Mispricing and Exchange Market Systems: The Effect of Infrastructure Upgrades

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Abstract

We study the effects of an infrastructure change at the Deutsche Boerse in Germany. On April 23rd 2007, Deutsche Boerse released an upgraded version of their electronic trading system Xetra. We examine the impact that this upgrade had on the efficiency of prices, measured as the level of mispricing, in the underlying liquid cash market and derivative futures market. Our analysis shows that the level of mispricings is economically and statistically (significant) reduced by the system upgrade.

1. Introduction

Securities exchanges are becoming increasingly automated. Over the course of the past two years most major exchanges have upgraded their trading infrastructure to accommodate the increase in algorithmic trading (AT) [17]. The increase in AT is the reason most often cited for the corresponding increase in securities markets volumes [15]. Interestingly few if any studies in the information systems (IS) and finance literature have focused on the effect of system upgrades on liquidity and price discovery.

This study focuses on the effect an infrastructure upgrade in one market – the Xetra stock market – has on the level of mispricing with the Eurex derivatives market. In modern markets, algorithms are used to identify deviations of price from fair value and implement the trading decisions. Since the cost of trading in spot and future markets differ, the amount of information impounded may differ. As a result, the predictions of the efficient market hypothesis (EMH) [11] may not always hold. Our study provides new evidence that the reduced latency of electronic trading systems improves the price discovery process and thus, produces more efficient prices.

The EMH states that asset prices should reflect all available information. It further breaks efficiency into three forms, weak, semi-strong and strong. The most important form of efficiency, in the context of this study, is the weak form. Weak form efficiency states that future prices cannot be predicted with past realization of public information, including, trades, quotes and other historical information. The infrastructure upgrade we study effectively improves the provision of public information in one market over another. By providing more timely prices the upgraded market prices should deviate less from the efficient price. We implicitly test this relationship below. The link between the EMH and electronic market infrastructure is understudied and addressed herein.

The two markets under analysis are both owned and operated by Deutsche Boerse. Xetra and Eurex are linked in two important ways: they both operate on the same underlying trading system, and the derivatives listed on Eurex have Xetra securities as underlyings. Due to this unique market structure we can measure the exact level of mispricing between the two markets. This feature is a contrast to other studies of mispricing in electronic markets.

Specifically we study the effect of the upgrade of the Xetra system on the mispricing between the German blue chip stock index - DAX and futures on the DAX. The DAX is calculated using real time trade prices in the underlying stocks. Moreover, we use trade prices of the most liquid DAX futures. Theoretically the DAX and DAX futures should have exactly the same price, with a small exception related to financing costs, which we adjust for in the following analyses. Empirically we often observe deviations in the pricing relationship between the two. We call these deviations mispricings and measure the effect of an IT infrastructure upgrade on these.

The paper is organized as follows. In section 2 we discuss related work in IS and finance. Section 3
covers the market microstructure that is relevant to this study. The data and methodology are presented in sections 4 and 5, respectively. We discuss and interpret the results in section 6 and conclude with a summary and provide an outlook for further research.

2. Related Work

As noted above, there is a strong link between the EMH and our study. The EFM is often tested in an event study [25] framework similar to the one we use. Event studies generally test for event returns that are significantly different than zero and attribute these to the event being studied. Event studies are also used to test for the impact of events on variables other than returns, and therefore not as direct tests of the EMH. Examples of these are [18] and [28]; these types of studies are usually used with natural experiments, like system-upgrades or regulation and rule changes. Event studies have been widely used to explain potential effects of corporate events e.g. changes in corporate strategies or changes to top management. Event studies are now also used in numerous disciplines, such as IS, accounting, and strategic management [26].

2.1. IS Literature

Event studies have recently gained importance in the IS literature. In general, event studies in IS can be grouped into four categories: IT investment (e.g. in ERP software, EAI, e-commerce activities), IT security, IT outsourcing and other IT-related topics (see [27] for a review of event studies in IS). Thus far there are relatively few (event) studies that analyze the effect of IT investments on financial market efficiency and market integration. This is surprising, especially considering the recent explosion in IT investment by securities exchanges and financial intermediaries. New order types, fully automated trading systems, and other features have been introduced at most securities exchanges worldwide.

