Arbitrage opportunities between NYSE and XETRA?: A comparison of simulation and high frequency data

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Abstract: This paper investigates the no-arbitrage condition of financial markets by comparing two stock markets: the New York Stock Exchange (NYSE) and the German Exchange Electronic Trading System (XETRA). We analyze German stocks that are traded simultaneously at both exchanges using high frequency data for XETRA, the NYSE, and the foreign exchange rates. Converting Euro-prices into Dollar-prices and vice versa reveals possibilities to discuss the efficiency of these two stock markets and arbitrage opportunities. One measure of efficiency is stock price clustering and we obtain the result that XETRA is more efficient if the exchange rate is taken into account. The observed difference in the clustering effect would not be observable, if the no-arbitrage condition held. We propose a trading strategy that exploits these differences. Furthermore, we compare our empirical findings with the results we obtain by simulating financial markets using a Random Walk as a model for the price movement.
Keywords: financial markets; simulation; no-arbitrage condition; stochastic processes

1 Introduction

When comparing different stock markets the following questions arise immediately: which stock market is more liquid or more efficient and are there arbitrage opportunities? According to the Efficient Market Hypothesis, financial markets are "informational efficient" and there are no arbitrage possibilities (Grossman 1976). In this paper, we analyze the intraday trades of selected German stocks (Daimler and Deutsche Bank) that are traded simultaneously at the New York Stock Exchange (NYSE) and at the German Exchange Electronic Trading System (XETRA). The conversion of the XETRA Euro stock prices into US-Dollar stock prices by the foreign exchange rates and vice versa enables us to discuss the question which stock market is more efficient: XETRA or the NYSE? To investigate this question we use the phenomenon of stock price clustering as a possible indication about the degree of the efficiency of a stock market. Stock price clustering describes the tendency of prices to deviate from a uniform distribution, tending instead to cluster at certain prices and avoiding others. This anomaly can be observed for different stock markets with different market structures and has been widely discussed in the literature (see for example Osborne, 1962, Niederhoffer, 1965, 1966, Ball et al., 1985, Harris, 1991, Christie et al., 1994, Kahn et al., 1999, Vogt et al., 2001, Huang and Stoll, 2001, Sopranzetti and Datar, 2002, Sonnemans, 2006).

The phenomenon of price clustering contradicts any strict definition of the Efficient Market Hypothesis and can be used for measuring the efficiency of stock markets (Ikenberry and Weston, 2008). Stock markets with a higher degree of stock price clustering are considered as less efficient stock markets. Our data yield the result of different extents of stock price clustering for stocks that are traded simultaneously at XETRA and the NYSE. We use different approaches to decide whether XETRA or the NYSE is the more efficient stock market which results in different answers. The first approach directly compares the stock prices on the two exchanges while for the second approach the foreign exchange rate is taken into account. To be more precise, the latter approach indicates that XETRA is the more efficient stock market when comparing converted XETRA-prices and actually observed NYSE-prices. But according to both approaches we observe a difference in the clustering structure between XETRA and the NYSE. The observed difference indicates a violation of the Efficient Market Hypothesis and therefore inefficiency between both analyzed stock markets. Furthermore, it puts some question on the no-arbitrage condition of financial markets. The no-arbitrage condition of financial markets implies that the Dollar-prices at the NYSE should be obtained by converting the Euro-prices at XETRA and vice versa (for companies that are traded simultaneously at both stock markets). We propose a trading strategy that exploits the differences in the observed clustering structure between converted and actually observed stock market prices (quasi-arbitrage opportunities). As these results apply to empirical intraday data of selected German stocks, we want to check whether we obtain the same results by simulating the stock markets. For this purpose, we use the Random Walk as a model for the price movement. The simulated data is in line with the Efficient Market Hypothesis and the no-arbitrage condition as well. Although the assumptions of applying a Random Walk as a model describing our empirical data are fulfilled, we observe substantial differences in the clustering structure. These results reinforce our empirical findings.

