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Dutch Blue Chips traded in Amsterdam and New York

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Abstract

Market integration is studied for Dutch stocks cross-listed at the NYSE. Trading starts in Amsterdam and ends in New York with a one-hour overlap. Both markets are not perfectly integrated in that they can be viewed as one market with the well-documented U-shape in volatility, volume and spread. Increased values for the hour of overlap suggest informed trading. Zooming in on this hour, markets are integrated in that price discovery on both sides of the Atlantic reflects the same underlying, new information. Not consistent across all stocks is the origin of this information, Amsterdam, New York or both.

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Abstract

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1 Introduction

An asset's price is unaffected by its location of trade. This classic finance paradigm predicts that claims on the same set of risky cash flows are assigned the same value irrespective of the international markets these claims are trading at. In other words, markets are perfectly integrated. A recent empirical study by Froot and Dabora (1999) shows that this is not true for three of the world' s largest and most liquid companies.

This paper presents an empirical analysis of market integration for Dutch blue chip stocks that are cross-listed at the New York Stock Exchange (NYSE). The data set consists of all bids, quotes and trades from July 1997 through to June 1998. Included are two of the three stocks studied by Froot and Dabora (1999): Royal Dutch and Unilever. The main contribution of this paper is that it adds an intraday perspective to market integration for markets as geographically distinct as Europe and the US. The one-hour trading overlap facilitates study of market integration. Although many event studies have looked at the effects of the start of cross-listing (IPO), still relatively little is known about mature trading in both markets. A basic understanding of such trading is increasingly important since not only do companies consolidate at a global level, they also raise capital in foreign equity markets by cross-listing their shares. As an example, figure 1 depicts the number of non-US companies listed at the NYSE from 1956 to 1998. This number has grown exponentially which has resulted in 379 cross-listings at the end of 1998. The surge of Electronic Communication Networks (ECN) as still another trading platform will add to this growth in dispersed trading of securities as does the trend to extend trading hours amongst the established exchanges. The Dutch data set is tailored to study of mature trading for cross-listed stocks, since it includes stocks such as Royal Dutch and Unilever that arguably represent the most mature level of US trading a non-US stock can achieve. Both stocks enjoy highly liquid trading in New York, they are registered shares as opposed to ADRs and they are members of the S&P500.

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Amsterdam and New York have the potential of being integrated for a number of reasons. First, both Amsterdam and New York are open trading platforms with virtually complete access for foreign investors. Second, no regulatory constraints prevent cross-border arbitrage in cross-listed stocks. Third, Dutch cross-listed stocks are liquid in both Amsterdam and New York trading. Fourth, since Amsterdam and New York trade the same stock for one hour each day, market makers and brokers face considerable cross-Atlantic competition for order flow. The NYSE is likely to meet tough competition from Amsterdam since broker commissions are amongst the lowest in Europe.

Market integration is assessed both indirectly through the study of intraday patterns and directly by modelling price discovery during the overlapping trading hour.

The indirect assessment builds on Werner and Kleidon (1996) who study UK stocks cross-listed at the NYSE. To the best of our knowledge this is the only intraday study on integration for stocks trading in different continents. Other papers have either studied intraday co-movements of entire markets, Goodhart and O'Hara (1997), or have modelled individual stocks using close to close returns, e.g. Froot and Dabora (1999). Well-known drawbacks of the latter approach are a potential bias due to heavy last minute trading -- Amsterdam is a clear-cut example -- and imperfect synchronisation due to different closing times.

The direct assessment of market integration is based on price discovery during the hour of trading overlap. The model developed in Hasbrouck (1995) is used to study the extent of market integration and the origin of information. The remainder of the introduction will elaborate on these two approaches.