There are a number of studies – that do not use the event study methodology – but look at the effects of IT and IT investments of exchanges and financial intermediaries. While the structure and competition of financial markets is analyzed by [1], the impact of lower transaction costs is outlined by [11]. Strategic decision choices for electronic trading systems [24] as well as liquidity effects of electronic limit order books [16] have also been the issue of interest.

To date, there are very few papers studying the issue of the integration of two markets from an IS perspective. [22] are concerned with the lead-lag relationship when the stocks are floor traded while the futures are screen traded. [13] look at the relative advantages of floor and screen trading systems using a similar approach to ours.

Still, none of these contributions look at the question of the effects of an IT upgrade on the integration of two already electronic financial markets. Specifically, we examine the contribution of IT investments on the integration of the futures and the spot market with respect to an infrastructure upgrade. This situation promises relevant results, since the theoretical relation between these two markets has already been examined extensively in the finance literature.

We also contribute to the “internationalization” of event studies in IS called for by [27]. They find that only two of the analyzed IS-related event studies use non-US stock data.

2.2. Finance Literature

The theoretical value of an index futures contract is equal to [6] the price of the underlying spot index plus the cost of carrying the spot index over the remaining life of the contract (cost of carry model, COC). The “carrying costs” consist of deferred interest payments paid on the stock index minus the deferred value of the dividend payments which accrue to the holders of the individual market constituents. The fair price of the index future contract is determined based on the assumption that spot markets are frictionless, i.e. there are no taxes or transaction costs and all market participants have equal access to financing at the risk free rate. The value of a future contract is expressed as follows:

\[
F(t,T) = S(t)e^{r(T-t)} - D(t,T)
\]

where \(F(t,T)\) equals the futures price at time \(t\) for a contract that matures at time \(T\), \(S(t)\) equals the spot index value at time \(t\), \(D(t,T)\) equals the time \(T\) value of dividends paid on the component stocks between \(t\) and \(T\), and \(r(T-t)\) equals the risk-free interest rate spanning the period from \(t\) to \(T\). If dividends are not relevant the formula can be simplified to:

\[
F(t,T) = S(t)e^{r(T-t)}
\]

The relationship between future and spot prices has been extensively studied in the finance literature. These articles can be broadly grouped into four categories. The first body of literature looks at which market leads and which market lags the other (e.g. [20]). A general finding in lead-lag studies is that the futures market leads the spot market with little or no feedback from the spot to the futures market (e.g. [29]). Second, authors have looked at the question, which model may be employed to explain the pricing...
behavior in the futures and spot market (e.g. [4], [30]). [30] provide for evidence that the widely applied COC model is particularly suited for studies in mature markets, which also holds for the German market. Third, arbitrage strategies – ex ante and ex post – have been extensively analyzed (e.g. [3], [5], [23]). Fourth, influence factors that cause a deviation from the theoretical equilibrium price relationship between the two markets have been studied. Usually these deviations result in a mispricing such that the corrected futures price is too low compared to the spot price. (e.g. [4], [6]). This fictitious under-pricing vanishes with a decreasing time to maturity.

We contribute to the fourth category by analyzing whether IT infrastructure might be a factor to explain deviations from theoretical equilibrium prices. Several factors have already been suggested to contribute to the mispricing behavior:

- **Taxes**: Taxes on capital transactions are usually not paid until gains or losses are realized. This means that investors have the right to realize losses and defer gains [6].
- **Risk-free and stochastic interest rate**: The interest rate in the COC formula is chosen dependent on the time to maturity. However, for firms looking for short term arbitrage opportunities the overnight rate may be more appropriate [19]. In a normal interest rate structure this will lead to a too low futures price. Moreover, interest rates are not constant over time causing an interest rate risk for the arbitrageur that has to be accounted for.
- **Position limits**: There may be market imposed position limits or own capital constraints influencing the actions of traders [5].
- **Transaction costs**: Arbitrage activities consume transaction costs and thereby limit arbitrage opportunities [5] [19]. Transaction costs include brokers’ fees, duties, exchange levies, short-selling costs and implicit costs associated with the bid-ask spread and the market impact.
- **Variation margin payments**: The COC formula does not account for the (volatile) margin payments in the futures market [19].
- **Short-selling restrictions**: Short selling in the spot market is much more costly than in the futures market [21].
- **Imperfect hedge**: Especially with indices consisting of many stocks, the configuration of a perfect hedge becomes a demanding task, limiting profitable arbitrage opportunities [19].
- **Infrequent trading**: Infrequent trading e.g in some component stocks in the spot market may cause a temporary deviation relative to the futures price [2].
- **Dividends**: Dividend payments are uncertain. Moreover, the reinvestment rate for the collected dividends is uncertain [19].
- **Market volatility**: A higher volatility reduces the risk of an arbitrageur [2].
- **Trading volume**: An (unexpected) high trading volume has a positive effect on mispricing [2].
- **Friday effect**: Mispricing is negative and significantly lower than the other days of the week, which may be related to negative information being released over the weekend and higher risk from holding futures contracts [2].
- **Infrastructure changes and differences** such as the trading system [13], [22].
- **Noise**: [12] suggests that “noise” is the primary explanation for mispricings.

In our model specification, we make sure to either rule out as many influence factors as possible due to the market microstructure and methodological design choices (dividends, infrequent trading, imperfect hedge) or control for the influence factor (volume, volatility, Friday effect) in order to separate as precisely as possible the effect of the infrastructure change from the issues listed above. Still, there are some potential influence factors that are not accounted for with good reason.

- First, the so-called tax timing option seems to have no significant influence on mispricing [6].
- Second, [23] find that interest rate volatility has little substantial impact on index futures prices.
- Third, the marginal trader may face much lower transaction costs than assumed in many models [2] and may not face position limits at the relevant boundaries. Therefore, transaction costs and position limits are not included here.
- Fourth, margin payments are not accounted for in any study in the finance and IS literature. This constitutes a prospect for further research and is not addressed here.

### 3. Market Microstructure

The DAX is the leading stock market index in Germany and comprises 30 German stocks selected according to market capitalization, turnover, industry, and availability of early opening prices. Each stock in the index must meet several requirements, including quarterly and annual financial reporting, minimum free-float, and industry representation. The DAX index is a capital-weighted performance index which is adjusted for price changes caused by subscription rights, stock splits, and dividends. It is calculated to an accuracy of 0.01 index points based on transaction
prices of the underlying stocks. About 95% of the trading volume in DAX stocks is carried out using the electronic trading system Xetra operated by Deutsche Boerse. The rest is traded at the seven regional exchanges. In our observation period, DAX stocks can be traded on Xetra from 9:00 a.m. until 5:30 p.m. (CET). The DAX is calculated as soon as at least 16 of the underlying stocks have been traded. As a result, at the beginning of the trading day, the index may include up to 14 prices resulting from transactions from the previous day. However, [13] report that, on average, trading in stocks included in the DAX starts within four minutes – we control for this effect in our model. This means that the problem of including overnight prices occurs only at the very beginning of a trading day. During trading hours the index is calculated multiple times each minute based on the latest transaction price of each stock in the Xetra system.

DAX futures trade exclusively on Eurex the fully electronic derivatives trading system operated by Deutsche Boerse. DAX futures are one of the most liquid stock futures in Europe. The Eurex trading system is open for trading from 7:30 a.m. to 22:30 p.m. (CET) where each trading day consists of four main trading periods: Pre-Trading, opening, continuous trading, and post-trading. In our study, we just focus on the continuous trading phase which overlaps with the Xetra trading period. The minimal price change in DAX futures is 0.5 index points – a tick size of 12.5 euro. DAX index futures contracts are based on a quarterly expiration cycle dates on the third Friday in March, June, September, and December.

There are several features, which imply that some of the above discussed sources of potential mispricing are not relevant for the German market, which makes a separation of the infrastructure effect easier. First, unlike other stock indices, e.g. S&P 500, FTSE-100, and Nikkei 225, the DAX measures the total performance of the underlying stock portfolio. As a consequence, dividends have no influence on potential mispricing. Second, the DAX is narrow, consisting of only 30 blue chips traded on the German stock market. They represent together at least 60% of the market capitalization and far more of the traded volume.