2 Empirical Approach

2.1 Data Description

We use high frequency data (all intraday trades) of German stocks (Daimler and Deutsche Bank) that are traded simultaneously at XETRA and the NYSE in November and December 2004 (15th of November through 29th of December). The data is obtained from the Trade and Quote (TAQ) database of the NYSE and the XETRA stock market. In addition, we use high frequency data of the foreign exchange rate Euro vs. US-Dollar. This data was recorded by using a computer program. In 2004, stock prices at XETRA were listed in Euros with a tick size (smallest trading unit or minimum price variation) of 1 Euro-cent while at the NYSE prices were listed in Dollar with a tick size of 1 Dollar-cent. To be more precise, we analyzed all intraday trades of 30 trading days and a time period between 3:30 pm and 5:30 pm for XETRA and 9:30 am to 11:30 am for the NYSE.

2.2 Empirical Results

One approach to answer the question whether XETRA or the NYSE is more efficient is analyzing the last digits of the stock prices of Daimler and Deutsche Bank at both stock markets. We obtain the following frequency distributions.

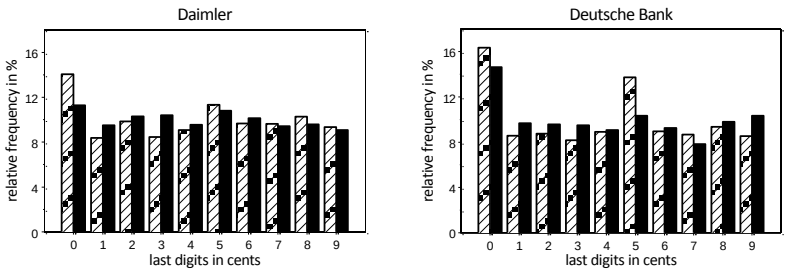

Fig. 1. Frequency distribution of the last digits of the stock prices of Daimler and Deutsche Bank at XETRA (dashed bar) and at the NYSE (solid black bar).

As can be seen from Figure 1, clustering exists and seems to be more pronounced at XETRA. This first impression of different extents of price clustering can more formally be tested by applying a measure *D* of clustering that is used in Ikenberry and Weston (2008). Under standard regularity conditions, the statistic *D* is Chi-squared distributed where large values of *D* imply a significant deviation from the expected distribution (uniform distribution). The test statistic *D* can be calculated for both XETRA (D_{XETRA}) and the NYSE (D_{NYSE}). However, this test does not address whether XETRA is more or less clustered compared to the NYSE. For this purpose, in a second step Ikenberry and Weston (2008) suggest comparing D_{XETRA} and D_{NYSE} by examining the ratio $\tilde{D}$ between both (it is assumed that the numerator has to be greater (or equal) than the denominator, otherwise the inverse has to be calculated). The statistic $\tilde{D}$ is *F*-distributed and enables us to test whether the degree of stock price clustering is the same for XETRA and the NYSE. Large values of $\tilde{D}$ imply that price clustering at XETRA is greater compared to the NYSE. Table 1 presents the numerical values of D_{XETRA} and D_{NYSE} for Daimler and Deutsche Bank and the corresponding ratio $\tilde{D}$. The latter indicates that XETRA is more clustered compared to the NYSE (*F*-test, 1% level of significance) and therefore the NYSE is the more efficient stock market according to this analysis. In addition, the numerical values of D_{XETRA} and D_{NYSE} imply that the last digits of the stock prices of Daimler and Deutsche Bank are not uniformly distributed (Chi-squared goodness of fit test, 1% level of significance).

	D_{XETRA}	D_{NYSE}	$\tilde{D}$
Daimler	1243*	38.82*	32.02*
Deutsche Bank	4314*	119.18*	36.2*

Table 1: Chi-squared test statistics and *F* test statistics,
* denotes significance at the 1% level.