Indirect Assessment of Market Integration

If markets are perfectly integrated and trading overlaps at some point in time, the intraday patterns in volatility, volume and spread as a proxy for cost of trading for both markets combined should resemble the U-shape documented for single markets. Such indirect assessment of market integration is carried out for UK stocks cross-listed at the NYSE in Werner and Kleidon (1996). The same methodology is used in this paper for comparison purposes. The results contribute to academic debate for two important reasons. First, the sample period studied by Werner and Kleidon is the year 1991. At this time, the London Stock Exchange was a dealer market and the New York Stock Exchange a specialist market. For both markets at the time, bid and ask quotes were available, but market participants could offer price improvements to provoke trades. Quoted spreads as studied by Werner and Kleidon therefore are a flawed proxy for cost of trading. This paper studies the Amsterdam stock exchange and the New York Stock Exchange in the year 1997 and 1998. In the taxonomy proposed by Madhavan (2000) both these exchanges are continuous, consolidated, auction markets. Amsterdam is an electronic market at this time and therefore price improvement can only occur through renewed quotes. In New York trading had changed over the years due to the arrival of the electronic Superdot system, which resembles an auction market. The specialist matches orders from both the floor and the system. The best quotes in New York are now, to some extent, disciplined by the Superdot system. Hence, quoted spreads for the sample studied in this paper are more likely to reflect the real cost of trading. In addition, this paper studies effective spread, which is an ex-post proxy for cost of trading and thus accounts for price improvement. Second, popular thought holds that due to globalisation markets around the world have increasingly integrated. Comparing the 1997-1998 results to the 1991 results will shed light on this issue through empirical evidence.

In their review of the high frequency literature in finance, Goodhart and O'Hara (1997) consider the U-shape pattern in volume, volatility and spread as the best known stylised fact. The intriguing feature of these intraday patterns is that they are difficult to explain theoretically, at least using basic models that split agents in informed traders, uninformed or liquidity traders and market makers (Kyle (1985), Glosten and Milgrom (1985), Admati and Pfleiderer (1988, 1989)). The latter model is in the spirit of Kyle but further sophisticates liquidity traders into discretionary and non-discretionary. The group of non-discretionary traders must trade a given number of shares in a certain time interval e.g. fifteen minutes, whereas discretionary liquidity traders can choose when to trade, but have to trade within a pre-specified larger time interval e.g. the full day. The Nash equilibrium of this trading game is such that trading volume is concentrated and may take place at any time in the trading day. This high volume time interval is further characterised by high volatility, since it attracts all discretionary traders including the informed.

Theoretical models can explain the empirical U-shape patterns for volume and volatility, but cannot explain a similar pattern in spread. On the contrary, the Admati and Pfleiderer model predicts an inverted U if the intraday volume pattern is U-shaped, since the high volumes exist for reasons of lower spreads! Potentially the assumption of discretionary traders is flawed.
Brock and Kleidon (1992) take a different viewpoint and, instead of introducing discretionary traders, argue that transactions demand at the open and close of trading is stronger and less elastic than at other times of day. At the open, there is a strong demand for two reasons. First, public news announcements prior to the open provoke trade. Second, the need to rebalance portfolios based on intensive price discovery at the previous day's market close is another trigger for trade. Similarly, when prospective market closure foreshadows an inability to readjust portfolios for 17 hours overnight and over 60 hours on Friday night, investors are focused on the need to rebalance before the closed period arrives. The Brock and Kleidon model is used to hypothesise intraday patterns for stocks listed on exchanges in different time zones. If both markets are perfectly integrated and have some, not necessarily long, trading overlap, intraday patterns will be U-shaped for the *overall* trading period. The null hypothesis of complete integration is depicted in figure 2.