Therefore, it is relatively affordable for arbitrageurs to trade a perfectly matching basket in a reasonable amount of time. Consequently, tracking error risks can be avoided. Finally, there is only a small execution risk both in the futures and spot market, since both markets are organized as low latency electronic markets and also highly liquid [4]. This feature makes our results even more interesting and relevant to the electronic markets literature.

Deutsche Boerse focused early on the development of an attractive environment for AT. In order to meet the customer’s demand of high market liquidity, low network latency, and small explicit transaction costs, Deutsche Boerse has continuously enhanced Xetra’s and Eurex’s transmission and transaction speed. Figure 1 shows Xetra’s and Eurex’s system exchange infrastructure. In addition, we depict crucial factors that influence latency. Besides the propagation delay which depends on the physical distance between the trader and the exchange infrastructure and the available bandwidth (serialization delay), the system latency is influenced by the network performance and compression algorithms.

Xetra Release 8.0 was a major step forward to enhanced bandwidth efficiency. The release was introduced on April 23rd, 2007 and optimized the broadcast of market information in order to boost the network performance and reduce the system load (see red circled 5 in Figure 1). The following three measures are directly associated with this release [8]:

- Only changes in the order book caused by new orders or quotes are broadcasted via the network and not the entire order book inventory.
- It became possible to split the data stream in sub-streams for different categories e.g. DAX or other indices, that is, the customers can now select the necessary data streams.
- New compression algorithms allow for more effective data compression.

This results in reduced network latency. In contrast to routinely introduced upgrades, Xetra Release 8.0 specifically was directed at improvements for AT participants. For arbitrage strategies trading speed is the most crucial factor, AT strategies are used to exploit mispricings between the two linked markets. In consequence, we see a strong influence of the release. However, we believe that our results can be applied to other European spot and futures markets: they are also organized as open limit book markets and increasingly focus on the needs of AT participants.

As discussed we assume that arbitrageurs always choose the fastest trading connection. Figure 2 depicts the end-to-end round-trip-times before and after the introduction of Xetra Release 8.0. With the new upgrade, Xetra allows for average end-to-end round-trip-times in Frankfurt of 13 milliseconds in June 2007. However, these benchmarks are only reached with a 1 Gbit connection and a co-located trading engine in Frankfurt [9]. Clearly, the smaller round-trip-times difference between Xetra and Eurex in June 2007 makes a higher number of arbitrage trades profitable. Thus, small deviations in the pricing relationship

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1 Xetra Release 10.0 introduced on June 15, 2009 is another example for a latency reducing upgrade. Likewise Euronext shifted from the NSC to the Universal Trading Platform in February 2009.
4. Data

The DAX, DAX futures, and DAX stock data used in our analyses are provided by SIRCA.2 The DAX value as well as trades and quotes are time stamped to the nearest 1,000th of a second. While DAX values are reported once per second, quotes and trades are reported when they occur in the market. Our two data samples comprise the following periods: March 22nd to May 22nd, 2007 and February 22nd to June 19th, 2007. The event date on April 23rd, 2007 is excluded from the analysis, i.e. we examine 20 and 40 trading days prior to and after the release of Xetra 8.0 in Sample 1 and Sample 2, respectively. In addition, we delete the first and last ten minutes of the trading day to avoid biases related to opening and closing procedures mentioned above.

DAX futures are based on quarterly expiration cycle dates in March, June, September, and December. The last trading day of the contract is on the third Friday of the expiration month. We follow each contract during the period it is the contract closest to expiration. This period begins on the expiration date of the prior contract and ends on the day prior to the expiration date of the next contract. The resulting continuous DAX futures time series is used in our analyses.

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2 We thank the Securities Industry Research Centre of Asia-Pacific for providing the data.
We separate the trading day into 1-min intervals and compute the midpoint of the latest bid and ask update of the chosen DAX futures contract for each interval \( t \). According to their time stamp the prior DAX value is chosen to calculate the mispricing between DAX and DAX futures:

\[
\text{Mispricing}_t = \text{DAX Futures Midpoint}_t - \text{DAX}_t
\]

Then, EURIBOR interest rates (downloaded from the webpage of the Deutsche Bundesbank) \( r \) and the number of days to the expiration of the DAX futures \( T \) are used to compute the corrected DAX values in each 1-min time interval \( t \) according to the COC model:

\[
\text{DAX Corrected}_{t,T} = \text{DAX}_t + e^{r(T-t)}
\]

