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Abstract

It is a stylized fact that trade indicator models (e.g. Madhavan, Richardson, and Roomans (1997) and Huang and Stoll (1997)) underestimate the bid-ask spread. We argue that this negative bias is due to an endogeneity problem which is caused by a negative correlation between the arrival of public information and trade direction. In our sample (the component stocks of the DAX30 index) we find that the the average correlation between these variables is -0.193. We develop modified estimators and show that they yield essentially unbiased spread estimates.

JEL classification: G14, G12.

Keywords: trade indicator model; information asymmetry; spread estimation.

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1. Introduction

For more than 30 years researchers have developed measures of the bid-ask spread and its components. Trade indicator models (as proposed by Glosten and Harris (1988), Huang and Stoll (1997) and Madhavan et al. (1997)) are a very important and popular class of models. The basic intuition of these models is that (1) because of bid-ask bounce the time series of transaction prices contains information on the size of the spread (as in Roll (1984)) and (2) suppliers of liquidity will adjust their bid and ask prices in response to the information content of trades they observe (as in Glosten and Milgrom (1985)). The data required to estimate a trade indicator model are a sequence of transaction prices and a trade indicator variable which indicates whether a trade was buyer-initiated or seller-initiated.[1]

It is well known that trade indicator models underestimate the actual bid-ask spread. Madhavan et al. (1997) report that their implied spread estimate obtained from their trade indicator model underestimates the spread by approximately one third. Grammig, Theissen, and Wünsche (2006) estimate the Huang and Stoll (1997) trade indicator model for a sample of German firms and find that the implied spread is approximately 20% lower than the actual spread. We perform a similar analysis (using data from Germany) and confirm these results.

In this paper we analyze *why* trade indicator models underestimate the spread. We focus on the models proposed by Madhavan et al. (1997) and Huang and Stoll (1997). We hypothesize, and confirm empirically, that the trade indicator models suffer from an endogeneity problem. New public information is negatively correlated with the trade indicator variable. This negative correlation, in turn, results in a downward bias in the estimated spread and adverse selection component. We propose a modified estimator that accounts for this negative correlation. Application of this estimator largely eliminates the bias. The primary advantage of the modified estimator is that it allows us to identify the source of the bias in implied spreads estimated from trade indicator models. The modified estimator also lends itself to application in empirical research. However, it requires additional data, namely, a time series of quote midpoints.[2]

The bias we document suggests that the results of trade indicator models should be interpreted with care. The importance of our findings derives from the widespread use of trade indicator models in the empirical literature.[3] For example Weston (2000) uses the

[1]The model proposed by Glosten and Harris (1988) allows the transitory and permanent components of the spread to depend on transaction size. Consequently, data on transaction volume is required for estimation of the model.

[2]In many applications the trade indicator variable is constructed by applying the Lee and Ready (1991) algorithm to trade and quote data. In this case quote data is needed anyway, and the additional data requirement of our modified procedure is not a cause for concern.

[3]We do not intend to provide a complete list of papers that apply trade indicator models. When selecting

Huang and Stoll (1997) model to analyze whether the (then) new Nasdaq order handling rules affected the components of the bid-ask spread. Green and Smart (1999) base their analysis of how an increase in noise trading affects the components of the spread on the Madhavan et al. (1997) model. Hatch and Johnson (2002) use the Madhavan et al. (1997) model to analyze whether mergers among NYSE specialist firms affect the spreads (and its components) of the stocks in which the specialist firms make a market. Chakravarty, Jaon, Upson, and Robert (2012) compare the bid-ask spreads of trades triggered by intermarket sweep orders and trades triggered by other orders using the Madhavan et al. (1997) model. Brockman and Chung (2001) find that the adverse selection component of the spread, measured by the Huang and Stoll (1997) estimator, increases in periods during which firms repurchase shares.

The application of trade indicator models is not confined to the equity market. Green (2004) uses the Madhavan et al. (1997) model to analyze the impact of trading on bond prices after economic news announcements. Bessembinder, Maxwell, and Venkataraman (2006) and Han and Zhou (2014) adapt the Madhavan et al. (1997) model to the corporate bond market while Bjønnes and Rime (2005) apply the Huang and Stoll (1997) model to the foreign exchange market.

Trade indicator models are not only used in market microstructure research but also in other areas of finance. Odders-White and Ready (2006) analyze the relation between credit ratings and stock liquidity. One of the liquidity measures they use is the Huang and Stoll (1997) estimator of the adverse selection component. Heflin and Shaw (2000) and Brockman, Chung, and Yan (44) use the Huang and Stoll (1997) model to analyze how block ownership of shares affects the spread and its components. Da, Gao, and Jagannathan (2011) analyze the stock selection ability of fund managers. They find that fund managers are more likely to benefit from trading stocks that are more heavily affected by information risk. One of the measures of information risk that the authors use is the adverse selection component as estimated by the Madhavan et al. (1997) model. Cao, Field, and Hanka (2004) use the Madhavan et al. (1997) model to analyze how lockup expirations after IPOs affect liquidity.

The remainder of the paper is organized as follows. In section 2 we describe our data and present descriptive statistics. The effective spread and price impact we estimate directly from the data serve as benchmarks against which the implied spread and adverse selection component obtained from the trade indicator models are evaluated. In section 3 we present the trade indicator models (both the structural and the corresponding statistical models), explain the endogeneity bias and derive our modified estimator. In this section we also present empirical evidence which supports the presence of the endogeneity bias, and evidence which suggests that the modified estimator can largely alleviate this problem. Section 4

the papers referred to in the text we confined ourselfes to research published in major journals.

concludes.

2. Data

Our data set includes intraday data on the constituent stocks of the DAX-30 index.[4] These stocks are traded in Xetra, an electronic open limit order book. The sample period is the first quarter of 2004. The data set contains time-stamped transaction prices, the bid-ask spread in effect immediately prior to the transaction, and a trade indicator variable which indicates whether the trade was buyer-initiated (trade indicator = 1) or seller-initiated (-1). Note that the trade indicator variable was provided by the exchange. We thus did not need to apply the Lee and Ready (1991) algorithm to classify trades.

Table 1 lists the 30 sample stocks. Even though they are the 30 most liquid German stocks, they cover a wide range in terms of market capitalization, trading volume, and transaction frequency. The largest stock (Deutsche Telekom) has more than 20 times the market capitalization of the smallest stock (TUI). Similarly, the most actively traded stock (Deutsche Telekom when trading activity is measured by volume and Allianz when it is measured by the transaction frequerncy) has more than 27 times the trading volume and more than 6 times the transaction frequency of the least active stock (Fresenius Medical Care). The last column of table 1 shows the average effective spread measured in Euro-Cent. Spreads range from 1.12 Cents (Deutsche Telekom) to 6.51 Cents (Adidas-Salomon).

Table 2 shows the average price impact for each stock. The price impact of a transaction t is measured by the product of the trade indicator and the change in the quote midpoint after the transaction. We estimate three alternative versions of the price impact measure. The first (which we denote the immediate price impact) is based on the change in the quote midpoint between transaction t and transaction (t+1), the second (third) is based on the change in the quote midpoint between transaction t and the first transaction recorded at least one minute (five minutes) after transaction t. The immediate price impact is smaller than the 1- and 5-minute price impact in all 30 cases. The 5-minute price impact is larger than the 1-minute price impact for almost all stocks, but the increase is much smaller than the increase from the immediate to the 1-minute price impact. These results suggest that it takes at least one minute for the price impact of a trade to be fully reflected in the quote midpoint.

[4] Grammig et al. (2006) use the same data set.

3. Trade indicator models

As noted in the introduction we consider the trade indicator models proposed by Madhavan et al. (1997) (henceforth MRR) and Huang and Stoll (1997). The main difference between these models is that MRR assume that the trade indicator variable follows a Markov process. The resulting first-order serial correlation of the tade inicator variable is explicitly included in the model. Huang and Stoll (1997), in contrast, implicitly assume that the trade indicator variable is serially uncorrelated.[5] We start with the richer MRR model.

3.1. The Madhavan, Richardson and Roomans Model

3.1.1. Structural model

We consider a market in which suppliers of liquidity (who may be limit order traders or market makers) post bid and ask prices at which other traders can buy or sell assets. We develop the model with an electronic open limit order book (such as Xetra, the trading system from which we draw our sample) in mind. Therefore, we do not allow transactions at prices within the quoted spread. Put differently, we assume throughout the paper that the parameter λ is equal to zero.[6]

The model ticks in transaction time. Every time t a trade occurs, p_t denotes the transaction price and the trade indicator variable $q_t \in \{1, -1\}$ denotes trade direction. q_t is 1 for a buyer-initiated trade and -1 for a seller-initiated trade. Buys and sells are assumed to occur with the same (unconditional) frequency, i.e. the unconditional probability of the events $\{q_t = 1\}$ and $\{q_t = -1\}$ equals $\frac{1}{2}$. Consequently, the unconditional expected value of q_t is $\mathrm{E}[q_t] = 0$ and the variance is $\mathrm{Var}[q_t] = 1$.

Denote by μ_t the expected value of the security conditional upon public information. Changes in μ_t depend on (i) new public information arrival modeled by the white noise process $\{u_t\}$ and (ii) (private) information contained in the order flow. In the spirit of Glosten and Milgrom (1985) the surprise in the order flow, $(q_t - \mathrm{E}[q_t \mid q_{t-1}])$, reveals some of the private information held by informed traders. The information content of the surprise component of the order flow is captured by the parameter $\theta_{\text{MRR}} \geq 0$. Thus, $\theta_{\text{MRR}}(q_t - \mathrm{E}[q_t \mid q_{t-1}])$ is the permanent impact of the order flow surprise on the expected value μ_t of the security. μ_t evolves according to

$$\mu_t = \mu_{t-1} + \theta_{\text{MRR}}(q_t - \mathrm{E}[q_t \mid q_{t-1}]) + u_t \ . \tag{1}$$

[5] This statement holds for their basic model (equation (5) in Huang and Stoll (1997)). In their three-way decomposition of the spread they allow for serial correlation in the trade indicator variable.

[6] MRR denote by λ the probability that a transaction occurs at a price inside the quoted spread.