The hypothesised overall U-shape pattern needs further sophistication triggered by a strand of literature referred to by O'Hara (1995) as 'Information and Multimarket Activity'. She classifies information as systematic and non-systematic. The non-systematic information pertains to one single security only, whereas the systematic information pertains to all securities combined, i.e. the market. The opening of the US market potentially reveals systematic information. Lin (1991) has summarised previous studies in this field which show that movement in the US market affects other markets, but not vice versa. Fortunately, the systematic and non-systematic information from US trading can be discriminated, since they start to be revealed at different times. One hour prior to the opening of New York trading, systematic information is revealed through US macro economic announcements. The opening of New York then allows for non-systematic or private information to be revealed through the start of trading in the individual cross-listed Dutch stocks. These observations require further sophistication of the null hypothesis of market integration. The systematic information disclosed one hour prior to the opening of the NYSE is expected to affect trading in Amsterdam through increased volume, volatility and spread. The perfect market integration hypothesis, however, does not allow new, private information to be revealed through the start of trading in the individual stocks at the NYSE open, since this information should have been incorporated through trading in Amsterdam. Hence, the null hypothesis is an overall W-shape pattern for volatility, volume and spread with a peak at 14:30 Central European Time (CET), since this is the time when systematic US information is revealed.

The empirical evidence for Dutch cross-listed shares rejects the hypothesised perfect market integration. Although all three legs of the W-shape pattern are evident, the start of US trading in the cross-listed shares adds a fourth leg. For Amsterdam the volume, volatility and spread clearly jump one-hour prior to the opening as well as at the opening of New York. Apparently the start of trading at the other side of the Atlantic does have informational consequences that provoke increased volume. If there were no new information, the higher volumes should have been accompanied by lower spreads. A jump in volatility and foremost a significant jump in spread suggests increased informed trading. Through high spreads the market can offset the expected loss *vis-à-vis* informed traders. The jump is more prominent for quoted spreads as compared to effective spreads, since the price of the option element contained in the bid and ask quotes is high in times of high volatility. In line with the results for Amsterdam, the overlapping, first hour of trading in New York is characterised by increased volume and volatility as can be inferred from the substantial drop upon the Amsterdam close. Remarkable is the jump in spreads upon the Amsterdam close as opposed to an expected drop due to less informed trading. Apparently, the competitive pressure provided by simultaneous trade in Amsterdam disappears and spreads jump. An alternative explanation is that extreme volume and volatility at *literally* the last minute in Amsterdam affect trading in New York afterwards. Informed traders that did not succeed to trade at the Amsterdam close redirect their intended trading to New York. This argument is less credible, since, in that case, price volatility in New York should have jumped after the close in Amsterdam.

Direct Assessment of Market Integration

The increased volume and volatility for the hour of overlap accompanied by higher spreads clearly reject the hypothesised intraday patterns for perfectly integrated markets. These findings are consistent with informed trading for this time of day. But if markets are not perfectly integrated as judged from a full-day perspective, are they integrated for the hour of trade overlap? Do prices reflect the same fundamental information, or, alternatively, is price discovery integrated for this hour? Price differentials may exist but should be transient for arbitrage reasons. In econometric terms, both price series may be non stationary, the price difference series should be stationary. The null hypothesis of market integration during the overlap is tested by evaluating whether or not both price series are cointegrated.

If volumes are high, prices are volatile, spreads are large indicating informed trading and if price discovery is integrated, arguably the most interesting question is: in which market does this new, private information originate? Hasbrouck (1995) has developed a practical econometric approach based on an error correction model to answer this question. In addition, model estimates yield impulse response functions that are informative on the long-term effect of a unit impulse on one of the exchanges and the adjustment rate of the other exchange.

Model estimates based on five-minute midquote returns show that both prices series are indeed cointegrated for all shares and, hence, markets are integrated by definition. Interestingly, results on the origin of information are mixed. Some stocks are clearly led by Amsterdam in the overlapping trading hour which means that information primarily originates in the Dutch market, some are led both by Amsterdam and New York, some are led solely by New York.

The results of both approaches to market integration show that markets are not perfectly integrated in that they can be viewed as one market open from 9:30 CET until 16:00 EST. The reason for this is that volume, volatility and spreads for all stocks during the overlapping trading hour are substantially higher than what is predicted based on well-documented U-shape patterns for single markets. Zooming in on this relatively intense trading during the overlap, markets appear to be integrated in that price discovery on both sides of the Atlantic reflects the same underlying new information. Price differentials exist but are transient.

