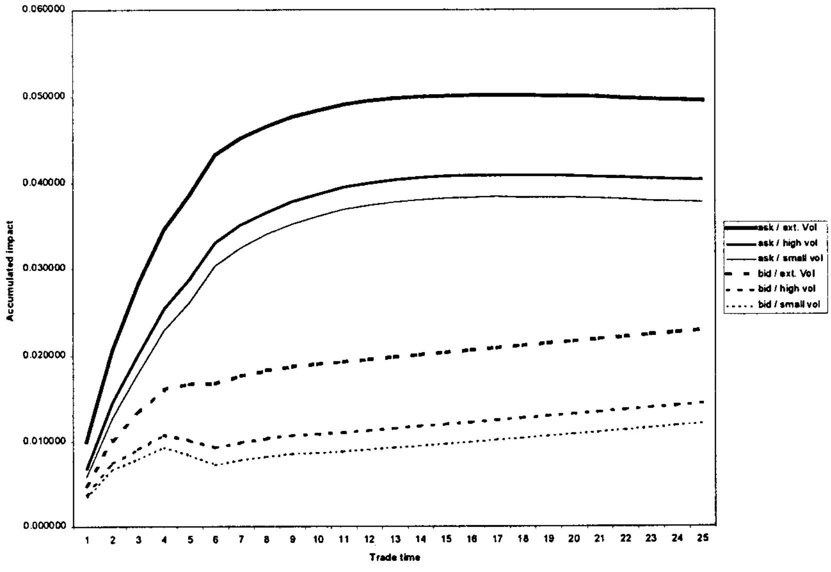


FIGURE 2

VEC model for IBM: Response of quotes after a "large-volume" versus an "small-volume" purchase.

This figure represents the response of both ask (continuous lines) and bid (dotted lines) quotes to an "large-volume" market purchase (thickest line) compared with a "small-volume" (thinnest line) and a "high-volume" market purchase, according to the VEC model estimated for IBM. An "large-volume" ("small-volume") trade is defined by the 95% (25%) percentile of the empirical distribution of trade volume.



APPENDIX A
Derivation of the VEC model (3.8)

From equation (3.2)

$$\left[1-\alpha_m^a L\right](a_t - m_t) = A_{x,t}(L)' x_t + \alpha_a^{EC}(a_{t-1} - b_{t-1}) + \varepsilon_t^a .$$

As $0<\alpha_m^a<1$, $\alpha(L) = \left[1-\alpha_m^a L\right]$ is an stationary polynomial in L. Then,

$$(a_t - m_t) = \alpha(L)^{-1} A_{x,t}(L)' x_t + \alpha(L)^{-1}\alpha_a^{EC} s_{t-1} + \alpha(L)^{-1}\varepsilon_t^a . \tag{A.1}$$

Let $\Delta=(1-L)$ be the first differencing operator. Pre-multiplying in (A.1) by Δ, and letting $\alpha(L)^{-1} A_{x,t}(L)\Delta = \widetilde{A}_{x,t}(L)$ and $\alpha(L)^{-1}\alpha_a^{EC}\Delta = \widetilde{\alpha}_a^{EC}(L)$ we obtain

$$\Delta a_t = \Delta m_t + \widetilde{A}_{x,t}(L)' x_t + \widetilde{\alpha}_a^{EC}(L) s_{t-1} + \theta(L)\varepsilon_t^a , \tag{A.2}$$

where $\theta(L)\varepsilon_t^a = (1-L)/(1-\alpha_m^a L)$ which can be approximated by a moving average polynomial of finite order, say q, $\theta(L)\varepsilon_t^a \approx \widetilde{\theta}(L)\varepsilon_t^a = (1-\widetilde{\theta}_a^1 L - \widetilde{\theta}_a^2 L^2 - \cdots - \widetilde{\theta}_a^q L^q)\varepsilon_t^a$. Substituting equation (3.1) in (A.2) we have

$$\Delta a_t = \widetilde{\mathrm{A}}_{\mathrm{x,t}}(\mathrm{L})' x_t + \widetilde{\alpha}_a^{EC}(L) s_{t-1} + \xi_t^a . \tag{A.3}$$

The error term $\xi_t^a = \widetilde{\theta}(L)\varepsilon_t^a + z^B v_{2,t}^B + z^S v_{2,t}^S + v_{1,t}$ has an invertible moving average (MA) representation. Inverting the MA or alternatively adding long-enough dynamics of the regressors of (A.3), Δa_t and also Δb_t (since they are highly correlated), the moving average structure disappears. Therefore, equation (A.3) could parsimoniously be approximated by

$$\Delta a_t = \alpha_a^{EC}(L) s_{t-1} + A_{aa}(L)\Delta a_{t-1} + A_{ab}(L)\Delta b_{t-1} + A_{x,t}(L)' x_t + u_t^a . \tag{A.4}$$