Considering the no-arbitrage condition of financial markets, stock prices at the NYSE should be obtained by multiplying the stock prices observed at XETRA with the corresponding exchange rate (that is valid for the observed time point) and maybe rounding these converted prices to the next possible Dollar-price (and vice versa).To be more precise, we do not expect any difference in the clustering structure between actually observed Dollar-prices and Dollar-prices that result from converting the Euro prices (and vice versa). The resulting frequency distributions of the last digits of those converted stock prices and of the last digits of the actually observed stock prices are presented in Figure 2 for the German company Deutsche Bank[1]. Analyzing the last digits of the transactions data of Deutsche Bank, we observe substantial differences between the clustering of converted and actually observed stock prices. In addition, the converted Euro-prices and the converted Dollar-prices seem to be uniformly distributed. We used a Chi-squared 'goodness of fit' test to check whether the observed distribution of the last digits differs from the expected distribution (that results from converting the stock prices). The numerical values of the test statistic are presented in Table 2, indicating statistical significance (at the 1% level) that the actually observed distribution of the last digits differs from the distribution we would expect after converting stock prices.

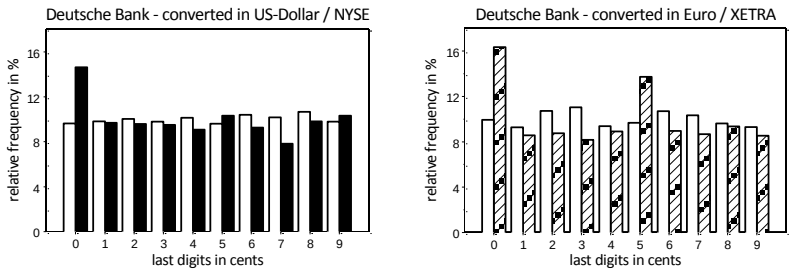

Fig. 2. Frequency distributions of the last digits of the stock prices of converted Deutsche Bank-prices (solid white bars) and of actually observed stock prices of Deutsche Bank at the NYSE (solid black bar) and at XETRA (dashed bar).

[1] Analyzing the stock prices of Daimler we obtain similar results. The corresponding plots can be made available by the corresponding author on request.

	Converted in US-Dollar vs.actually observed US-Dollar *D*	Converted in Euro vs. actually observed Euro *D*
Daimler	67.12	191.96
Deutsche Bank	149.42	4891.10

Table 2: Chi-squared test statistics, * denotes significance at the 1% level

Iit is obvious that the actually observed Dollar-prices at the NYSE reveal a clustering pattern, while there is only a low degree of stock price clustering for the last digits of into US-Dollar converted Euro-prices (Figure 2). Furthermore, the latter seem to be uniformly distributed. But the degree of stock price clustering of Dollar-prices that result from converting the Euro-prices at XETRA corresponds to the degree of stock price clustering we observe at XETRA for these are the same prices, only in different currencies. This leads to the result that the NYSE reveals an additional stock price clustering and therefore we can conclude that the NYSE has a higher degree of stock price clustering compared to XETRA and also that XETRA is a more efficient stock market. That means, comparing converted XETRA-prices and actually observed NYSE-prices yields that XETRA is more efficient.

Summarizing our empirical findings concerning the phenomenon of stock price clustering, we observe different extents of price clustering for the same stocks traded simultaneously on two stock markets. This implies inefficiency between both analyzed stock markets XETRA and the NYSE (for the stock prices of Daimler and Deutsche Bank). But the different approaches how to compare the degree of stock price clustering (with and without using the exchange rate) yield that we cannot strictly respond to our question whether XETRA or the NYSE is the more efficient stock market. If the exchange rate is taken into account we obtain the result that XETRA is more efficient when comparing converted Euro-prices and actually observed Dollar-prices. Nevertheless, we do not expect this observed inefficiency between both stock markets if the no-arbitrage condition of financial markets held.

In the following, we want to provide a trading strategy how to benefit from this observed inefficiency and we calculate a proxy of possible profits. For the purpose of investigating possible arbitrage opportunities (or quasi-arbitrage opportunities to be more precise) it is necessary to know for example the bid price for a specific stock at XETRA, the ask price at NYSE and the corresponding exchange rate at a point in time. As these prices are in most cases not available, we use transaction prices as proxies for this procedure. Analyzing those trades provides a strong indication about the existence or non-existence of (quasi-)arbitrage opportunities. That means we are noting a stock price at XETRA at one point in time and we are converting this Euro-price into a Dollar-price by using the exchange rate that is valid at the time (and vice versa). In a next step we compare the difference between this converted price and the next possible transaction that occurs at the NYSE (and vice versa). If the no-arbitrage condition is fulfilled this difference is zero. Our data and analysis provide empirical evidence that the differences are not zero in most

cases. Table 3 presents the proportions of zero differences and non-zero differences between converted and actually observed stock prices for Daimler and Deutsche Bank. The proportion of non-zero differences exceeds 80% (the results are significant at the 1% level, binomial test).