The remainder of the paper is structured in five sections. Section 2 describes the setting and introduces the model to estimate the intraday patterns. Section 3 documents the intraday patterns for volatility, volume and spread for both markets. In section 4 price discovery for the overlapping trading hour is modelled. Section 5 re-estimates the intraday patterns based on a stratification of the stocks based on the results of section 4. Section 6 concludes the paper with a brief discussion of the results.

2 The Setting: Amsterdam and New York

This study is based on trade and quote data from the Amsterdam stock exchange (AEX) and the NYSE for July 1, 1997 through June 30, 1998. Seven Dutch blue chip stocks cross-listed in New York have been selected for the current study: Aegon, Ahold, KLM, KPN, Philips, Royal Dutch and Unilever. Although three other Dutch companies were also cross-listed at the time, they are not included because of too short trading history in New York.

The timetable for Amsterdam and New York trading in the sample period shows that there is a one-hour trading overlap each day. In 1997 the end of daylight savings time for the Netherlands and the US coincide. In 1998, however, the start of daylight savings time for the Netherlands is one week prior to the US start. This implies that there is no trading overlap from March 30th to April 3rd, 1998. This week will be studied to further test the results and explanations developed in the paper. Another relevant event for the timetable is the US macro economic announcements one hour prior to the opening of the NYSE.

Summary statistics for the seven Dutch stocks are tabulated in the table 1. The companies are highly diverse, since they differ in terms of industry, number of outstanding shares and market capitalisation. Trading in Amsterdam is more active than in New York when looked at the average numbers of trades and quotes per day. The activity for these stocks in Amsterdam compared to New York in terms of ratios ranges from 1 to 20. The diversity is also reflected in the means for the trading variables studied in this paper which are trade price volatility, midquote volatility, volume, quoted and effective spread. Definitions and calculations of these variables are enclosed as an appendix. Apart from these marked differences, a closer look shows some striking similarities. First, for none of the stocks New York has been able to generate more volume than Amsterdam. Second, remarkable is the consistently higher New York market share measured in terms of number of trades as compared to volume. Apparently, the average volume per trade is smaller in New York. This suggests that institutional traders trade in Amsterdam, leaving only US retail investors to trade in New York. This, however, is opposite to Werner and Kleidon (1996) who find higher average volume per trade in New York as compared to London. Third, consistent with New York not being a complete auction market, quoted spreads are up to almost 300% higher in New York. A more comparable measure of cost of trading is the effective spread. It is widely used as an ex-post measure of cost of trading, since it is based on actual trades. It is defined as twice the difference between the transaction price and the mid-point of the prevailing bid and ask quotes. Evaluating effective spreads clearly puts Amsterdam and New York more in line. For Philips, Royal Dutch and Unilever spreads in New York are lower. This result should be interpreted with care, since average volume per trade is higher in Amsterdam. Hence, the average Amsterdam trade potentially bites deeper into the limit order book and therefore meets a higher effective spread. Although determining which exchange is more competitive is beyond the scope of this paper, effective spread results show that exchanges are indeed competitive which is a promising result in view of the integration questions addressed in this study.

Comparing Amsterdam to New York based on statistics for the overlapping hour yields a similar picture. The main difference is higher average values for all variables during the hour of overlap.

Although studies that focus on intraday patterns are numerous and consistently document U-shape patterns, the comparison of patterns for cross-listed stocks is limited. Werner and Kleidon

(1996) are the first to study market integration through intraday patterns. Their approach is used for the current sample because it both allows for the strong firm-specific effects and it offers a benchmark. The intraday patterns for volatility, volume and spread are estimated using ordinary least squares regressions. In order to estimate a cross-section model incorporating all stocks, the variable of interest is scaled to make up for firm-specific means. The series $\{X_{s,d,t}\}$, where *X* is either volatility, volume or spread, where subscript s denotes the specific stock, *d* denotes the day and *t* denotes a specific fifteen minute interval, is scaled by the stock-specific, day-specific mean $\omega_{s,d}$.