The errors are white noise, $E(u_t^a) = 0$ and $E(u_t^a, u_{t-k}^a) = 0\ \forall k$, with the autoregressive polynomials $A_{ij}(L)$ having all roots outside the unit circle. Let,

$$A_{x,t}(L)' x_t = A_{ij}^B(L) f_{ij}^B(MC_{t-1}, D_{t-1}) x_t^B + A_{ij}^S f_{ij}^S(MC_{t-1}, D_{t-1}) x_t^S = A_{ij,t}(L)' x_t .$$

Equation (A.4) can now be written as

$$\Delta a_t = \alpha_a^{EC}(L) s_{t-1} + A_{aa}(L)\Delta a_{t-1} + A_{ab}(L)\Delta b_{t-1} + A_{aB,t}(L) x_t^B + A_{aS,t}(L) x_t^S + u_t^a , \tag{A.5}$$

which is the first equation of the system (3.8).

The corresponding equation for Δb_t is similarly obtained by repeating the previous steps for equation (3.3) obtaining the equivalent expression of equation (A.3) for b_t

$$\Delta b_t = \widetilde{\mathrm{B}}_{\mathrm{x,t}}(\mathrm{L})' x_t + \widetilde{\alpha}_b^{EC}(L) s_{t-1} + \xi_t^b . \tag{A.6}$$

Notice that ξ_t^a and ξ_t^b have a component in common ($z^B v_{2,t}^B + z^S v_{2,t}^S + v_{1,t}$) and, therefore, they are mutually correlated. This correlation depends on the importance of the idiosyncratic components in each of the residuals. From the same arguments we can obtain the equivalent model to (A.5) for Δb_t with white noise errors

$$\Delta b_t = \alpha_b^{EC}(L)s_{t-1} + A_{ba}(L)\Delta a_{t-1} + A_{bb}(L)\Delta b_{t-1} + A_{bB,t}(L)x_t^B + A_{bS,t}(L)x_t^S + u_t^b. \tag{A.7}$$

As the errors u_t^a and u_t^b are mutually correlated and therefore efficient estimation requires at least a joint estimation of (A.5) and (A.7).

From (3.4) using (A.1)-(A.2) we obtain,

$$\begin{aligned} x_t^B &= \mu^B \widetilde{B}_{x,t}(L)'x_{t-1} + (\mu^B \widetilde{\alpha}_a^{EC}(L)L + \pi^B)s_{t-1} + \alpha(L)^{-1}\varepsilon_t^a + v_{2,t}^B = \\ &= \varphi_{x,t}^B(L)'x_{t-1} + \varphi_s^B(L)s_{t-1} + \xi_t^B \end{aligned} \tag{A.8}$$

where the error term $\xi_t^B = \alpha(L)^{-1}\varepsilon_t^a + v_{2,t}^B$ has an invertible moving average (MA) representation. As previously done, this moving average structure can be approximated by,

$$x_t^B = \alpha_B^{EC}(L)s_t + A_{Ba}(L)\Delta a_{t-1} + A_{Bb}(L)\Delta b_{t-1} + A_{BB,t}(L)x_{t-1}^B + A_{BS,t}(L)x_{t-1}^S + u_t^B \tag{A.9}$$

where $E(u_t^B) = 0$ and $E(u_t^B, u_{t-k}^B) = 0 \; \forall k$.

The corresponding equation for x_t^S is similarly obtained by repeating the previous steps with equation (3.5). We first obtain,

$$x_t^S = \varphi_{x,t}^S(L)'x_{t-1} + \varphi_s^S(L)s_{t-1} + \xi_t^S \tag{A.10}$$

where the error term $\xi_t^S = \alpha(L)^{-1}\varepsilon_t^b + v_{2,t}^S$. Following the argument stated right after equation (A.8), we get the last equation of the system (3.8),

$$x_t^S = \alpha_S^{EC}(L)s_{t-1} + A_{Sa}(L)\Delta a_{t-1} + A_{Sb}(L)\Delta b_{t-1} + A_{SB,t}(L)x_{t-1}^B + A_{SS,t}(L)x_{t-1}^S + u_t^S \tag{A.11}$$

Notice that equations (A.9) and (A.11) have correlated errors if either $v_{2,t}^S$ and $v_{2,t}^B$ or ε_t^b and ε_t^a are correlated, which is a very likely event.