	Converted in US-Dollar vs. actually observed US-Dollar		Converted in Euro vs. actually observed Euro	
	Difference<>0	Difference=0	Difference<>0	Difference=0
Daimler	83.77%	16.23%	81.15%	18.85%
Deutsche Bank	92.11%	7.89%	91.10%	8.90%

Table 3: Proportions of zero differences between Dollar-prices that result from converting the Euro-prices and actually observed Dollar-prices (and between Euro-prices that result from converting the Dollar-prices and actually observed Euro-prices, respectively).

As the proportion of non-zero differences clearly indicates possible (quasi-) arbitrage opportunities, we want to provide a trading strategy that takes advantage of the observed inefficiency between the two analyzed stock markets and of the observed non-zero differences.
As a signal to buy or sell shares (in this context, a sale also can be a short sale) we consider the most recent observable difference (between converted XETRA-prices and actually observed NYSE-prices or converted NYSE-prices and actually observed XETRA-prices, respectively). If this difference exceeds 0.05 US-Dollar or Euro, we buy the stock on the observed market and sell the same on the other market. We propose a short sale of shares on the main market and a buy (or buy to cover) on the other market, if the observed difference is less than -0.05 US-Dollar or Euro. The following Table 4 presents the average profits of this strategy for the period of investigation and one traded share.

	Converted in US-Dollar vs. actually observed US-Dollar		Converted in Euro vs. actually observed Euro	
	Mean profit per one share per trade in US-Dollar	Number of trades	Mean profit per one share per trade in Euro	Number of trades
Daimler	0.01295	227	0.01917	73
Deutsche Bank	0.03432	1172	0.03352	565

Table 4: Mean profit and number of trades for the suggested trading strategy.

It can be argued that the proposed strategy yields not enough profit to achieve a considerable net profit when taking transaction costs into account. But considering the fee structure of the U.S. broker TradeStation Securities, Inc., a complete transaction can for example be traded for less than 0.00699 US-Dollar per share by

using a so called flat fee[2]. For this case, the calculated average profit per trade seems to be quite lucrative. We can conclude that the suggested trading strategy yields a positive profit when considering transaction costs.

3 Simulation Approach

As the results in Section 2 apply to empirical transactions data of selected German stocks we want to verify, whether we obtain similar results by simulating financial markets. The observed extent of stock price clustering in the empirical data already puts some question on the Efficient Market Hypothesis and the no-arbitrage condition as well. In this Section, we want to check more formally, whether a well known stochastic process emphasizes or contradicts our empirical findings (Fama, 1969). For this purpose, we use the Random Walk as a model for the price movement (which is in line with the Efficient Market Hypothesis) for both stock markets XETRA and the NYSE (Cootner, 1962). According to the Random Walk Hypothesis differences of successive stock prices are normally distributed with expectation zero and variance σ^2[3]. The following Figure 3 presents the frequency distributions of the price differences of the stock prices of Deutsche Bank[4] (for XETRA and the NYSE), and Figure 4 presents the frequency distribution of the price differences of the simulated stock prices[5]. According to these plots, the assumption of a Random Walk as a model for the price movement seems to be suitable and in the next Subsection, we want to have a detailed look at the last digits of simulated stock prices.

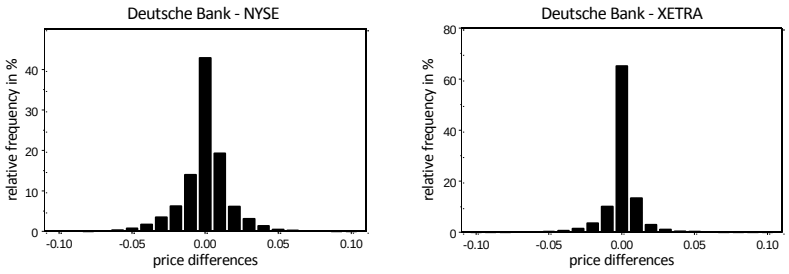

Fig. 3. Frequency distributions of the price differences of the stock prices of Deutsche Bank.