$$Y_{s,d,t} \equiv \frac{X_{s,d,t}}{\hat{\omega}_{s,d}} \qquad (1)$$

The scaled series $\{Y_{s,d,t}\}$ is used in a cross-section regression to estimate the intraday patterns. The model is defined as:

$$Y_{s,d,t} = \left\{ \sum_{j=t_0}^{T} (I^j(t) \cdot \alpha_j) \right\} + \left\{ \sum_{j=t_0}^{T} (I^j(t) \cdot \sigma_j) \right\} \cdot \varepsilon_{s,d,t} \qquad (2)$$

The intraday patterns are incorporated in the α vector, $I^j(t)$ takes the value one if $j = t$ and zero otherwise. The $\varepsilon_{s,d,t}$ is an identically and independently distributed error term with zero mean and unit variance. By construction, the intraday variance is allowed to be heteroskedastic and is reflected in the σ vector. Such heteroskedasticity is likely because of the U-shape pattern and was found in the Werner and Kleidon study. This time of day specific variance will prove useful in testing whether intraday patterns in Amsterdam significantly differ from the average pattern in London. In addition, it enables statistical testing of sudden jumps or drops in a straightforward manner. Going from time interval j to j+1 the model not only allows for a new intraday average, but also for a confidence interval solely based on the day over day volatility for that particular fifteen minutes of the day. Effectively, it makes the results more robust to outliers, since these will not only affect the interval average but also enlarge confidence intervals for that specific interval.

3 The Intraday Patterns

The empirical intraday patterns for volatility, volume and spread are estimated and discussed in this section.

3.1 Amsterdam Benchmarked against London

The trades and quotes sample for Amsterdam is comprised of 261 trading days, which yields 7,308 fifteen-minute intervals. The inclusion of seven stocks in the sample thus results in 51,156 observations. The number of explanatory variables is 28, which is the number of fifteen-minute intervals in a day. The intraday patterns are depicted in figure 3a. The size of intraday jumps and their statistical significance is tabulated in table 2.

3.1.1 Trade Price Volatility

The intraday volatility pattern in Amsterdam is determined by modelling fifteen-minute squared returns, which are based on trade prices. As can be seen in the first graph in figure 3a, it has the familiar U-shape, although somewhat distorted. The first remarkable difference with a pure 'U' is the sudden jump from 0.73 to 1.13 at 14:30 CET. Volatility jumps by 53%, which indicates that US macro-economic announcements reveal new information for Dutch stocks. These price changes from 14:30 to 14:45 are clearly larger than justified by the "U" shape. The second jump is at 15:30 showing an increase in volatility from 0.90 to 1.31, which is a jump of 47%. The New York open apparently moves the stocks in the Amsterdam market. Volatility then steadily increases and jumps to record levels at the close i.e. more than 250 times the average volatility in the day. This end-of-the-day effect shows prices either jump or fall to an extent not witnessed throughout the day. The 99% confidence intervals show that these sudden changes in volatility are firm results, since these intervals are small compared to the size of the change. The ratio of the 14:30 jump to the standard error for the interval starting at 14:30 is 8.4. The same ratio for 15:30 is 8.8.

Comparing the intraday volatility patterns of Amsterdam to the London patterns reported in Werner and Kleidon (1996) reveals some remarkable differences. The Amsterdam pattern is easily understood for the pattern is smooth with jumps at meaningful times. The London pattern, on the other hand, is relatively irregular with unexpected jumps and drops. Although the Amsterdam pattern is significantly different from the average London pattern, this result should be interpreted with care. The irregularity of the London pattern might be the result of a poor model fit for London and this pattern thus will be accompanied by wide confidence intervals. The jump in volatility at the New York open is evidenced in both samples, whereas Amsterdam is unique in showing a volatility jump one hour prior to the New York open.