The interest rate \( r \) is obtained by linear interpolation of daily, weekly, monthly and 3-month interest rates according to the remaining days to expiration \((T-t)\). In the next step, we calculate the Deviation Corrected, as follows:

\[
\text{Deviation Corrected} = \frac{\text{DAX Futures Midpoint}_t - \text{DAX Corrected}_t}{\text{DAX Corrected}_t}
\]

The difference in trading volumes, returns, volatility, and quoted spreads is incorporated as control variables into the regression framework. We use the reported DAX value for the calculation of the return and the volatility variables. In contrast, the trading volume and the quoted spread are calculated from the trade and quote data of the DAX index constituents. 29 DAX stocks are taken into account for the calculations. In order to avoid biases, we exclude Altana from our analyses because it was replaced on June 18th, 2007 by Merck. The DAX futures volume, return, volatility, and spread variables are computed from the constructed 1-min intervals as stated above. Finally, we calculate for every control variable in each 1-min interval the difference between the computed DAX futures and DAX variable. Section 5 describes the calculation in more detail. We report descriptive statistics of the variables in Table 1.

In addition we apply the following three cleaning operations in order to control for outliers. We delete time intervals with a quoted spread larger than 1,000 bps and intervals where the DAX futures midpoint or the DAX value deviates more than 0.5 % from the prior interval. In sum less than 1% of 1-min intervals are affected. In the end 19,300 observations in Sample 1 and 38,315 in Sample 2 are taken into account for the analyses.

5. Methodology

We use a simple and common statistical estimation model, the General Method of Moments (GMM) [14]. Statistical models in a financial econometrics context are well developed and often used to answer questions of similar nature to ours. This allows us to answer the question whether infrastructure upgrades affect the mispricing in financial markets.

We estimate a GMM of the following form to arrive at our results:

\[
\text{Dev}_t^2 = a + \sum_{k=5}^{0} \beta_k \text{VolDiff}_{t+k}^2 + \sum_{k=5}^{0} \gamma_k \text{RDiff}_{t+k}^2 + \sum_{k=5}^{0} \delta_k \text{VolaDiff}_{t+k}^2 + \sum_{k=5}^{0} \epsilon_k \text{SpreadDiff}_{t+k} + \lambda_k \text{Dummy}_{t+k} + u_t
\]

where \( \text{Dev}_t^2 \) is the dependent variable, the square of the deviation in the cash market and futures price. We take the square for two reasons, (i) the results are strictly positive and (ii) we underweight very small and less important deviations, i.e. < 1 and emphasize large deviations i.e. > 1. This transformation essentially negates the effects of a large number of small deviations that are economically insignificant without influencing the key results. The \( \text{Dummy}_{t+k} \) variable is our variable of interest and takes the value of 0 before the introduction of Xetra 8.0 and 1 thereafter. The remaining variables represent our control variables for five one minute lags, i.e. \( x = 5 \). \( \text{VolDiff}^2 \) is the square of the difference in log trading volumes in Euro between DAX futures and the DAX. One minute returns are computed as follows:

\[
\text{R}_{i,t} = \ln \left( \frac{\text{Midpoint}_{t+i}}{\text{Midpoint}_{t+i-1}} \right)
\]

where \( i \) is the DAX futures or a time stamped DAX value in a one minute interval \( t \). Using prevailing quotes, the \text{Midpoint} is defined as \((\text{Quoted Sell Price} - \text{Quoted Buy Price})/2\). In order to control for the difference in volatility between DAX futures and the DAX stocks, we incorporate the squared realized volatility difference \( \text{VolaDiff}^2 \). We compute the realized volatility as follows:

\[
\text{Vola}_{i,t} = \text{R}_{i,t} \ast \text{R}_{i,t}
\]

For the control variable \text{Spread} we use an averaged value over all incorporated 29 DAX stocks and quote data of DAX futures, respectively. We use standard calculations for relative quoted spreads:
We use Newey-West standard errors that are robust to autocorrelation across days in our sample. This allows us to make strong inferences, for instance that the effect is not driven by a time-trend.