[2] TradeStation Securities, Inc Flat fee 6.99$ per trade max 5000 shares per trade, minimum 30 Trades per month on account. The example is calculated with 2000 shares per trade.

[3] Our data reveal an expected value of zero for the price differences. For the purpose of simulation, the variance has to be estimated using the mean squares error.

[4] The stock prices of Daimler reveal a similar pattern and all Figures can be shown on request by the corresponding author.

[5] The frequency distributions of price differences of converted stock prices and of converted simulated stock prices reveal the same pattern.

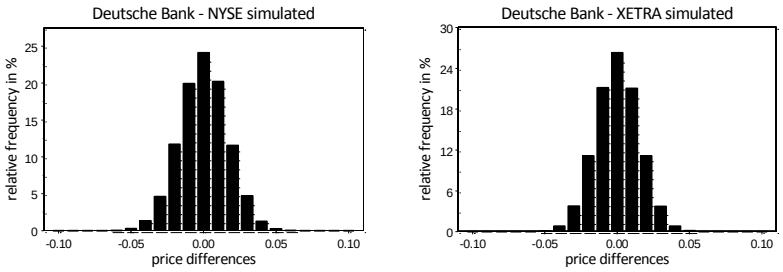

Fig. 4. Frequency distributions of the price differences of the simulated stock prices of Deutsche Bank.

3.1 Stock Price Clustering of Simulated Data

As in Subsection 2.2, the last digits of the simulated stock market prices of Deutsche Bank imply the frequency distributions presented in Figures 5. The stock prices of Daimler reveal the same results. The usage of converted simulated stock prices or converted stock prices shows the same results concerning the stock price clustering phenomenon.

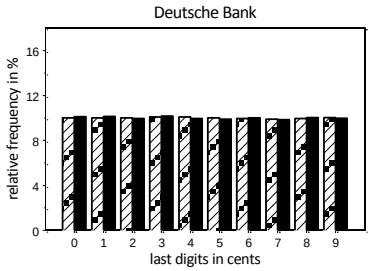

Fig. 5. Frequency distributions of the last digits of simulated stock prices at XETRA (dashed bar) and the NYSE (solid black bar).

Figure 5 implies a uniform distribution of the last digits of simulated stock prices (the same argument holds for the last digits of converted stock prices and converted simulated stock prices) and the degree of stock price clustering does not differ between the two exchanges (Chi-squared goodness of fit test, 1% level of significance). This is a result that contradicts our empirical findings. Although the price differences seem to be normally distributed, the stock price clustering reveals substantial differences between empirical and simulated data. We would expect the results of the simulated data for our empirical data if the Efficient Market

Hypothesis, and the no-arbitrage condition of financial markets as well, held. Therefore, our analysis reinforce the efficiency differences between XETRA and the NYSE and that trading German stocks simultaneously at both stock markets reveals (quasi-)arbitrage opportunities from the Behavioral Finance point of view.

4 Conclusion

This paper investigates the question which stock market is more efficient: XETRA or the NYSE? We examine this question by analyzing high frequency data of selected German stocks (Daimler and Deutsche Bank) that are traded simultaneously at both stock markets. If we take the exchange rate into account we show that German stocks are traded more efficiently at the German stock exchange XETRA. This result also hints at arbitrage possibilities. Furthermore, we analyzed quasi-arbitrage opportunities by suggesting a trading strategy. We have shown that simultaneous trading on both stock markets leads to lucrative profits after subtracting transaction costs. Even if this can only serve as a proxy, it provides a clear indication of arbitrage. As these results apply to empirical intraday data, we want to check whether we obtain similar results by simulating the stock markets. The simulation results reveal that the stock price clustering and the differences between the two exchanges cannot be explained by two Random Walks or two processes which are the same on both stock exchanges.

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