Note that this process is a martingale and reduces to a simple random walk if there were no informed traders (in which case $\theta_{\text{MRR}} = 0$). Suppliers of liquidity post quotes which are assumed to be ex-post rational (or regret-free). Consequently, the bid and the ask price are set conditional upon the next trade being seller-initiated ($q_t = -1$) and buyer-initiated ($q_t = 1$), respectively. Further, the liquidity providers require a compensation for their service. This compensation is assumed to be a constant amount $\phi_{\text{MRR}} \geq 0$ per share. The parameter ϕ_{MRR} models the transitory effect of order flow on prices.[7] The ask and bid prices evolve as

$$p_t^a = \mu_{t-1} + \theta_{\text{MRR}}(1 - \text{E}[q_t \mid q_{t-1}]) + \phi_{\text{MRR}} + u_t \ , \tag{2}$$

$$p_t^b = \mu_{t-1} + \theta_{\text{MRR}}(-1 - \text{E}[q_t \mid q_{t-1}]) - \phi_{\text{MRR}} + u_t \ . \tag{3}$$

The resulting transaction price is

$$p_t = \mu_t + \phi_{\text{MRR}} q_t + \eta_t \ , \tag{4}$$

where $\{\eta_t\}$ is a white-noise error process which, among other things, captures rounding errors caused by the existence of a discrete minimum tick size.[8] Combining equations (1) and (4) yields

$$p_t = \mu_{t-1} + \theta_{\text{MRR}}(q_t - \text{E}[q_t \mid q_{t-1}]) + \phi_{\text{MRR}} q_t + u_t + \eta_t \ . \tag{5}$$

Next we specify the process for the trade indicator variable $\{q_t\}$. Like Madhavan et al. (1997) we assume a general Markov process for trade direction. However, as already noted above, we do not allow for transaction at prices within the quoted spread. The process is characterized by the fixed transition probability $\text{P}[q_t = q_{t-1} \mid q_{t-1}] = \gamma$. If traders split up larger orders into several smaller trades we expect $\gamma > \frac{1}{2}$. Similarly, price continuity rules, trade reporting practices, and other institutional factors may cause γ to deviate from $\frac{1}{2}$.

With this specification the conditional expectation $\text{E}[q_t \mid q_{t-1}]$ in eq. (5) is

$$\begin{aligned} \text{E}[q_t \mid q_{t-1} = 1] &= \text{P}[q_t = q_{t-1} \mid q_{t-1} = 1](1) + \text{P}[q_t \neq q_{t-1} \mid q_{t-1} = 1](-1) \qquad (6) \\ &= \gamma - (1 - \gamma) \ , \\ \text{E}[q_t \mid q_{t-1} = -1] &= \text{P}[q_t \neq q_{t-1} \mid q_{t-1} = -1](1) + \text{P}[q_t = q_{t-1} \mid q_{t-1} = -1](-1) \qquad (7) \\ &= (1 - \gamma) - \gamma \ . \end{aligned}$$

[7] As also pointed out by Madhavan et al. (1997), ϕ_{MRR} may cover order processing costs, inventory holding costs, and possibly also rents earned by the suppliers of liquidity.

[8] Ball and Chordia (2001) proposes a model that takes the rounding of prices onto the tick grid explicitly into account.

The first-order autocorrelation of the trade indicator variable is $\rho_{\text{MRR}} = \frac{\mathrm{E}[q_t q_{t-1}]}{\mathrm{V}[q_t]} = \gamma - (1-\gamma)$ and therefore eq. (6) and eq. (7) can be summarized by

$$\mathrm{E}[q_t \mid q_{t-1}] = \rho_{\text{MRR}} q_{t-1} \ . \tag{8}$$

Inserting eq. (8) into eq. (5) and recognizing that (from the first lag of eq. (4)) $\mu_{t-1} = p_{t-1} - \phi_{\text{MRR}} q_{t-1} - \eta_{t-1}$ yields the expression

$$\Delta p_t = (\phi_{\text{MRR}} + \theta_{\text{MRR}}) q_t - (\phi_{\text{MRR}} + \rho_{\text{MRR}} \theta_{\text{MRR}}) q_{t-1} + u_t + \Delta \eta_t \ . \tag{9}$$

This equation is identical to equation (4) in Madhavan et al. (1997) and is the basis for the empirical analysis.

Effective spread The effective spread implied by eq. (9) is $2(\phi_{\text{MRR}} + \theta_{\text{MRR}})$. To see this, start from the definition of the effective half-spread,

$$\frac{s_{\text{MRR}}}{2} = q_t (p_t - m_t) \ , \tag{10}$$

where m_t denotes the quote midpoint at time t,

$$m_t = \frac{p_t^a + p_t^b}{2} \ . \tag{11}$$

Inserting the ask and bid prices eq. (2) and eq. (3), respectively, and conditioning on q_{t-1} yields

$$\begin{aligned} m_t|_{\{q_{t-1}=1\}} &= \frac{p_t^a|_{\{q_{t-1}=1\}} + p_t^b|_{\{q_{t-1}=1\}}}{2} = \frac{2\mu_{t-1} - 2\rho_{\text{MRR}}\theta_{\text{MRR}} + 2u_t}{2} \\ &= \mu_{t-1} - \rho_{\text{MRR}}\theta_{\text{MRR}} + u_t \ , \end{aligned} \tag{12}$$

$$\begin{aligned} m_t|_{\{q_{t-1}=-1\}} &= \frac{p_t^a|_{\{q_{t-1}=-1\}} + p_t^b|_{\{q_{t-1}=-1\}}}{2} = \frac{2\mu_{t-1} + 2\rho_{\text{MRR}}\theta_{\text{MRR}} + 2u_t}{2} \\ &= \mu_{t-1} + \rho_{\text{MRR}}\theta_{\text{MRR}} + u_t \ . \end{aligned} \tag{13}$$

which implies

$$m_t = \mu_{t-1} - \rho_{\text{MRR}}\theta_{\text{MRR}} q_{t-1} + u_t \ . \tag{14}$$

This expression reflects the fact that the suppliers of liquidity take the serial correlation in the order flow into account when setting their quotes. The effective half-spread conditional on q_{t-1} is

$$\begin{aligned} \frac{s_{\text{MRR}}}{2}\Big|_{\{q_{t-1}=1\}} &= q_t(p_t - m_t) && (15)\\ &= \mu_{t-1} + \theta_{\text{MRR}} - \theta_{\text{MRR}}\rho_{\text{MRR}} + \phi_{\text{MRR}} + u_t - \mu_{t-1} + \rho_{\text{MRR}}\theta_{\text{MRR}} - u_t \\ &= (\phi_{\text{MRR}} + \theta_{\text{MRR}}) \ , \\ \frac{s_{\text{MRR}}}{2}\Big|_{\{q_{t-1}=-1\}} &= q_t(p_t - m_t) && (16)\\ &= \mu_{t-1} + \theta_{\text{MRR}} + \theta_{\text{MRR}}\rho_{\text{MRR}} + \phi_{\text{MRR}} + u_t - \mu_{t-1} - \rho_{\text{MRR}}\theta_{\text{MRR}} - u_t \\ &= (\phi_{\text{MRR}} + \theta_{\text{MRR}}) \ , \end{aligned}$$

from which it immediately follows that the effective spread implied by the MRR model is

$$s_{\text{MRR}} = 2(\phi_{\text{MRR}} + \theta_{\text{MRR}}) \ . \tag{17}$$

3.1.2. Estimation of basic model

The basic model (9) is nonlinear in its parameters $(\phi_{\text{MRR}}, \theta_{\text{MRR}}, \rho_{\text{MRR}})'$. To estimate these parameters we follow Madhavan et al. (1997) and use the Generalized Method of Moments (GMM) with moment conditions

$$\mathbf{E}\begin{bmatrix} q_t q_{t-1} - q_t^2 \rho_{\text{MRR}} \\ \xi_t q_t \\ \xi_t q_{t-1} \end{bmatrix} = \mathbf{0} \ , \tag{18}$$

where

$$\xi_t = \Delta p_t - (\phi_{\text{MRR}} + \theta_{\text{MRR}})q_t + (\phi_{\text{MRR}} + \rho_{\text{MRR}}\theta_{\text{MRR}})q_{t-1} \tag{19}$$

is the residual.

We estimate this model for the 30 stocks in our sample. Table 3 reports, for each sample stock, the structural parameters $(\phi_{\text{MRR}}, \theta_{\text{MRR}}, \rho_{\text{MRR}})'$ and the implied effective spread, $s_{\text{MRR}} = 2(\phi_{\text{MRR}} + \theta_{\text{MRR}})$. The last three columns show the actual spread (taken from Table 1), the difference between the implied spread and the actual spread in Cents, and the percentage difference between implied and actual spread. We report Newey-West standard errors to account for serial correlation and heteroscedasticity. The results are consistent with those reported by Madhavan et al. (1997) and Grammig et al. (2006). The spread implied by the trade indicator model is systematically lower than the actual spread measured directly from the data, $\bar{s} = \frac{1}{N}\sum_{t=1}^{N} 2q_t(p_t - m_t)$ where N is the number of trades. The last column reveals that the bias amounts to approximately 20%. The objective of this paper is to analyze why such a bias occurs. We argue that there is an endogeneity problem in eq. (9), that is, one of the regressors (q_t and/or q_{t-1}) is correlated with the error term ($u_t + \Delta\eta_t$). Our argument is best explained in the context of the statistical model corresponding to eq. (9) which we derive in the next section.

3.1.3. Statistical model

We search for a statistcal model that corresponds to our strcutural model (9). As pointed out in Hasbrouck (2007) the corresponding statistical model must be able to generate the full joint distribution of the variables under consideration (i.e. price changes and the trade indicator variable). The trade indicator model assumes a zero mean and stationary autocovariance for the stochastic processes $\{\Delta p_t\}$ and $\{q_t\}$. For models of this kind Wold's theorem (see e.g. Brockwell and Davis (2009) and the application to the Roll (1984) model in Hasbrouck (2007)) states that a corresponding moving average (MA) process exists and is of the form

$$x_t = \sum_{j=0}^{\infty} \delta_j \epsilon_{t-j} + \kappa_t \ , \tag{20}$$

where $\{\epsilon_t\}$ is a white-noise process, $\delta_0 = 1$ (a normalization), and $\sum_{j=0}^{\infty} \delta_j < \infty$. κ_t is a linearly deterministic process which, in this context, means that it can be predicted arbitrarily well by a linear projection on past observations of x_t. For a purely stochastic process $\kappa_t = 0$, and we are left with a moving average representation.