Since we are not sure of the true distribution of the mispricing variable, GMM is an ideal estimation technique. GMM is very general and essentially estimates the moments directly from the data. The GMM in our case attains similar results to an OLS regression; however, the GMM results are statistically more conservative and therefore reported.

6. Empirical Results

The descriptive statistics are reported in Table 1. We report the statistics computed over 40 (Sample 1) and 80 (Sample 2) trading days. The statistics are comparable over both of the sample periods. We present the results for both samples to show that the technology effect that we find is robust to different time frames. In fact we find that our results remain robust over a sample period of 160 days but do not report these for brevity.

Table 1 shows clearly the normal relationship between cash (index) prices and the corresponding futures price. After correcting for the costs of carrying the underlying DAX stocks using the COC, we attain a mean mispricing of -1.36 and -1.31 index ticks of 40 and 80 trading days, respectively. The sign of this relationship is consistent with other literature (e.g. [4], [6]). It shows that the corrected cash index was slightly higher on average than futures prices. Interesting is that the mean of this variable is stable across the two sample sections highlighting its invariance to a time trend.

The remaining variables reported in Table 1 are control variables. The mean quoted relative spread (multiplied by 10) of 6.58 basis points (bps) demonstrates that both markets are highly liquid. This is important because mispricings tend to correlate negatively with liquidity. The relationship becomes clearer with an example. Imagine the following situation: the costs to trade one unit of asset\(_1\) is 10 bps and the cost to trade one unit of asset\(_2\) is 1 basis point. Also imagine that the assets are equivalent, i.e. that one unit of each asset have the same payoff in every state of nature, and trade in the same units (i.e. Euros). In this setting the prices of each asset can deviate by up to 9 bps of the price. Clearly any mispricing within 9 bps is a function of liquidity. Only mispricing outside of a liquidity corridor is relevant. We control for this implicitly when interpreting the results of our estimation model using the spread control variables.

Table 1. Descriptive Statistics

This table presents descriptive statistics for the DAX and DAX futures for two samples between March 22\(^{nd}\) 2007 and May 22\(^{nd}\) 2007 and February 22\(^{nd}\) 2007 and June 19\(^{th}\) 2007, respectively. To calculate the DAX futures midpoint the last available DAX index futures quote in a 1-min interval during the trading day is taken. The last prior time stamped DAX value in the corresponding 1-min intervals is used to compute the Mispricing. We use linear interpolated EURIBOR interest rates in order to correct the DAX(stock market) according to the COC model. Deviation Corrected is reported in thousands. We incorporate the squared quoted spread difference (Spread\(^2\)), the squared difference of the log trading volumes in Euro (Vol\(^2\)), the squared return difference (RD\(^2\)), and the squared realized volatility (Vola\(^2\)) between DAX futures and the DAX as control variables. We calculate these variables from the time stamped DAX value and trade, quote, and order data of DAX futures contracts and DAX stocks. Spread\(^2\) is reported in bps/10, RD\(^2\) in millions, and Vola\(^2\) in 100 millions.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Sample 1 22-MAR to 22-MAY-2007</th>
<th>Sample 2 22-FEB to 19-JUN-2007</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Days</strong></td>
<td>40</td>
<td>80</td>
</tr>
<tr>
<td><strong>Observations</strong></td>
<td>19,300</td>
<td>38,315</td>
</tr>
<tr>
<td><strong>DAX Futures Midpoint</strong></td>
<td>7,301.86</td>
<td>7,279.75</td>
</tr>
<tr>
<td><strong>DAX (Spot market)</strong></td>
<td>7,260.73</td>
<td>7,249.24</td>
</tr>
<tr>
<td><strong>Mispricing</strong></td>
<td>41.12</td>
<td>41.12</td>
</tr>
<tr>
<td><strong>DAX Index Corrected</strong></td>
<td>7,303.21</td>
<td>7,281.05</td>
</tr>
<tr>
<td><strong>Mispricing Corrected</strong></td>
<td>-1.36</td>
<td>-1.31</td>
</tr>
<tr>
<td><strong>Deviation Corrected</strong></td>
<td>0.18</td>
<td>0.16</td>
</tr>
<tr>
<td><strong>Vol(^2)</strong></td>
<td>1.9249</td>
<td>2.0773</td>
</tr>
<tr>
<td><strong>RD(^2)</strong></td>
<td>0.0280</td>
<td>0.0330</td>
</tr>
<tr>
<td><strong>Vola(^2)</strong></td>
<td>0.1116</td>
<td>0.1571</td>
</tr>
<tr>
<td><strong>Spread(^2)</strong></td>
<td>0.6582</td>
<td>0.7019</td>
</tr>
</tbody>
</table>
To test introduction of a low latency cash market we run a GMM [14] estimation. The dependent variable is $Devt^2$ as specified in section 5. The remaining variables are our control variables and dummy variable of interest Xetra Release 8.0. As mentioned above we control explicitly in our estimation for volume, return, volatility and liquidity (quoted spread) differences between the two markets. The intuition behind controlling for these variables is that we are only interested in the ‘pure’ effect of the Xetra 8.0 upgrade.