3.1.2 Volume

The volume pattern is determined by studying the total number of shares traded in each fifteen-minute interval. The second graph in figure 3a shows the Amsterdam volume pattern. It closely resembles the volatility pattern: a U-shape with jumps at 14:30 and 15:30 and a record volume at the close. Although the jump at 14:30 is more restricted, 26%, the jump at 15:30 is comparable in size with the volatility jump, 55%. The intraday volume and volatility patterns combined clearly reject the hypothesis of perfect market integration, since under this hypothesis the 15:30 jump in volatility and volume would not exist. Both jumps are significant, since the jump to standard error ratios are 9.6 and 20.8 for 14:30 and 15:30 respectively.

The comparison to the intraday patterns for the UK sample shows that London volume and volatility do not jump on the 14:30 events in the US, whereas they do at the actual open of the NYSE, but to a lesser extent. In other words, the current sample Dutch stocks appear to be more sensitive to US events and NYSE trading.

3.1.3 Quoted Spread

The third graph in figure 3a shows the quoted spread pattern. It resembles the volatility and volume patterns with the exception of a relatively small jump at the close. At 14:30 the quoted spread jumps by 10% and the 15:30 jump is 5%. The spreads in the final two hours of trading are 5% to 10% higher than the previous hours. These results indicate that market participants in

Amsterdam are quoting more carefully to protect themselves against informed trading. Both jumps are significant, since the jump to standard error ratios are 12.1 and 8.4 for 14:30 and 15:30 respectively.

The comparison with London shows that the London results do not show any sign of higher cost of trading as indicated by increased quoted spreads, on the contrary, spreads continue to decline steadily. This remarkable difference can be understood by the different trading structures of both markets. Quotes in the 1991 London dealer market were to some extent indicative since dealers could offer price improvement. Quotes in the 1997-1998 Amsterdam market were the only means to provoke trade and were therefore more informative on the actual price participants wanted to trade at. Alternatively, European markets have become more dependent on information emanating from the US market over the years. The other difference is the steady decline in quoted spreads in the first few hours of trading in Amsterdam from 1.58 at the start to 0.91 at noon. The London quoted spreads start at 1.10 and rapidly drop to 1.03 in the first hour of trading and then gradually decline to a level of 1.01 at noon.

3.2 New York Trading in Dutch Stocks Benchmarked against UK Stocks

The trades and quotes sample for New York comprised of 261 trading days, which translate into 6,786 fifteen-minute intervals. The inclusion of seven stocks in the sample thus yields 47,502 observations. The number of explanatory variables is 26, which is the number of fifteen-minute intervals in a day. The intraday patterns are depicted in figure 3b. The size of intraday jumps and their statistical significance is tabulated in table 2.

3.2.1 Trade Price Volatility

As can be seen in the first graph of figure 3b, the volatility pattern in New York has the U-shape pattern. Remarkable though is the excessive volatility in the first hour of trading as evidenced by the 26% drop in volatility upon the Amsterdam close. In particular the first fifteen minutes are characterised by very high volatility compared to the rest of the day. This, in combination with the 47% jump in volatility in Amsterdam suggests that private information is revealed through the start of trading in New York. Such informed trading continues through the first hour with relatively high levels of volatility. As soon as Amsterdam closes volatility drops in New York, although this drop is not as substantial as the 15:30 jump in Amsterdam. Interestingly, high volatility at literally the last minute of trading in Amsterdam does not convey the inclusion of new, private information, since New York price discovery for the same shares does not show a significant jump immediately after the close. On the contrary, it drops at the close. The statistical significance of the drop is evident from the drop to standard error ratio, which equals 7.2.

Compared to UK cross-listed stocks, current sample Dutch stocks appear to be more sensitive to simultaneous price discovery in the domestic market.

3.2.2 Volume

The second graph in figure 3b shows that the intraday volume pattern at the NYSE is similar in shape to the volatility pattern. The volume drop at the time of the Amsterdam close is 24%. The drop is significant, since the drop to standard error ratio is 7.8. The pattern for UK stocks does not show such a strong volume drop and less growth in volume towards the market close.