The structural model in (9) contains two stochastic processes, namely the price differences $\{\Delta p_t\}$ and the trade indicator $\{q_t\}$. The interaction of these variables is described by a multivariate linear model,

$$p_t = \mu_t + \phi^{mod}_{\text{MRR}} q_t \ , \qquad \phi^{mod}_{\text{MRR}} \geq 0 \ , \tag{21}$$

$$\mu_t = \mu_{t-1} + w_t \ , \tag{22}$$

$$w_t = u_t + \theta^{mod}_{\text{MRR}} v_t \ , \qquad \theta^{mod}_{\text{MRR}} \geq 0 \ , \tag{23}$$

$$q_t = \rho^{mod}_{\text{MRR}} q_{t-1} + v_t \ , \qquad |\rho^{mod}_{\text{MRR}}| < 1 \ , \tag{24}$$

where $\{u_t\}$ and $\{v_t\}$ are white-noise processes, and μ_t denotes, as before, the expected value of the security conditional upon public information as of time t. To see that the system of linear equations in (21) - (24) indeed corresponds to the MRR trade indicator model we take first differences of the price eq. (21) and substitute $\Delta\mu_t = w_t$ from (22).

$$\begin{aligned}\Delta p_t &= w_t + \phi^{mod}_{\text{MRR}}(q_t - q_{t-1}) \\ &= u_t + \theta^{mod}_{\text{MRR}} v_t + \phi^{mod}_{\text{MRR}}(q_t - q_{t-1}) \qquad (25)\\ &= \theta^{mod}_{\text{MRR}}(q_t - \rho^{mod}_{\text{MRR}} q_{t-1}) + \phi^{mod}_{\text{MRR}}(q_t - q_{t-1}) + u_t \\ &= (\phi^{mod}_{\text{MRR}} + \theta^{mod}_{\text{MRR}})q_t - (\phi^{mod}_{\text{MRR}} + \rho^{mod}_{\text{MRR}}\theta^{mod}_{\text{MRR}})q_{t-1} + u_t \ .^9 \qquad (26)\end{aligned}$$

The final expression is identical to eq. (9).

To arrive at an autoregressive moving average (ARMA) vector representation we transform (25) a little further:

$$\begin{aligned}\Delta p_t &= u_t + \theta^{mod}_{\text{MRR}} v_t + \phi^{mod}_{\text{MRR}}(\rho^{mod}_{\text{MRR}} q_{t-1} - q_{t-1} + v_t) \\ &= u_t + (\phi^{mod}_{\text{MRR}} + \theta^{mod}_{\text{MRR}})v_t + \phi^{mod}_{\text{MRR}}(\rho^{mod}_{\text{MRR}} - 1)q_{t-1} \ , \qquad (27)\end{aligned}$$

and use equation (27) together with (24) for the vector representation,

$$\begin{aligned} y_t = \begin{bmatrix}\Delta p_t \\ q_t\end{bmatrix} &= \begin{bmatrix}1 & \phi^{mod}_{\text{MRR}} + \theta^{mod}_{\text{MRR}} \\ 0 & 1\end{bmatrix}\begin{bmatrix}u_t \\ v_t\end{bmatrix} + \begin{bmatrix}0 & \phi^{mod}_{\text{MRR}}(\rho^{mod}_{\text{MRR}} - 1) \\ 0 & \rho^{mod}_{\text{MRR}}\end{bmatrix}\begin{bmatrix}\Delta p_{t-1} \\ q_{t-1}\end{bmatrix} \\ &= \boldsymbol{\psi}_{\text{MRR}}\varepsilon_t + \boldsymbol{\varphi}_{\text{MRR}} y_{t-1} \\ &= \varepsilon^*_t + \boldsymbol{\varphi}_{\text{MRR}} y_{t-1} \ , \qquad (28)\end{aligned}$$

where $\boldsymbol{\psi}_{\text{MRR}}\varepsilon_t = \varepsilon^*_t$ is a standardization necessary for estimation of a VARMA model.[10] Define

$$\boldsymbol{\varphi}_{\text{MRR}} = \begin{bmatrix}0 & \phi^{mod}_{\text{MRR}}(\rho^{mod}_{\text{MRR}} - 1) \\ 0 & \rho^{mod}_{\text{MRR}}\end{bmatrix} = \begin{bmatrix}\varphi_{11} & \varphi_{12} \\ \varphi_{21} & \varphi_{22}\end{bmatrix} \qquad (29)$$

The vector moving average (VMA) representation of the model in equation (28) then is

$$y_t = (\mathbf{I} - \boldsymbol{\varphi}_{\text{MRR}} L)^{-1}\varepsilon^*_t \ , \qquad (30)$$

where $\mathbf{I}$ is the identity matrix. For $\{y_t\}$ to be a stable process all the roots of the polynomial $(\mathbf{I} - \boldsymbol{\varphi}_{\text{MRR}} L)^{-1}$ must lie outside the unit circle.

Estimation of the VARMA model eq. (28) does not yield estimates of $(\phi^{mod}_{\text{MRR}} + \theta^{mod}_{\text{MRR}})$ and

[9] The original model derived above also considers an error process $\{\eta_t\}$ accounting for rounding errors, etc. If we want this error term to be included in the statistical model we would add the error process $\{\eta_t\}$ to the price equation (21).

[10] See for instance Lütkepohl (2005, p.448).

$\theta^{mod}_{\text{MRR}}$. However, inspection of the covariance matrix

$$\mathbf{\Omega}^{\text{MRR}}_{\varepsilon^*} = \mathbf{E}[\varepsilon^* \varepsilon^{*\prime}] = \begin{bmatrix} \text{V}[u_t + (\phi^{mod}_{\text{MRR}} + \theta^{mod}_{\text{MRR}})v_t] & \text{Cov}[u_t, v_t] + (\phi^{mod}_{\text{MRR}} + \theta^{mod}_{\text{MRR}})\sigma^2_v \\ \text{Cov}[u_t, v_t] + (\phi^{mod}_{\text{MRR}} + \theta^{mod}_{\text{MRR}})\sigma^2_v & \sigma^2_v \end{bmatrix} \tag{31}$$

where σ^2_v denotes the variance of the white-noise process $\{v_t\}$ yields the following insight. As long as the covariance between the trade innovation v_t and the public information arrival u_t is zero, the effective half-spread $(\phi^{mod}_{\text{MRR}} + \theta^{mod}_{\text{MRR}})$ can be estimated directly from the covariance matrix in eq. (31) by dividing the element (1, 2) by the element (2, 2).

However, if this covariance is non-zero, the MRR model suffers from an endogeneity problem. This can be seen from eq. (26) using the expression for the trade indicator process, q_t in eq. (24). If u_t and v_t are correlated, so are q_t and u_t. Whether u_t and v_t are correlated is an empirical question. Therefore, we now go back to the data in order to obtain an estimator of the covariance between u_t and v_t.

3.1.4. Estimation of covariances

To obtain an estimator for $(\phi^{mod}_{\text{MRR}} + \theta^{mod}_{\text{MRR}})$ we need an estimate of the variance of the white-noise process $\{v_t\}$ and an estimate of the covariance between $\{u_t\}$ and $\{v_t\}$. Remember that $\{u_t\}$ is public information arrival and $\{v_t\}$ the order flow surprise. To obtain an estimate of the variance of $\{v_t\}$ we can estimate eq. (24) by OLS. This regression also provides us with the time series of $\{v_t\}$. In order to estimate the covariance between $\{u_t\}$ and $\{v_t\}$ we also need the time series of $\{u_t\}$. To obtain this time series we first-difference the quote midpoint equation (14) and substitute $\Delta\mu_{t-1} = u_{t-1} + \theta^{mod}_{\text{MRR}} v_{t-1}$ from eq. (22) and eq. (23).

$$\begin{aligned} \Delta m_t &= \Delta\mu_{t-1} - \rho^{mod}_{\text{MRR}} \theta^{mod}_{\text{MRR}} \Delta q_{t-1} + \Delta u_t \\ &= -\rho^{mod}_{\text{MRR}} \theta^{mod}_{\text{MRR}} \Delta q_{t-1} + \theta^{mod}_{\text{MRR}} v_{t-1} + u_{t-1} + \Delta u_t \qquad (32) \\ &= \alpha_1 \Delta q_{t-1} + \alpha_2 v_{t-1} + u_t \ . \qquad (33) \end{aligned}$$

We estimate eq. (33) by OLS and retain the residuals. Now, equipped with the time series of $\{u_t\}$ and $\{v_t\}$, we can estimate the covariance [11]

$$\widehat{\text{Cov}}[u_t, v_t] = \text{Cov}[\hat{u}_t, \hat{v}_t] \ . \tag{34}$$

[11] Note that $\text{Cov}[u_t, v_t] \neq 0$ does not imply $\text{Cov}[u_t, v_{t-1}] \neq 0$ because the error processes $\{u_t\}$ and $\{v_t\}$ are assumed to be serially uncorrelated. Consequently, estimating eq. (33) by OLS yields unbiased estimates.

We apply this procedure to our data. The results are shown in Table 4. The covariance between $\{u_t\}$ and $\{v_t\}$ is negative for all 30 sample stocks. Estimates of the correlation range from -0.041 to -0.257 with a mean value of -0.193. These results provide strong evidence that $\{u_t\}$ and $\{v_t\}$ are correlated and that, therefore, the trade indicator model suffers from an endogeneity problem. Economically, the non-zero correlation between $\{u_t\}$ and $\{v_t\}$ implies that the arrival of public information is correlated with the surprise component of the order flow. A possible interpretation of a non-zero correlation is that the suppliers of liquidity make errors when adjusting their quotes to new public information (or are simply adjusting their quotes too slowly). Other traders who observe these errors (or who are faster than the suppliers of liquidity, e.g. high frequency traders) react by submitting orders. These orders will be buy orders ($q_t = 1$) when the actual quote change is too small (u_t smaller than the true price impact of new public information) and will be sell orders ($q_t = -1$) when the actual quote change is too large (u_t larger than the true price impact of new public information). This will then result in a negative correlation between public information arrival and the order flow surprise.