Importantly, we find a negative and robustly significant coefficient on the Xetra 8.0 variable. This shows unequivocally that the Xetra 8.0 release reduces the mispricing present in the DAX cash and futures markets. This implies one of two things, either the upgrade allows for better technical arbitrage between the two markets which leads to a lower mean mispricing, or the posted prices in the cash market become more efficient.

Although we cannot disentangle these two effects our interpretation with respect to technology in financial markets is the same. Market participants are exploiting the reduction in latency through the application of computer algorithms and thereby reducing mispricing and increasing price efficiency. Exploitation often has a negative connotation, however in this context it is positive in that inefficiencies are being exploited and thereby reduced.

In Table 2 we present two separate models, one without a variable capturing the effects of the Xetra 8.0 upgrade (model A) and one with (model B). We present both models over two sample periods (sample 1 and sample 2). To further study the effect of the infrastructure upgrade we inspect the R-square of both models. R-square essentially measures the model fit, i.e. how much of the variance in the dependent variable do the explanatory (independent) variables describe. The R-square can take values between 0 and 1, i.e. a R-square of 0.2 is the equivalent of saying 20% of the variance is being explained by the model.

In financial applications R-squares are typically lower than in the natural sciences. What we focus on in our analysis is the additional amount of variance we explain by including the Xetra 8.0 variable in our model. In both sample periods the results are quite staggering. In the models without the dummy variable Xetra Release 8.0, we have R-squares of 0.106 and

### Table 2. Regression Results

The Regression is computed with 1-min data intervals using Hansen’s Generalized Method of Moments (GMM) [14]. The following model is used:

$$Devt^2 = \alpha + \sum_{k=1}^{\delta} \beta_k VolDiff_{t+k}^2 + \sum_{k=1}^{\delta} \gamma_k RDiff_{t+k}^2 + \sum_{k=1}^{\delta} \delta_k VolaDiff_{t+k}^2 + \sum_{k=1}^{\delta} \varepsilon_k SpreadDiff_{t+k}^2 + \lambda_{\text{Expiration Dummy}}_{t} + \lambda_{\text{Friday Dummy}}_{t} + \lambda_{\text{Intraday Dummy}}_{t} + \lambda_{\text{Xetra Release 8.0 Dummy}}_{t} + \epsilon_t$$

where all variables are as specified before with additional dummy variables Expiration, Friday, and Intraday taking zero on the last 5 trading days before the expiration of a futures contract, on Fridays, and in the first and last 30 minutes of a trading day and null otherwise. As there is no expiration date in Sample 1, the dummy variable Expiration is not taken into account. The dummy variable Xetra Release 8.0 captures the impact of the introduction of Xetra Release 8.0 on April 23rd 2007 on the mispricing between the DAX futures and the DAX. It equals one after the event date and zero otherwise. In contrast to Model A, the event dummy variable Xetra Release 8.0 is incorporated in Model B. Due to space restrictions we only report the contemporaneous control variables. * denotes significance at the 10% level, ** at the 5% level, and *** at the 1% level.