3.2.3 Quoted Spread

The quoted spread intraday pattern reflects a single-legged “U” as can be seen from the third graph in figure 3b. Spreads do not increase at the end of the day. Contrary to the Amsterdam pattern, there is no threat of new information being revealed through the start of trading elsewhere. The remarkable difference with the Werner and Kleidon finding for UK stocks is the sudden 9% jump in spreads upon the close of trading in Amsterdam. The jump is significant as is evident in a jump to standard error ratio of 10.3. A straightforward explanation is that extreme volume and volatility at the close in Amsterdam reveals new information that will affect New York trading afterwards. Informed traders that did not succeed to trade at the close in Amsterdam redirect their intended trading to New York. This implies that price changes, and therefore volatility, are large in New York just after the close in Amsterdam. The empirical finding of a volatility drop, however, makes this explanation unlikely. An alternative explanation for the jump in spreads is the drop in volume. This explanation too is unlikely since spreads decline to levels even below the overlapping hour levels in the course of the day on even lower trading volumes.

The most likely explanation is that spreads in New York seem to be sensitive to the competitive pressure for order flow caused by simultaneous trade in Amsterdam. Such downward pressure, apparently, dominates the upward pressure on spreads due to informed trading in the first hour. This finding is interesting in view of the debate on the level of monopolistic power of the New York specialist.

3.3 Improved Proxies for Volatility and Spread

To benchmark results against the Werner and Kleidon findings the same methodology has been used in the current paper. Unfortunately the proxies for volatility and spread are flawed. In the remainder of this section these proxies are criticised and improved proxies are introduced to test the robustness of previous results. First, trade price volatility is a flawed proxy for volatility since it suffers from the bid ask bounce. Both volatility jumps in Amsterdam might be biased upwards due to simultaneous jumps in spread, which create a stronger bid ask bounce effect. An improved proxy for volatility is midquote volatility since it does not suffer from such bounce. Second, quoted spread is a flawed proxy for cost of trading for two reasons. First, the best bid and ask quote might not be backed by volume. If volume for these quotes is relatively small and the limit order book is not deep, a large sell order, for example, can only be executed by biting deep into the order book. Only part of the total order can be executed at the best bid, the rest is executed against less favourable bid prices. On the other hand, trades might take place within the bid ask spread, because both buyer and seller might offer some margin to establish a trade. These are the main reasons for studying the ex-post effective spread which is defined as twice the distance from the trade price to the midquote based on the best bid and offer at the time of the trade.

The intraday patterns for both midquote volatility and effective spread are calculated and depicted in figures 4a and 4b for Amsterdam and New York respectively. The size and significance of intraday jumps are tabulated in table 2. The figures also contain the patterns that were based on the Werner and Kleidon proxies to see how results are affected by the proxy change. The results show that the intraday patterns are barely affected by the proxy change. Only the New York pattern for effective spread is different from the quoted spread pattern, but that difference is caused by a higher average effective spread at the first fifteen minutes of trading. This affects the full day results because of scaling. Apparently, the effective spread in the first fifteen minutes compared to the rest of the day is larger than the quoted spread, indicating that the many market orders bite deep into the probably thin order book at the start of the day. The same is true for the market in Amsterdam, but to a lesser extent. Most importantly the relative size of the jumps and drops throughout the day are unaffected by these proxy changes. This strengthens confidence in the effects documented in the previous sections.

3.4 One Week with No Trading Overlap

The week with no trading overlap due to non-synchronous change to daylight savings time is studied to evaluate whether the intraday peaks for both markets are caused by the open or close of the other market. The intraday patterns shift in line with the US market opening up one hour later compared to the other weeks in the sample. The period is too short, however, to find statistically significant results.