3.1.5. Estimation of VAR model

So far we have shown that the MRR model suffers from an endogeneity problem because $\{u_t\}$ and $\{v_t\}$ and, in consequence, q_t and u_t are correlated. We now want to analyze whether this endogeneity problem is indeed the reason why the implied spread from the trade indicator model underestimates the actual spread. To this end we propose the following three-step estimation procedure to obtain (i) an estimate of the adverse-selection component $\theta^{mod}_{\text{MRR}}$ and (ii) an unbiased estimate of the effective spread.

1. Estimate via least-squares an AR(1) model of the trade indicator variable $\{q_t\}$ (eq. (24))

$$q_t = \rho^{mod}_{\text{MRR}} q_{t-1} + v_t \ .$$

2. Estimate the following model by OLS (eq. (33))

$$\Delta m_t = \alpha_1 \Delta q_{t-1} + \alpha_2 \hat{v}_{t-1} + u_t \ .$$

   Use the residuals from this regression together with those from step 1, $\hat{v}_t$, to compute the covariance $\text{Cov}[\hat{u}_t, \hat{v}_t]$.

3. Next, use a maximum likelihood approach (see for example Lütkepohl (2005)) to esti-

mate the VAR model (eq. (28))

$$y_t = \varepsilon_t^* + \boldsymbol{\varphi}_{\text{MRR}} y_{t-1} \ .$$

Obtain the variance-covariance matrix of the residuals (eq. (31)), $\hat{\boldsymbol{\Omega}}_{\varepsilon^*}^{\text{MRR}}$, and compute the effective spread by inserting the covariance, $\text{Cov}[\hat{u}_t, \hat{v}_t]$, from step 2 into the expression

$$\hat{s}_{\text{MRR}}^{mod} = 2\frac{(\hat{\boldsymbol{\Omega}}_{\varepsilon^*}^{\text{MRR}}(1,2) - \text{Cov}[\hat{u}_t, \hat{v}_t])}{\hat{\boldsymbol{\Omega}}_{\varepsilon^*}^{\text{MRR}}(2,2)} \ .$$

The parameter $\hat{\alpha}_2$ from step 2 provides an estimate of the adverse-selection component $\theta_{\text{MRR}}^{mod}$ and $\frac{\hat{s}_{\text{MRR}}^{mod} - 2\hat{\alpha}_2}{2} = \hat{\phi}_{\text{MRR}}^{mod}$ is an estimate of the transitory component of the spread.

We apply this three-step procedure to our 30 sample stocks.[12] The results are shown in table 5. All parameters exhibit the expected signs: $\hat{\rho}_{\text{MRR}}^{mod} = \hat{\varphi}_{22} > 0$, $\hat{\alpha}_1 = -\widehat{\rho_{\text{MRR}}^{mod}\theta_{\text{MRR}}^{mod}} < 0$, $\hat{\alpha}_2 = \hat{\theta}_{\text{MRR}}^{mod} > 0$, and $\hat{\varphi}_{12} = \widehat{\phi_{\text{MRR}}^{mod}(\rho_{\text{MRR}}^{mod} - 1)} < 0$. Furthermore, estimates from all three steps are significant at the 1% level. We also tested each polynomial for roots outside the unit circle and found all estimated polynomials to be stable.

The last three columns of table 5 show three estimates of the effective bid-ask spread. $\overline{s}$, taken from Table 1 is the spread estimated directly from the data and serves as benchmark, as before. $\hat{s}_{\text{MRR}}^{0}$ is the implied spread obtained under the assumption that $\text{Cov}[u_t, v_t] = 0$. It is almost identical to the implied spread obtained from the structural MRR model (eq. (9)) shown in Table 3. Most importantly, it exhibits the same 20% downward bias documented earlier. In contrast, the estimate of the effective spread obtained under the assumption that $\text{Cov}[u_t, v_t] = \text{Cov}[\hat{u}_t, \hat{v}_t]$, denoted $\hat{s}_{\text{MRR}}^{mod}$, approximates the actual spread $\overline{s}$ very well. It does not show the downward bias that plagues the MRR implied spread. In fact, $\hat{s}_{\text{MRR}}^{mod}$ is smaller than $\overline{s}$ in 14 cases, larger in 15 cases, and in one case the values (rounded to the third digit) are identical. The mean implied spread is 2.933 which is indeed very close to the average actual spread of 2.955. The largest relative deviation between the implied spread and the actual spread for any individual stock is 3.57% (as compared to an *average* relative deviation of 19.9% for the biased estimator $\hat{s}_{\text{MRR}}^{0}$). From these results we conclude that our modified estimator yields an unbiased estimate of the effective bid-ask spread.

As noted above, $\hat{\alpha}_2$ shown in table 5 is an estimate of the adverse-selection component and can be compared to the estimate of θ_{MRR} shown in Table 3. This comparison reveals that our modified estimator yields significantly larger estimates of the adverse selection component. In fact, while the θ_{MRR} estimates are similar in magnitude to the immediate price impacts

[12] All estimations were conducted in `R-3.0.1` using the package `dse` (version `2013.3.2`). See Petris (2010) for further information about the `dse`-package.

shown in table 2, the estimates we obtain when using our modified estimator are much closer to the 1-minute and 5-minute price impacts. In contrast, the transitory component obtained when using our estimator (not shown in table 5 but obtainable using the expression $\frac{\hat{s}^{mod}_{\text{MRR}}-2\hat{\alpha}_2}{2} = \hat{\phi}^{mod}_{\text{MRR}}$) is similar in magnitude to the MRR estimate of ϕ_{MRR} shown in Table 3.

3.2. *The model by Huang and Stoll*

In this section we repeat our analysis for the Huang and Stoll (1997) trade indicator model. As noted earlier, Huang and Stoll (1997) assume that the trade indicator variable is serially uncorrelated. Their model can be derived from the MRR model by setting the autocorrelation of the trade indicator variable, ρ_{MRR} in eq. (9), to zero.

$$\begin{aligned}\Delta p_t &= (\phi_{\text{HS}} + \theta_{\text{HS}})q_t - (\phi_{\text{HS}} + 0 \cdot \theta_{\text{HS}})q_{t-1} + u_t + \Delta\eta_t \\ &= \phi_{\text{HS}}\Delta q_t + \theta_{\text{HS}}q_t + \theta_{\text{HS}}q_{t-1} - \theta_{\text{HS}}q_{t-1} + u_t + \Delta\eta_t \\ &= (\phi_{\text{HS}} + \theta_{\text{HS}})\Delta q_t + \theta_{\text{HS}}q_{t-1} + u_t + \Delta\eta_t\ . \end{aligned} \tag{35}$$

3.2.1. *Estimating the basic model*

We stimate the basic Huang and Stoll (1997) model for our 30 sample stocks. The results are shown in Table 6. All parameter estimates are significant at the 1% level. The effective spread estimates (and, by implication, the bias relative to the effective spread estimated directly from the data) implied by the model are virtually identical to those obtained from the MRR model (table 3). However, the components of the spread estimated by the Huang and Stoll (1997) model differ from those obtained from the MRR model. The transitory component is smaller and the adverse selection component larger than the corresponding MRR estimates.

3.2.2. *Statistical model*

We now derive the statistical model corresponding to the Huang and Stoll (1997) structural model. We start from eq. (28) and set $\rho^{mod}_{\text{MRR}} = 0$. This results in $q_t = v_t$ and we get the following VAR representation for the Huang and Stoll model[13]

$$y_t = \begin{bmatrix} \Delta p_t \\ q_t \end{bmatrix} = \begin{bmatrix} 1 & \phi_{\text{HS}}^{mod} + \theta_{\text{HS}}^{mod} \\ 0 & 1 \end{bmatrix} \begin{bmatrix} u_t \\ v_t \end{bmatrix} + \begin{bmatrix} 0 & -\phi_{\text{HS}}^{mod} \\ 0 & 0 \end{bmatrix} \begin{bmatrix} \Delta p_{t-1} \\ q_{t-1} \end{bmatrix} \tag{39}$$

$$= \boldsymbol{\psi}_{\text{HS}} \varepsilon_t + \boldsymbol{\varphi}_{\text{HS}} y_{t-1} \ . \tag{40}$$

A normalization of the error term $\varepsilon_t^* = \boldsymbol{\psi}_{\text{HS}} \varepsilon_t$ results in the equation system

$$y_t = \varepsilon_t^* + \boldsymbol{\varphi}_{\text{HS}} y_{t-1} \tag{41}$$

which can be estimated by maximum likelihood.

As in the VAR model in eq. (28) the variance-covariance matrix contains in its element $(1,2)$ the term $\text{Cov}[u_t, v_t] + \phi_{\text{HS}}^{mod} \sigma_v^2$ and in its element $(2,2)$ the variance of the trade indicator variable, σ_v^2 (remember that in the Huang and Stoll (1997) model $v_t = q_t$).

3.2.3. Estimation of covariances

As in the MRR model we wish to estimate the covariance between public information arrival and the order flow surprise (which here is equal to the trade indicator variable because the expected value of q_t is zero). We obtain an estimate of $\{u_t\}$ from the equation for the first difference of the quote midpoint (see equation (3) in Huang and Stoll (1997)),

$$\Delta m_t = \theta_{\text{HS}}^{mod} q_{t-1} + u_t \ . \tag{42}$$

Least-squares estimation gives us residuals $\hat{u}_t$ which can be used to calculate an estimate of the covariance between the trade indicator process $\{q_t\}$ and the process of new public information arrival $\{u_t\}$,

$$\widehat{\text{Cov}}[u_t, q_t] = \text{Cov}[\hat{u}_t, q_t] \ . \tag{43}$$

Table 7 shows the covariance estimates that we obtain when we apply this procedure to our data. All covariances are negative and similar in magnitude to the estimates obtained from the MRR model. This confirms our previous evidence that new public information arrival and the trade indicator are negatively correlated.