<table>
<thead>
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<tbody>
<tr>
<td></td>
<td>Model A1</td>
<td>Model B1</td>
</tr>
<tr>
<td>Trading Days</td>
<td>40</td>
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<tr>
<td>Observations</td>
<td>19,300</td>
<td>19,300</td>
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<tr>
<td>R-Square</td>
<td>0.1064</td>
<td>0.2191</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>0.2004 ***</td>
<td>0.2324 ***</td>
</tr>
<tr>
<td>$\beta$</td>
<td>-0.0014 **</td>
<td>-0.0014 **</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>0.7409 ***</td>
<td>0.7318 ***</td>
</tr>
<tr>
<td>$\delta$</td>
<td>-0.0044</td>
<td>-0.0043</td>
</tr>
<tr>
<td>$\varepsilon$</td>
<td>0.0019</td>
<td>0.0225 ***</td>
</tr>
<tr>
<td>$\lambda_{\text{Expiration}}$</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>$\lambda_{\text{Friday}}$</td>
<td>0.0371 ***</td>
<td>0.0285 ***</td>
</tr>
<tr>
<td>$\lambda_{\text{Intraday}}$</td>
<td>0.0112</td>
<td>-0.0169 *</td>
</tr>
<tr>
<td>$\lambda_{\text{Xetra Release 8.0}}$</td>
<td>-</td>
<td>-0.1619 ***</td>
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0.085 and in models incorporating Xetra Release 8.0 the R-squares are roughly doubled – between 0.219 and 0.15. Clearly the evidence suggests that this seemingly innocuous change, in that the market microstructure is left entirely intact, is impacting positively the way trade in both markets is occurring. An additional interesting result is that the size of the intercept coefficient increases with the inclusion of Xetra 8.0 in the model. What this implies is that the model is better able to capture the constant level of mispricing for which we cannot control. Although intercepts are generally only interpretable when all dependent variables are zero, we still think that the direction, if not the absolute size, of the effect is clear. This interpretation is not crucial to the results of the paper, it is however, some further evidence that IT infrastructure is an important factor in electronic markets, and has a direct effect on price efficiency. 

The likely channel is through technical arbitrage that is easier to implement post-upgrade. A more in-depth statistical analysis of all the potential effects and determinants must be left to future work. Our results are supported by the findings of [28]. It is shown that the quote-based information as well as the liquidity increased after the introduction of Xetra Release 8.0. AT participants seem to process more information post-upgrade. Their activities even reduce the lead of the futures market over the spot market, e.g. the reaction of both markets towards new information is strengthened significantly [29]. We show that this effect is mainly driven by smaller non-arbitrage boundaries. To sum up, our findings imply that more information is incorporated post-upgrade into the price discovery process. In regard to the EMH, we conclude that smaller end-to-end round-trip-times lead to more efficient spot market prices as the level of mispricing decreases.

7. Conclusion

We present evidence that a pure IT-infrastructure upgrade reduces the amount of mispricing in a highly liquid electronic market. The level of mispricing falls even after controlling for variables that are strongly correlated with mispricing, like volume, liquidity and volatility. This demonstrates the robustness of the results to alternative explanations.

This study has implications beyond electronic securities markets. By allowing market participants faster access to a trading platform, prices better reflect supply and demand, which by definition will induce more trade. Increasing trade on electronic platforms is beneficial in that suppliers and demanders are able to execute more trades, which by definition must be welfare increasing (assuming of course that participants are rational utility maximizers). Platform operators also benefit as they typically profit per transaction, users of a specific platform may also be willing to pay higher transaction fees if they are certain, that the prices on the platform are in fact better. User’s willingness to pay more is also related to their ability to reduce search and monitoring costs. Still, while the costs of 2.0 Mio € for the XETRA Release 8.0 can be looked up in Deutsche Boerse’s annual report 2007, the assessment of the (social) value of this infrastructure upgrade cannot be determined given the data available and remains a topic for further research.

Other future research topics in this area are numerous. It would be interesting to get access to participant level futures trading level data to study how trading actually changed. An interesting question here is, whether or not there was a broad change in trading or if this effect is driven by a small number of participants. It would also be interesting to extend this type of research to other electronic markets. These results may have also implications for trading platforms like eBay and other online auctions.

In conclusion we think that these results show that improving the IT-infrastructure has a robustly positive effect on electronic securities markets, and that these results can be transferred to other electronic markets. Also we view this as weak evidence that AT plays a positive role in the price development process by reducing welfare reducing price inefficiencies.

8. References