APPENDIX B

The control sample

Code	Name	Observations (January to March, 1996)
GE	General Electric Co.	106.407
GTE	GTE Corp.	87.149
TXN	Texas Instruments	77.277
ELY	Callaway Golf Co.	36.402
CMB	Chase Manhattan Co.	31.689
HM	Homestake Mining Corp.	27.165
SLB	Schlumberger Ltd.	23.206
GP	Georgia-Pacific Corp.	23.131
USS	United States Surgical Corp.	19.210
GRN	General Re Corp.	15.272

APPENDIX C

Control sample: VEC estimations.

This table summarizes the estimation results of the VEC model in (6.3) for each of the different variables considered to characterize trade and market conditions (MC_t^j) for the control sample data. The summation of the significant coefficients of $MC_{t-k}^j x_{t-k}^B$ ($\delta_5^{B,i}(1)$) and $MC_{t-k}^j x_{t-k}^S$ ($\delta_5^{B,i}(1)$) for each equation are reported. Only those coefficients that are jointly significant at the 5% level according to the results of the Wald tests performed to test the null $\delta_5^{B,i}(1) = 0$ and $\delta_5^{B,i}(1) = 0$ are reported.

		Vol_t				$Tlas_t$				$Risk_t$				Reg_t			
Coef.x 1000		Δa_t	Δb_t	x_t^B	x_t^S	Δa_t	Δb_t	x_t^B	x_t^S	Δa_t	Δb_t	x_t^B	x_t^S	Δa_t	Δb_t	x_t^B	x_t^S
USS	Buy	0.0013		0.0061	-0.0082	-0.0139			0.2666	266.97			-2058.08	-13.98	-6.75	-181.66	152.52
	Sell	-0.0005	-0.0021	-0.0102	0.0061		0.0285			-196.54	-201.65		-1549.65	7.92	20.96	105.41	-137.41
HM	Buy	0.0009	0.0004	0.0086	-0.0087	-0.0148		-0.2722	0.2800	131.94				-15.15	-7.37	-172.15	161.62
	Sell	-0.0006	-0.0018	-0.0097	0.0091		0.0164				-276.06			7.59	18.79	154.11	-163.08
GP	Buy	0.0017	0.0009		-0.0063	-0.0737	-0.0362		0.3557	262.16	209.40	-798.68	-839.45	-37.13	-15.35	-249.85	213.04
	Sell	-0.0014	-0.0030	-0.0087			0.0660		0.3144	-188.87	-203.13	-1291.49		20.65	34.87	87.97	-102.95
TXN	Buy	0.0017	0.0007	0.0039	-0.0066	-0.1304			1.1290	67.67	59.92		-671.82	-22.83	-14.14	-202.21	123.41
	Sell	-0.0003	-0.0011	-0.0094	0.0061		0.0747	0.8113	0.8767		-81.66	-1316.21		18.82	26.31	126.64	-204.93
CMB	Buy	0.0016	0.0005		-0.0042	-0.0836			0.5304	250.21	136.40		-965.92	-23.77	-15.46	-238.25	181.13
	Sell	-0.0008	-0.0018	-0.0053			0.0540			-201.33	-285.65		-887.10	18.27	31.98	254.23	-257.26
GE	Buy	0.0017	0.0008	0.0104	-0.0132	-0.2138		-1.5006	2.4029	154.38		1139.62	-1830.91	-19.06	-11.20	-214.29	212.26
	Sell	-0.0007	-0.0028	-0.0222	0.0212		0.1698	0.8019		-64.37	-141.11	-1475.34		9.16	17.31	191.64	-213.97
GRN	Buy		0.0015						0.1566	28.49	48.65			-56.26	-28.84	-107.28	158.96
	Sell	-0.0027			-0.0074					-46.32	-77.82	-340.38		42.38	60.59		
ELY	Buy	0.0022	0.0004	0.0136	-0.0194	-0.0576		-0.4228	0.8029	153.61		1455.63	-2503.97	-15.36	-9.20	-130.36	75.90
	Sell	-0.0006	-0.0015	-0.0114	0.0073		0.0301	0.4514		-72.33	-181.71	-1950.35		9.60	15.02	47.84	-99.84
GTE	Buy	0.0008	0.0002	0.0071	-0.0081	-0.0822		-1.3744	1.8194	49.73	-27.78	1939.48	-2700.69	-17.05	-8.96	-132.62	120.68
	Sell	-0.0004	-0.0011	-0.0059	0.0052		0.0775	0.7488		24.96	-106.26	-758.70		7.56	14.75	82.29	-97.81
SLB	Buy	0.0021	0.0011		-0.0076	-0.0807			0.5335	207.22	223.94		-1800.68	-27.29	-8.87	-235.08	172.73
	Sell	-0.0010	-0.0032	-0.0102			0.0334	0.2219	0.2576	-102.56	-176.42		-1625.28	13.79	33.02	180.54	-230.46

APPENDIX C (Cont.)