[13]It can be shown that this VAR model derives directly from the statistical model,

$$p_t = \mu_t + \phi_{\text{HS}}^{mod} q_t \ , \tag{36}$$
$$\mu_t = \mu_{t-1} + w_t \ , \tag{37}$$
$$w_t = u_t + \theta_{\text{HS}}^{mod} q_t \ , \tag{38}$$

and further that this statistical model is identical to the structural model in eq. (35).

3.2.4. Estimation of VAR model

Building on the statistical model derived above we now propose a two-step procedure for a modified estimate of the effective spread from the HS model.

1. Estimate via least squares the model

$$\Delta m_t = \theta_{\text{HS}}^{mod} q_{t-1} + u_t \ ,$$

   and use the residuals to compute the covariance $\text{Cov}[\hat{u}_t, q_t]$.
2. Use maximum likelihood to estimate the VAR model (eq. (41)),

$$y_t = \varepsilon_t^* + \boldsymbol{\varphi}_{\text{HS}} y_{t-1} \ .$$

   Then take the variance-covariance matrix of the residuals, $\hat{\boldsymbol{\Omega}}_{\varepsilon^*}^{\text{HS}}$, and, by using the covariance $\text{Cov}[\hat{u}_t, q_t]$ from step 1, compute the effective spread as

$$\hat{s}_{\text{HS}}^{mod} = 2 \frac{\hat{\boldsymbol{\Omega}}_{\varepsilon^*}^{\text{HS}}(1,2) - \text{Cov}[\hat{u}_t, q_t]}{\hat{\boldsymbol{\Omega}}_{\varepsilon^*}^{\text{HS}}(2,2)} \ .$$

We apply this two-step procedure to our data. The results are summarized in Table 8. All parameters, without exception, possess the expected sign ($\hat{\theta}_{\text{HS}}^{mod} > 0$ and $\hat{\varphi}_{12} = -\hat{\phi}_{\text{HS}}^{mod} < 0$). The effective spread $\hat{s}_{\text{HS}}^{0}$ estimated under the assumption that $\text{Cov}[u_t, q_t] = 0$ is similar to the implied effective spread $\hat{s}_{\text{HS}}$ from the structural model (for these results see table 6). When comparing the implied spreads from the two-step procedure for the HS model $\hat{s}_{\text{HS}}^{mod}$ and the estimates from the three-step procedure for the MRR model ($\hat{s}_{\text{MRR}}^{mod}$ in table 5) we find that the former exhibit a small but systematic negative bias of about 1%. This bias is due to the fact that the Huang and Stoll (1997) model does not take the serial correlation of the trade indicator variable into account.

Note that the adverse selection component estimated by our two-step procedure is simply the slope of a regression of changes in the quote midpoint on the lagged trade indicator variable and is thus identical by definition to the immediate price impact shown in table 2.

To conclude, the modified Huang and Stoll (1997) model also corrects the bias of the structural model to a large extent, but does not perform as well as the modified Madhavan et al. (1997) model.

4. Conclusion

This paper is motivated by the stylized fact that trade indicator models, such as the popular models by Madhavan et al. (1997) and Huang and Stoll (1997), underestimate the bid-ask spread. We argue that this negative bias is due to an endogeneity problem. In order to substantiate our claim we develop the statistical models that correspond to the structural Madhavan et al. (1997) and Huang and Stoll (1997) models. The VARMA representation of these models reveals that, in both cases, the spread implied by the model depends on the covariance between public information arrival and the surprise in the trade indicator variable. If this covariance is different from zero the structural models suffer from an endogeneity problem which results in biased spread estimates. We use data for the component stocks of the DAX30 index and the first quarter of 2004 and find that the covariance is negative and substantial (the average correlation is -0.193).

We then develop modified estimators which take the covariance between public information arrival and the surprise component in the order flow explicitly into account. The modified Huang and Stoll (1997) model has a bias of only about 1% (as compared to almost 19% for the original model). The modified Madhavan et al. (1997) is essentially unbiased. A potential drawback of the modified estimator is that it requires additional data, namely, a time series of quote midpoints. In many applications this will not be a cause for concern, though. Estimation of any trade indicator model requires a trade indicator variable. This variable, in turn, is usually obtained by applying the Lee and Ready (1991) algorithm to trade and quote data (as is done in Huang and Stoll (1997) and Madhavan et al. (1997)). Thus, quote data is required anyway.

Appendix A. Tables

Table 1: The table shows the stocks contained in the DAX-30 index together with their ticker symbols, market capitalization (31st December, 2003), trading volume (Q1, 2004), number of transactions (Q1, 2004), and effective spread (Q1, 2004). The latter two columns contain solely trading on the electronic limit order market Xetra.

Stock	Ticker	Market Cap [bio. Euro]	Trading Volume [bio. Euro]	Transactions	Eff. Spread [Euro-Cent]
Adidas-Salomon	adsft	4.12	2.04	62,394	6.51
Altana	altft	6.72	1.98	69,721	3.87
Allianz	alvft	38.51	18.54	288,276	4.86
BASF	basft	25.52	7.96	164,692	2.18
Bayer	bayft	17.09	5.67	153,092	1.71
BMW	bmwft	22.99	5.62	134,603	2.07
Commerzbank	cbkft	9.25	3.40	92,285	1.52
Continental	contft	4.07	1.64	63,703	2.89
Deutsche Brse	db1ft	4.86	2.28	62,518	3.51
Deutsche Bank	dbkft	38.34	19.78	252,666	2.96
DaimlerChrysler	dcxft	37.80	12.00	211,053	1.98
Deutsche Post	dpwft	18.16	2.80	83,772	1.76
Deutsche Telekom	dteft	61.04	22.42	283,502	1.12
E.ON	eoaft	35.94	10.27	183,284	2.54
Fresenius MC	fmeft	3.96	0.82	39,538	5.29
Henkel	hen3ft	3.68	1.16	44,704	5.05
Hypovereinsbank	hvmft	9.65	6.29	123,296	1.82
Infineon	ifxft	7.99	9.37	178,506	1.20
Lufthansa	lhaft	5.06	2.81	85,964	1.55
Linde	linft	5.09	1.43	57,135	3.50
MAN	manft	3.39	1.77	67,326	2.67
Metro	meoft	11.34	2.48	78,735	3.10
Mnchener Rck.	muv2ft	22.23	13.26	218,564	4.62
RWE	rweft	16.54	6.24	147,573	2.11
SAP	sapft	42.14	11.80	178,952	6.48
Schering	schft	7.79	3.28	97,004	2.89
Siemens	sieft	56.84	20.57	281,927	2.63
Thyssen Krupp	tkaft	8.08	2.42	80,258	1.76
TUI	tuift	2.96	1.68	67,646	2.32
VW	vowft	14.20	6.67	162,360	2.17
Mean		**18.18**	**6.95**	**133,835**	**2.95**

Table 2: The table shows the price impacts for all stocks in the DAX-30 index where N denotes the number of transactions. Impacts are calculated in three different ways: (1) with the next sequential midquote, (2) the next midquote after 1 minute and (3) the next midquote after 5 minutes. Results were obtained by using `R-3.0.2` and the `xts`-package (`version 0.9.7`).

Stock	Ticker	N	Next Transaction [Euro Cent]	1 Minute [Euro Cent]	5 Minutes [Euro Cent]
Adidas-Salomon	adsft	62,394	1.7841	2.4910	2.9337
Altana	altft	69,721	1.0114	1.4035	1.5530
Allianz	alvft	288,276	1.1330	1.6811	2.1625
BASF	basft	164,692	0.5774	0.9584	1.0396
Bayer	bayft	153,092	0.4265	0.5950	0.5706
BMW	bmwft	134,603	0.5378	0.7609	0.8049
Commerzbank	cbkft	92,285	0.3684	0.4591	0.5281
Continental	contft	63,703	0.7793	1.1076	1.6022
Deutsche Boerse	db1ft	62,518	0.8626	1.2821	1.3380
Deutsche Bank	dbkft	252,666	0.7329	1.1480	1.3767
DaimlerChrysler	dcxft	211,053	0.4688	0.7273	0.8260
Deutsche Post	dpwft	83,772	0.3756	0.4721	0.4951
Deutsche Telekom	dteft	283,502	0.1518	0.2306	0.2811
E.ON	eoaft	183,284	0.6386	1.0643	1.0768
Fresenius MC	fmeft	39,538	1.4475	1.8328	2.1103
Henkel	hen3ft	44,704	1.3155	1.8675	2.3577
Hypovereinsbank	hvmft	123,296	0.4433	0.5670	0.7075
Infineon	ifxft	178,506	0.2160	0.2682	0.2769
Lufthansa	lhaft	85,964	0.3620	0.4901	0.6102
Linde	linft	57,135	1.0203	1.5109	1.9072
MAN	manft	67,326	0.7039	0.9773	1.1019
Metro	meoft	78,735	0.9246	1.3071	1.6146
Muenchener Rueck	muv2ft	218,564	1.1587	1.9262	2.2624
RWE	rweft	147,573	0.5479	0.8294	0.9195
SAP	sapft	178,952	1.6708	2.6361	2.5552
Schering	schft	97,004	0.7274	0.9894	1.2963
Siemens	sieft	281,927	0.6306	1.0125	1.0951
Thyssen Krupp	tkaft	80,258	0.4030	0.4963	0.5726
TUI	tuift	67,646	0.5696	0.7699	0.9512
VW	vowft	162,360	0.5664	0.8709	0.8856
Mean		**133,835**	**0.7519**	**1.0911**	**1.2604**

Table 3: The table shows the results from a GMM estimation of the model by Madhavan et al. (1997). Newey-West standard errors are shown below each estimate and the standard error for the arithmetic average is used for the empirical spread. All estimations were performed in the statistical programming language `R-3.0.2` using the package `gmm (version 1.4.5)`.