Control sample: VEC estimations.

Coef.x 1000		$Deptha_t$				$Depthb_t$				$Pres_t$			
		Δa_t	Δb_t	x_t^B	x_t^S	Δa_t	Δb_t	x_t^B	x_t^S	Δa_t	Δb_t	x_t^B	x_t^S
USS	Buy	-0.00030	-0.00017							-0.8410	-0.7526	-7.1379	7.4828
	Sell	0.00006	0.00007		0.00094	0.00020	0.00050	0.00249	-0.00247	-0.1594	-0.7497	-2.5514	3.0239
HM	Buy	-0.00019	-0.00005	-0.00105	0.00099	0.00000		0.00107	-0.00095	0.0001	0.0000	0.0013	
	Sell	0.00004		-0.00123	0.00120	0.00020	0.00050	0.00249	-0.00247	0.0000	0.0002	0.0014	-0.0015
GP	Buy	-0.00074	-0.00026		0.00168	-0.00037		0.00400	-0.00257	-0.4850		-4.2527	3.8539
	Sell		0.00040		0.00221	0.00095	0.00195		0.00313	-0.1666	-0.2275		
TXN	Buy	-0.00041	-0.00014		0.00131	-0.00013		0.00175	-0.00191	-0.7769	-0.6333	-6.3392	8.3833
	Sell		0.00009	-0.00191	0.00291	0.00035	0.00057		0.00116	-0.3223	-0.4944		2.2859
CMB	Buy	-0.00092	-0.00041			-0.00013		0.00218	-0.00161	-2.0274	-1.0844	-7.2296	8.2090
	Sell	0.00008	0.00021	-0.00170	0.00244	0.00041	0.00100			-0.3383	-0.5660		0.9998
GE	Buy	-0.00039	-0.00013	-0.00129	0.00165		-0.00008	0.00103	-0.00089	-0.7269	-0.1075	-7.6405	8.7576
	Sell	0.00009	0.00010	-0.00218	0.00226	0.00011	0.00052	0.00222	-0.00223	-0.1283	-1.0139	-3.9640	4.4329
GRN	Buy				0.00874	0.00223		0.01311	-0.00880			-9.9203	12.6561
	Sell	-0.00329	-0.00508	-0.01208			0.00595	0.01226		-2.1430	-3.7751	-6.5258	
ELY	Buy	-0.00024	-0.00012					0.00116	-0.00164		-0.0697		-0.7576
	Sell			-0.00231	0.00247	0.00008	0.00048			-0.2833	-0.7704	-6.0984	6.4893
GTE	Buy	-0.00023	-0.00009	-0.00239	0.00251		0.00001			-0.2362	-0.3232	-3.1238	2.9274
	Sell	0.00002	0.00003	-0.00109	0.00120	0.00004	0.00012	0.00022	-0.00015	-0.1138	-0.4002	-2.5894	2.7481
SLB	Buy	-0.23618	-0.32320					0.00213	-0.00314	-2.3691	-1.5125		8.6809
	Sell			-2.58940	2.74810	0.00059	0.00144			-0.3505	-0.8077	-2.4472	3.3897

APPENDIX D

Tests of asymmetric short-term dynamics

This appendix shows the null hypotheses of a set of Wald tests that investigate the existence of asymmetries in the mean short-term dynamics of bid and ask quotes. The first six hypotheses correspond to the restricted VEC model given by (6.1) and (6.2) but including the trading-time dummies. The next six hypotheses correspond to the VEC (6.3). These hypotheses are tested for vol_t, $tlast_t$, reg_t, $risk_t$ and $pres_t$. For some variables the signs in these hypotheses must be changed to adapt the null to the signs of the estimated coefficients. The meaning of rejecting these nulls is explained for the case of vol_t. The last set of null hypotheses compare the effect of $deptha_t$ and $depthb_t$. To do that, the VEC (6.3) is estimated including both variables.