		Parameters			**Spread**			
Ticker	N	ϕ_{MRR}	θ_{MRR}	ρ_{MRR}	$\hat{s}_{\text{MRR}}$	$\overline{s}$	Bias	Rel. Bias
		Std. err.			[Euro-Cent]	[Euro-Cent]	[Euro-Cent]	[%]
adsft	62,394	0.008822	0.016643	0.2079	5.093	6.51	-1.416	-21.8
		2.956e-04	2.887e-04	4.567e-03	6.142e-04	2.619e-04		
altft	69,721	0.006137	0.009613	0.2142	3.150	3.87	-0.722	-18.7
		1.763e-04	1.691e-04	4.671e-03	3.978e-04	1.313e-04		
alvft	288,276	0.009059	0.010127	0.1977	3.837	4.86	-1.027	-21.1
		1.082e-04	9.642e-05	2.675e-03	2.694e-04	1.336e-04		
basft	164,692	0.003308	0.005569	0.2403	1.775	2.18	-0.405	-18.6
		5.978e-05	6.262e-05	3.269e-03	1.388e-04	4.102e-05		
bayft	153,092	0.003203	0.003620	0.1857	1.364	1.71	-0.349	-20.4
		3.997e-05	4.248e-05	3.195e-03	9.296e-05	3.792e-05		
bmwft	134,603	0.003532	0.004885	0.2025	1.683	2.07	-0.386	-18.7
		5.900e-05	6.388e-05	3.496e-03	1.357e-04	4.292e-05		
cbkft	92,285	0.002941	0.002992	0.2058	1.187	1.52	-0.334	-22.0
		4.236e-05	4.499e-05	4.265e-03	9.293e-05	3.864e-05		
contft	63,703	0.003454	0.007834	0.2414	2.258	2.89	-0.636	-22.0
		1.345e-04	1.437e-04	5.027e-03	3.252e-04	1.226e-04		
db1ft	62,518	0.005320	0.009083	0.2679	2.881	3.51	-0.625	-17.8
		1.563e-04	1.698e-04	4.984e-03	3.467e-04	1.174e-04		
dbkft	252,666	0.005337	0.006804	0.2165	2.428	2.96	-0.534	-18.0
		6.752e-05	6.532e-05	2.654e-03	1.623e-04	4.923e-05		
dcxft	211,053	0.003796	0.004317	0.2281	1.623	1.98	-0.354	-17.9
		4.316e-05	4.221e-05	2.893e-03	9.755e-05	3.222e-05		
dpwft	83,772	0.003908	0.003203	0.1983	1.422	1.76	-0.333	-19.0
		5.420e-05	5.359e-05	4.316e-03	1.279e-04	5.583e-05		
dteft	283,502	0.003647	0.001089	0.2242	0.947	1.12	-0.175	-15.6
		1.418e-05	1.269e-05	2.703e-03	2.484e-05	8.167e-06		
eoaft	183,284	0.004137	0.006073	0.2440	2.042	2.54	-0.498	-19.6
		6.414e-05	6.730e-05	3.036e-03	1.461e-04	4.615e-05		
fmeft	39,538	0.006392	0.013644	0.2305	4.007	5.29	-1.278	-24.2
		2.836e-04	3.011e-04	5.760e-03	5.922e-04	2.769e-04		
hen3ft	44,704	0.006125	0.014285	0.2666	4.082	5.05	-0.970	-19.2
		2.633e-04	2.885e-04	5.616e-03	5.649e-04	2.041e-04		

Table 3: *(continued)*

		Parameters			Spread			
Ticker	N	ϕ_{MRR}	θ_{MRR}	ρ_{MRR}	$\hat{s}_{\mathrm{MRR}}$	$\overline{s}$	Bias	Rel. Bias
		Std. err.			[Euro-Cent]	[Euro-Cent]	[Euro-Cent]	[%]
hvmft	123,296	0.003713	0.003486	0.1862	1.440	1.82	-0.378	-20.8
		4.790e-05	4.928e-05	3.508e-03	1.213e-04	4.089e-05		
ifxft	178,506	0.003306	0.001457	0.1992	0.953	1.20	-0.243	-20.3
		2.007e-05	1.854e-05	3.307e-03	4.300e-05	1.373e-05		
lhaft	85,964	0.002983	0.003219	0.2259	1.240	1.55	-0.311	-20.0
		4.588e-05	4.640e-05	4.299e-03	9.561e-05	4.346e-05		
linft	57,135	0.002961	0.010837	0.2594	2.760	3.50	-0.736	-21.1
		1.689e-04	1.883e-04	5.104e-03	3.580e-04	1.316e-04		
manft	67,326	0.003968	0.006794	0.2477	2.152	2.67	-0.515	-19.3
		1.159e-04	1.218e-04	4.831e-03	2.641e-04	8.581e-05		
meoft	78,735	0.003181	0.008790	0.2311	2.394	3.10	-0.710	-22.9
		1.242e-04	1.331e-04	4.447e-03	2.591e-04	9.356e-05		
muv2ft	218,564	0.008387	0.010666	0.2104	3.810	4.62	-0.814	-17.6
		1.096e-04	1.158e-04	2.775e-03	2.767e-04	8.312e-05		
rweft	147,573	0.003510	0.004820	0.2163	1.666	2.11	-0.439	-20.9
		5.822e-05	6.143e-05	3.359e-03	1.399e-04	4.164e-05		
sapft	178,952	0.010699	0.014314	0.1954	5.003	6.48	-1.474	-22.8
		1.720e-04	1.604e-04	3.015e-03	4.225e-04	1.359e-04		
schft	97,004	0.005012	0.006597	0.2052	2.322	2.89	-0.568	-19.7
		9.979e-05	1.059e-04	3.985e-03	2.412e-04	9.056e-05		
sieft	281,927	0.004987	0.005709	0.2141	2.139	2.63	-0.495	-18.8
		5.224e-05	5.106e-05	2.638e-03	1.211e-04	4.184e-05		
tkaft	80,258	0.003653	0.003511	0.1943	1.433	1.76	-0.324	-18.4
		5.269e-05	5.344e-05	4.141e-03	1.169e-04	4.461e-05		
tuift	67,646	0.003946	0.005369	0.2142	1.863	2.32	-0.457	-19.7
		8.749e-05	8.801e-05	4.716e-03	1.883e-04	8.246e-05		
vowft	162,360	0.003686	0.005070	0.2274	1.751	2.17	-0.424	-19.5
		5.691e-05	5.973e-05	3.333e-03	1.265e-04	4.119e-05		
Mean	**133,835**	**0.004770**	**0.007014**	**0.2199**	**2.357**	**2.95**	**-0.598**	**-19.9**

Table 4: The table shows for all stocks in the DAX-30 index the variances of the new public information announcement, u_t, and the trade innovation, v_t, as well as their common covariance and the correlation coefficient. All estimations were performed in the statistical progrmming language `R-3.0.2`.

Ticker	N	σ_u^2	σ_v^2	Cov$[u_t, v_t]$	Corr$[u_t, v_t]$
adsft	62,394	0.0012492	0.957	-0.006303	-0.1823
altft	69,721	0.0003948	0.954	-0.003429	-0.1767
alvft	288,276	0.0102886	0.960	-0.004097	-0.0412
basft	164,692	0.0001225	0.942	-0.002085	-0.1941
bayft	153,092	0.0000633	0.965	-0.001690	-0.2163
bmwft	134,603	0.0001139	0.959	-0.001996	-0.1910
cbkft	92,285	0.0000484	0.958	-0.001687	-0.2478
contft	63,703	0.0002438	0.941	-0.002624	-0.1732
db1ft	62,518	0.0003256	0.928	-0.002735	-0.1573
dbkft	252,666	0.0002077	0.953	-0.002616	-0.1859
dcxft	211,053	0.0000854	0.947	-0.001782	-0.1982
dpwft	83,772	0.0000591	0.961	-0.001508	-0.2002
dteft	283,502	0.0000142	0.950	-0.000838	-0.2282
eoaft	183,284	0.0001564	0.940	-0.002374	-0.1957
fmeft	39,538	0.0008230	0.947	-0.005190	-0.1859
hen3ft	44,704	0.0006795	0.929	-0.003982	-0.1585
hvmft	123,296	0.0000696	0.965	-0.001923	-0.2347
ifxft	178,506	0.0000220	0.959	-0.001180	-0.2569
lhaft	85,964	0.0000497	0.949	-0.001495	-0.2177
linft	57,135	0.0003416	0.932	-0.003078	-0.1725
manft	67,326	0.0001933	0.938	-0.002501	-0.1857
meoft	78,735	0.0002839	0.947	-0.003297	-0.2011
muv2ft	218,564	0.0005249	0.955	-0.004163	-0.1859
rweft	147,573	0.0001126	0.952	-0.002220	-0.2144
sapft	178,952	0.0010630	0.962	-0.006635	-0.2075
schft	97,004	0.0002112	0.958	-0.002633	-0.1851
sieft	281,927	0.0001445	0.954	-0.002388	-0.2034
tkaft	80,258	0.0000585	0.962	-0.001545	-0.2058
tuift	67,646	0.0001189	0.953	-0.001959	-0.1840
vowft	162,360	0.0001254	0.948	-0.002260	-0.2073
Mean	**133,835**	**0.0006065**	**0.951**	**-0.002740**	**-0.1932**

Table 5: The table shows the results from the three step estimation for each stock of the DAX-30 index. $\hat{s}^0_{\text{MRR}}$ is the spread estimated under the assumption that $\text{Cov}[u_t, v_t] = 0$ and $\hat{s}^{mod}_{\text{MRR}}$ is the spread estimated with an estimate of the empirical $\text{Cov}[u_t, v_t]$. All estimations have been performed in the statistical programming language `R-3.0.2` and for the VAR model the `R`-package `dse (version 2013.3.2)` has been used.