Restricted VEC model: (6.1) and (6.2) with trading-time dummies

Cod.	H_0	Rejection implications
$H^R_{q,1}$	$\sum_{i=0}^{5}\delta_i^{B,a} = -\sum_{i=0}^{5}\delta_i^{S,b}$	The mean short-term impact of BITs on the ask quote is different to the mean short-term impact of the SITs on the bid quote.
$H^R_{q,2}$	$\sum_{i=0}^{5}\delta_i^{S,a} = -\sum_{i=0}^{5}\delta_i^{B,b}$	The mean short-term impact of SITs on the ask quote is different to the mean short-term impact of the BITs on the bid quote.
$H^R_{q,3}$	$\sum_{i=0}^{5}\eta_i^{a} = -\sum_{i=0}^{5}\eta_i^{b}$	The mean short-term impact of the immediacy costs level on the ask quote is different to its mean impact on the bid quote.
$H^R_{x,1}$	$\sum_{i=1}^{5}\delta_i^{B,B} = \sum_{i=1}^{5}\delta_i^{S,S}$	The positive autocorrelation of BITs differs from the positive autocorrelation of SITs.
$H^R_{x,2}$	$\sum_{i=1}^{5}\delta_i^{S,B} = \sum_{i=1}^{5}\delta_i^{B,S}$	The probability of observing a market purchase after a market sale is different from the probability of observing a market sale after a market sale.
$H^R_{x,3}$	$\sum_{i=0}^{5}\eta_i^{B} = \sum_{i=0}^{5}\eta_i^{S}$	The negative effect of immediacy costs on the probability of observing a new trade is different for BITs and SITs.

Extended VEC model (6.3). (Example: $MC_t^j = vol_t^*$)

Cod.	H_0	Rejection implications
$H^E_{q,1}$	$\sum_{k=0}^{5}\delta_k^{B,a}\lambda_k^{B,a} = -\sum_{k=0}^{5}\delta_k^{S,b}\lambda_k^{S,b}$	The effect of vol_t on the impact of a BIT on the ask quote is different to its effect on the impact of a SIT on the bid quote.
$H^E_{q,2}$	$\sum_{k=0}^{5}\delta_k^{S,a}\lambda_k^{S,a} = -\sum_{k=0}^{5}\delta_k^{B,b}\lambda_k^{B,b}$	The effect of vol_t on the impact of a SIT on the ask quote is different to its effect on the impact of a BIT on the bid quote.
$H^E_{x,1}$	$\sum_{k=1}^{5}\delta_k^{B,B}\lambda_k^{B,B} = -\sum_{k=1}^{5}\delta_k^{S,S}\lambda_k^{S,S}$	The influence of vol_t on the positive autocorrelation of market purchases differs to its influence on the positive autocorrelation of market sales.
$H^E_{x,2}$	$\sum_{k=1}^{5}\delta_k^{S,B}\lambda_k^{S,B} = -\sum_{k=0}^{5}\delta_k^{B,S}\lambda_k^{B,S}$	The influence of vol_t on the probability of observing a market purchase after a market sale is different from its influence on the probability of observing a market sale after a market sale.
Extended VEC model (6.3) with both $deptha_t$ and $depthb_t$		
$H^E_{q,3}$	$\sum_{k=0}^{5}\delta_{Da,k}^{B,a}\lambda_{Da,k}^{B,a} = -\sum_{k=0}^{5}\delta_{Db,k}^{S,b}\lambda_{Db,k}^{S,b}$	The influence of $deptha_t$ on the impact of a BIT on the ask quote differs from the influence of $depthb_t$ on the impact of a SIT on the bid quote.
$H^E_{q,4}$	$\sum_{k=0}^{5}\delta_{Da,k}^{S,a}\lambda_{Da,k}^{S,a} = -\sum_{k=0}^{5}\delta_{Db,k}^{B,b}\lambda_{Db,k}^{B,b}$	The influence of $deptha_t$ on the impact of a SIT on the ask quote differs from the influence of $depthb_t$ on the impact of a BIT on the bid quote.
$H^E_{x,3}$	$\sum_{k=1}^{5}\delta_{Da,k}^{B,B}\lambda_{Da,k}^{B,B} = -\sum_{k=1}^{5}\delta_{Db,k}^{S,S}\lambda_{Db,k}^{S,S}$	The influence of $deptha_t$ on the positive autocorrelation of market purchases differs to the influence of $depthb_t$ on the positive autocorrelation of market sales.
$H^E_{x,4}$	$\sum_{k=1}^{5}\delta_{Da,k}^{S,B}\lambda_{Da,k}^{S,B} = -\sum_{k=0}^{5}\delta_{Db,k}^{B,S}\lambda_{Db,k}^{B,S}$	The influence of $deptha_t$ on the probability of observing a market purchase after a market sale is different from the influence of $depthb_t$ on the probability of observing a market sale after a market sale.

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