		Step 1	**Step 2**		**Step 3**		**Spread**		
Ticker	N	ρ^{mod}_{MRR}	α_1 $(-\rho^{mod}_{\text{MRR}}\theta^{mod}_{\text{MRR}})$	α_2 $(\theta^{mod}_{\text{MRR}})$	φ_{12}	φ_{22}	$\hat{s}^0_{\text{MRR}}$ [Euro-Cent]	$\hat{s}^{mod}_{\text{MRR}}$ [Euro-Cent]	$\overline{s}$ [Euro-Cent]
adsft	62,394	0.2079	-0.0056873	0.023242	-0.006969	0.2077	5.091	6.408	6.509
		4.570e-03	2.043e-04	3.961e-04	2.058e-04	3.916e-03			
altft	69,721	0.2142	-0.0028208	0.012892	-0.004807	0.2138	3.149	3.867	3.873
		4.674e-03	1.055e-04	2.165e-04	1.155e-04	3.700e-03			
alvft	288,276	0.1977	-0.0018046	0.012811	-0.007251	0.1977	3.837	4.690	4.864
		2.683e-03	8.026e-04	9.563e-04	6.712e-05	1.826e-03			
basft	164,692	0.2403	-0.0017277	0.007509	-0.002512	0.2401	1.775	2.218	2.180
		3.275e-03	4.375e-05	8.166e-05	3.996e-05	2.392e-03			
bayft	153,092	0.1857	-0.0009004	0.005172	-0.002603	0.1857	1.364	1.714	1.714
		3.199e-03	2.840e-05	5.459e-05	3.075e-05	2.511e-03			
bmwft	134,603	0.2025	-0.0013274	0.006701	-0.002811	0.2025	1.683	2.099	2.069
		3.499e-03	4.288e-05	8.669e-05	4.187e-05	2.669e-03			
cbkft	92,285	0.2058	-0.0007368	0.004450	-0.002328	0.2058	1.187	1.539	1.521
		4.274e-03	3.161e-05	5.792e-05	3.364e-05	3.221e-03			
contft	63,703	0.2414	-0.0027634	0.010472	-0.002609	0.2413	2.257	2.814	2.894
		5.034e-03	8.927e-05	1.704e-04	8.901e-05	3.845e-03			
db1ft	62,518	0.2679	-0.0029509	0.011577	-0.003875	0.2678	2.879	3.468	3.506
		4.989e-03	1.164e-04	2.141e-04	1.061e-04	3.853e-03			
dbkft	252,666	0.2165	-0.0017910	0.009157	-0.004176	0.2165	2.428	2.977	2.963
		2.661e-03	4.114e-05	9.033e-05	4.367e-05	1.942e-03			
dcxft	211,053	0.2281	-0.0012290	0.005940	-0.002930	0.2280	1.622	1.998	1.977
		2.905e-03	3.147e-05	5.858e-05	3.021e-05	2.119e-03			

Table 5: *(continued)*

		Step 1	Step 2		Step 3		Spread		
Ticker	N	ρ^{mod}_{MRR}	α_1 $(-\rho^{mod}_{\text{MRR}}\theta^{mod}_{\text{MRR}})$	α_2 $(\theta^{mod}_{\text{MRR}})$	φ_{12}	φ_{22}	$\hat{s}^{0}_{\text{MRR}}$ [Euro-Cent]	$\hat{s}^{mod}_{\text{MRR}}$ [Euro-Cent]	$\overline{s}$ [Euro-Cent]
dpwft	83,772	0.1983	-0.0007756	0.004544	-0.003129	0.1982	1.423	1.736	1.755
		4.323e-03	3.427e-05	6.712e-05	4.175e-05	3.386e-03			
dteft	283,502	0.2242	-0.0004575	0.001970	-0.002828	0.2241	0.947	1.123	1.122
		2.707e-03	9.483e-06	1.775e-05	1.229e-05	1.823e-03			
eoaft	183,284	0.2440	-0.0019933	0.008365	-0.003125	0.2439	2.042	2.547	2.540
		3.040e-03	5.111e-05	9.402e-05	4.306e-05	2.265e-03			
fmeft	39,538	0.2305	-0.0041443	0.018533	-0.004886	0.2304	4.006	5.102	5.285
		5.766e-03	1.980e-04	3.492e-04	2.059e-04	4.894e-03			
hen3ft	44,704	0.2666	-0.0047732	0.017840	-0.004489	0.2661	4.080	4.937	5.052
		5.631e-03	1.872e-04	3.370e-04	1.781e-04	4.559e-03			
hvmft	123,296	0.1862	-0.0006756	0.005155	-0.003018	0.1862	1.439	1.838	1.818
		3.524e-03	3.273e-05	7.266e-05	3.631e-05	2.798e-03			
ifxft	178,506	0.1992	-0.0003704	0.002556	-0.002644	0.1996	0.952	1.198	1.196
		3.314e-03	1.494e-05	2.577e-05	1.718e-05	2.317e-03			
lhaft	85,964	0.2259	-0.0007677	0.004425	-0.002304	0.2258	1.240	1.555	1.551
		4.313e-03	3.522e-05	5.756e-05	3.585e-05	3.322e-03			
linft	57,135	0.2594	-0.0037667	0.013863	-0.002163	0.2591	2.757	3.417	3.496
		5.115e-03	1.227e-04	2.164e-04	1.120e-04	4.041e-03			
manft	67,326	0.2477	-0.0022059	0.009229	-0.002971	0.2476	2.152	2.685	2.667
		4.837e-03	8.110e-05	1.562e-04	7.810e-05	3.734e-03			
meoft	78,735	0.2311	-0.0028111	0.011995	-0.002452	0.2308	2.394	3.091	3.104
		4.452e-03	9.332e-05	1.687e-04	8.414e-05	3.468e-03			

Table 5: *(continued)*

		Step 1	Step 2		Step 3		Spread		
Ticker	N	$\rho^{mod}_{\mathrm{MRR}}$	α_1	α_2	φ_{12}	φ_{22}	$\hat{s}^0_{\mathrm{MRR}}$	$\hat{s}^{mod}_{\mathrm{MRR}}$	$\overline{s}$
			$(-\rho^{mod}_{\mathrm{MRR}}\theta^{mod}_{\mathrm{MRR}})$	$(\theta^{mod}_{\mathrm{MRR}})$			[Euro-Cent]	[Euro-Cent]	[Euro-Cent]
muv2ft	218,564	0.2104	-0.0030833	0.014645	-0.006623	0.2104	3.810	4.681	4.625
		2.781e-03	7.524e-05	1.648e-04	7.447e-05	2.091e-03			
rweft	147,573	0.2163	-0.0014486	0.006929	-0.002750	0.2162	1.666	2.132	2.105
		3.364e-03	4.198e-05	8.435e-05	3.991e-05	2.542e-03			
sapft	178,952	0.1954	-0.0040698	0.020747	-0.008577	0.1953	5.001	6.381	6.476
		3.023e-03	1.129e-04	2.249e-04	1.146e-04	2.318e-03			
schft	97,004	0.2052	-0.0017597	0.009021	-0.003979	0.2050	2.321	2.871	2.890
		3.989e-03	6.773e-05	1.354e-04	7.010e-05	3.143e-03			
sieft	281,927	0.2141	-0.0016441	0.007958	-0.003918	0.2140	2.137	2.638	2.634
		2.645e-03	3.356e-05	6.420e-05	3.516e-05	1.840e-03			
tkaft	80,258	0.1943	-0.0009069	0.004923	-0.002941	0.1942	1.433	1.754	1.757
		4.145e-03	3.661e-05	6.452e-05	4.263e-05	3.462e-03			
tuift	67,646	0.2142	-0.0014879	0.007181	-0.003099	0.2139	1.863	2.273	2.320
		4.723e-03	6.107e-05	1.071e-04	6.375e-05	3.756e-03			
vowft	162,360	0.2274	-0.0013031	0.007023	-0.002842	0.2274	1.751	2.227	2.175
		3.340e-03	4.183e-05	7.897e-05	3.978e-05	2.417e-03			
Mean	**133,835**	**0.2199**	**-0.0020728**	**0.009561**	**-0.003720**	**0.2198**	**2.356**	**2.933**	**2.955**

Table 6: The table shows estimation results from the model of Huang and Stoll (1997). ϕ_{HS} denotes the transitory component of the spread and θ_{HS} the adverse selection component. All estimations were conducted in `R-3.0.2`.

Ticker	N	ϕ_{HS}	θ_{HS}	$\hat{s}_{\text{HS}}$	$\overline{s}$	Bias	Rel Bias
		Std. err.		[Euro-Cent]	[Euro-Cent]	[Euro-Cent]	[%]
adsft	62,394	0.012280	0.0131824	5.092	6.51	-1.417	-21.8
		3.777e-04	3.035e-04				
altft	69,721	0.008196	0.0075555	3.150	3.87	-0.722	-18.7
		2.310e-04	1.740e-04				
alvft	288,276	0.011062	0.0081262	3.838	4.86	-1.027	-21.1
		1.549e-04	1.162e-04				
basft	164,692	0.004646	0.0042324	1.776	2.18	-0.404	-18.5
		7.721e-05	5.753e-05				
bayft	153,092	0.003873	0.0029494	1.364	1.71	-0.349	-20.4
		5.225e-05	3.926e-05				
bmwft	134,603	0.004519	0.0038961	1.683	2.07	-0.386	-18.7
		7.828e-05	5.722e-05				
cbkft	92,285	0.003557	0.0023784	1.187	1.52	-0.334	-22.0
		5.022e-05	3.903e-05				
contft	63,703	0.005342	0.0059456	2.258	2.89	-0.636	-22.0
		1.822e-04	1.316e-04				
db1ft	62,518	0.007759	0.0066456	2.881	3.51	-0.625	-17.8
		1.948e-04	1.502e-04				
dbkft	252,666	0.006811	0.0053298	2.428	2.96	-0.535	-18.0
		9.462e-05	7.079e-05				
dcxft	211,053	0.004782	0.0033294	1.622	1.98	-0.354	-17.9
		5.521e-05	4.150e-05				
dpwft	83,772	0.004544	0.0025697	1.423	1.76	-0.332	-18.9
		7.577e-05	5.490e-05				
dteft	283,502	0.003889	0.0008461	0.947	1.12	-0.175	-15.6
		1.233e-05	1.216e-05				
eoaft	183,284	0.005622	0.0045905	2.042	2.54	-0.497	-19.6
		8.319e-05	6.241e-05				
fmeft	39,538	0.009539	0.0105000	4.008	5.29	-1.277	-24.2
		3.488e-04	2.758e-04				
hen3ft	44,704	0.009937	0.0104722	4.082	5.05	-0.971	-19.2
		3.337e-04	2.563e-04				
hvmft	123,296	0.004363	0.0028343	1.439	1.82	-0.379	-20.8
		7.936e-05	5.157e-05				
ifxft	178,506	0.003597	0.0011641	0.952	1.20	-0.243	-20.4
		2.234e-05	1.901e-05				

Table 6: *(continued)*

Ticker	N	ϕ_{HS} Std. err.	θ_{HS}	$\hat{s}_{HS}$ [Euro-Cent]	$\overline{s}$ [Euro-Cent]	Bias [Euro-Cent]	Rel Bias [%]
lhaft	85,964	0.003708	0.0024947	1.240	1.55	-0.311	-20.0
		5.083e-05	4.139e-05				
linft	57,135	0.005771	0.0080257	2.759	3.50	-0.737	-21.1
		2.095e-04	1.591e-04				
manft	67,326	0.005656	0.0051081	2.153	2.67	-0.514	-19.3
		1.504e-04	1.105e-04				
meoft	78,735	0.005211	0.0067599	2.394	3.10	-0.710	-22.9
		1.440e-04	1.137e-04				
muv2ft	218,564	0.010630	0.0084203	3.810	4.62	-0.815	-17.6
		1.631e-04	1.120e-04				
rweft	147,573	0.004554	0.0037767	1.666	2.11	-0.439	-20.9
		8.091e-05	5.902e-05				
sapft	178,952	0.013496	0.0115176	5.003	6.48	-1.474	-22.8
		2.554e-04	1.893e-04				
schft	97,004	0.006365	0.0052438	2.322	2.89	-0.568	-19.7
		1.365e-04	9.889e-05				
sieft	281,927	0.006206	0.0044811	2.137	2.63	-0.497	-18.9
		6.474e-05	5.045e-05				
tkaft	80,258	0.004337	0.0028288	1.433	1.76	-0.324	-18.4
		6.978e-05	5.370e-05				
tuift	67,646	0.005096	0.0042199	1.863	2.32	-0.457	-19.7
		1.077e-04	8.581e-05				
vowft	162,360	0.004839	0.0039164	1.751	2.17	-0.424	-19.5
		6.826e-05	5.336e-05				
Mean	**133,835**	**0.006340**	**0.0054447**	**2.357**	**2.95**	**-0.598**	**-19.9**

Table 7: The table shows for all stocks in the DAX-30 index the variances of the new public information announcement, u_t, the variance of the trade indicator, q_t, as well as their common covariance and the correlation coefficient. All estimates were performed in the statistical programming language `R-3.0.2`.

Ticker	N	σ_u^2	σ_q^2	$\text{Cov}[u_t, q_t]$	$\text{Corr}[u_t, q_t]$
adsft	62,394	0.00124621	0.9999	-0.006219	-0.17617
altft	69,721	0.00039429	1.0000	-0.003425	-0.17249
alvft	288,276	0.01027869	0.9983	-0.004182	-0.04128
basft	164,692	0.00012235	0.9997	-0.002095	-0.18941
bayft	153,092	0.00006326	0.9994	-0.001696	-0.21329
bmwft	134,603	0.00011382	0.9995	-0.001998	-0.18736
cbkft	92,285	0.00004837	1.0000	-0.001705	-0.24511
contft	63,703	0.00024351	0.9992	-0.002594	-0.16631
db1ft	62,518	0.00032504	0.9999	-0.002751	-0.15262
dbkft	252,666	0.00020771	0.9994	-0.002639	-0.18316
dcxft	211,053	0.00008536	0.9983	-0.001796	-0.19460
dpwft	83,772	0.00005899	0.9999	-0.001521	-0.19809
dteft	283,502	0.00001419	0.9998	-0.000836	-0.22192
eoaft	183,284	0.00015605	1.0000	-0.002380	-0.19051
fmeft	39,538	0.00081994	1.0000	-0.005201	-0.18164
hen3ft	44,704	0.00067751	0.9997	-0.003981	-0.15297
hvmft	123,296	0.00006960	0.9991	-0.001953	-0.23425
ifxft	178,506	0.00002201	0.9975	-0.001195	-0.25491
lhaft	85,964	0.00004965	0.9996	-0.001521	-0.21592
linft	57,135	0.00034056	0.9992	-0.003053	-0.16549
manft	67,326	0.00019291	0.9989	-0.002508	-0.18069
meoft	78,735	0.00028310	0.9999	-0.003292	-0.19568
muv2ft	218,564	0.00052437	0.9989	-0.004159	-0.18173
rweft	147,573	0.00011254	0.9984	-0.002224	-0.20982
sapft	178,952	0.00106215	0.9999	-0.006632	-0.20352
schft	97,004	0.00021102	0.9999	-0.002642	-0.18191
sieft	281,927	0.00014440	1.0000	-0.002396	-0.19937
tkaft	80,258	0.00005840	0.9999	-0.001548	-0.20259
tuift	67,646	0.00011880	0.9980	-0.001963	-0.18028
vowft	162,360	0.00012537	1.0000	-0.002297	-0.20512
Mean	**133,835**	**0.00060567**	**0.9994**	**-0.002747**	**-0.18927**

Table 8: The table shows the results for the two-step estimation procedure of the Huang and Stoll (1997) model for each stock of the DAX-30. $\hat{s}^0_{\text{HS}}$ is the spread estimated under the assumption that $\text{Cov}[u_t, q_t] = 0$ and $\hat{s}^{mod}_{\text{HS}}$ is the spread estimated with an estimate of the empirical $\text{Cov}[u_t, q_t]$. All estimations have been performed in the statistical programming language `R-3.0.2` and for the VAR model the R-package `dse (version 2013.3.2)` has been used.

		Parameters		**Spreads**		
Ticker	N	θ^{mod}_{HS} Std. err.	φ_{12} $(-\phi^{mod}_{\text{HS}})$	$\hat{s}^0_{\text{HS}}$ [Euro-Cent]	$\hat{s}_2$ [Euro-Cent]	$\overline{s}$ [Euro-Cent]
adsft	62,394	0.01784	-0.01226	5.091	6.33	6.51
		3.006e-04	1.841e-04			
altft	69,721	0.01011	-0.00817	3.148	3.83	3.87
		1.694e-04	1.021e-04			
alvft	288,276	0.01133	-0.01104	3.837	4.67	4.86
		2.001e-04	5.838e-05			
basft	164,692	0.00577	-0.00464	1.775	2.19	2.18
		6.206e-05	3.479e-05			
bayft	153,092	0.00426	-0.00387	1.364	1.70	1.71
		4.403e-05	2.586e-05			
bmwft	134,603	0.00538	-0.00451	1.683	2.08	2.07
		6.639e-05	3.599e-05			
cbkft	92,285	0.00368	-0.00355	1.187	1.53	1.52
		4.612e-05	2.808e-05			
contft	63,703	0.00779	-0.00533	2.257	2.78	2.89
		1.276e-04	8.001e-05			
db1ft	62,518	0.00863	-0.00773	2.879	3.43	3.51
		1.523e-04	9.382e-05			
dbkft	252,666	0.00733	-0.00680	2.428	2.96	2.96
		7.204e-05	3.760e-05			
dcxft	211,053	0.00469	-0.00478	1.622	1.98	1.98
		4.515e-05	2.541e-05			
dpwft	83,772	0.00376	-0.00454	1.423	1.73	1.76
		5.531e-05	3.460e-05			
dteft	283,502	0.00152	-0.00389	0.947	1.11	1.12
		1.441e-05	8.493e-06			
eoaft	183,284	0.00639	-0.00562	2.042	2.52	2.54
		6.743e-05	3.739e-05			
fmeft	39,538	0.01447	-0.00950	4.006	5.05	5.29
		2.615e-04	1.860e-04			
hen3ft	44,704	0.01316	-0.00992	4.080	4.88	5.05
		2.436e-04	1.575e-04			

Table 8: *(continued)*

		Parameters		Spreads		
Ticker	N	θ_{HS}^{mod}	φ_{12}	$\hat{s}_{\text{HS}}^{0}$	$\hat{s}_2$	$\overline{s}$
		Std. err.	$(-\phi_{\text{HS}}^{mod})$	[Euro-Cent]	[Euro-Cent]	[Euro-Cent]
hvmft	123,296	0.00443	-0.00436	1.439	1.83	1.82
		5.974e-05	3.063e-05			
ifxft	178,506	0.00216	-0.00359	0.952	1.19	1.20
		2.047e-05	1.310e-05			
lhaft	85,964	0.00362	-0.00370	1.240	1.54	1.55
		4.544e-05	2.990e-05			
linft	57,135	0.01020	-0.00574	2.757	3.37	3.50
		1.565e-04	1.005e-04			
manft	67,326	0.00704	-0.00564	2.152	2.65	2.67
		1.171e-04	6.903e-05			
meoft	78,735	0.00925	-0.00522	2.394	3.05	3.10
		1.254e-04	7.515e-05			
muv2ft	218,564	0.01159	-0.01063	3.810	4.64	4.62
		1.340e-04	6.433e-05			
rweft	147,573	0.00548	-0.00455	1.666	2.11	2.11
		6.663e-05	3.457e-05			
sapft	178,952	0.01671	-0.01346	5.001	6.33	6.48
		1.842e-04	1.008e-04			
schft	97,004	0.00727	-0.00636	2.321	2.85	2.89
		1.134e-04	6.109e-05			
sieft	281,927	0.00631	-0.00620	2.137	2.62	2.63
		4.898e-05	2.978e-05			
tkaft	80,258	0.00403	-0.00433	1.433	1.74	1.76
		5.020e-05	3.514e-05			
tuift	67,646	0.00570	-0.00509	1.863	2.26	2.32
		7.865e-05	5.443e-05			
vowft	162,360	0.00566	-0.00483	1.751	2.21	2.17
		6.041e-05	3.451e-05			
Mean	**133,835**	**0.00752**	**-0.00633**	**2.356**	**2.91**	**2.95**

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