4 Price Discovery in the Overlapping Trading Hour

The increased volume and volatility for the hour of overlap accompanied by higher spreads clearly reject the hypothesised intraday patterns for perfectly integrated markets. These findings are consistent with informed trading for this time of day. But if markets are not perfectly integrated as judged from a full-day perspective, is price discovery then integrated for the overlapping trading hour? Price differences should be transient for arbitrage reasons. Hence, both price series may be non stationary, the price difference series should be stationary otherwise prices would drift apart without bound. The null hypothesis of market integration for price discovery during the overlap is tested by evaluating whether or not both price series are cointegrated.

If volumes are high, prices are volatile, spreads are large indicating informed trading and if price discovery is integrated, arguably the most interesting question is: in which market does this new, private information originate? This question is addressed in Hasbrouck (1995). In this paper an error correction model not only determines which market drives price discovery but also details the interaction between both markets for each stock.

To study price discovery in the overlapping hour five minute midquote returns have been calculated and modelled. Midquotes are the preferred proxy for price for two reasons. First, quote returns are not subject to excessive negative autocorrelation that results from a bid-ask bounce present in trade price returns. This bias was first documented by Roll (1984). Second, the sample of quotes is larger than the trade sample. The interval length is fixed at five minutes instead of two minutes or one minute, because these data were least affected by intervals not containing a quote and therefore uninformative. To facilitate comparison, the Amsterdam quote series are translated into dollars using day to day NLG-USD exchange rates. Admittedly, applying interday exchange rate series to intraday quotes is debatable. The impact on the results, however, is limited for two reasons. First, if intraday exchange rate returns are not correlated with stock returns, model estimates are less efficient but not biased. Second, the intraday volatility of the USD-NLG exchange rate is very small compared to the volatility of midquote returns.

To gain insight in the dynamics of the quote series, auto- and cross-correlations are summarised in table 3. These statistics lead to some interesting first thoughts. Contemporaneous returns show strong positive correlation, ranging from 0.27 to 0.70. This is a first strong indication that markets are integrated, i.e. price discovery reflects the same underlying information. The significantly positive cross-correlations with either AEX or NYSE lagged five minutes are evidence of potential lagged response to innovations in price discovery on the other exchange. First order autocorrelations are also significant although to a lesser extent. The fact that these are either positive or negative shows that the strong bouncing effect present in trade returns is not evident in quote returns. Significance of higher order auto- and cross-correlations is scattered, most dynamics is within one lag.

The correlation pattern in midquote returns is consistent with an error correction model as presented in Hasbrouck (1995). The positive first order cross-correlations are potentially the result of 'error correction'. The model is represented as:

$$
\begin{aligned}
r_t^{AEX} &\equiv \Delta \log(P_t^{AEX}) \\
r_t^{NYSE} &\equiv \Delta \log(P_t^{NYSE}) \\
r_t^{AEX} &= \alpha^{AEX}(\log(P_{t-1}^{AEX}) - \log(P_{t-1}^{NYSE})) + \sum_{i=1}^{4} \gamma_i^{AEX,AEX} r_{t-i}^{AEX} + \sum_{i=1}^{4} \gamma_i^{AEX,NYSE} r_{t-i}^{NYSE} + \varepsilon_t^{AEX} \\
r_t^{NYSE} &= \alpha^{NYSE}(\log(P_{t-1}^{AEX}) - \log(P_{t-1}^{NYSE})) + \sum_{i=1}^{4} \gamma_i^{NYSE,AEX} r_{t-i}^{AEX} + \sum_{i=1}^{4} \gamma_i^{NYSE,NYSE} r_{t-i}^{NYSE} + \varepsilon_t^{NYSE}
\end{aligned}
\tag{3}
$$

The validity of the model depends on the validity of two assumptions. First, the midquote series should be integrated of order one and, if this is true, both series should be cointegrated. Dickey-Fuller test statistics show that both these assumptions are valid for all seven stocks at a 99% confidence level. The stationarity of the cointegrating relation, which is the difference between the midquotes in Amsterdam and New York, ensures that price differences are transient. Apparently markets are integrated during the hour of trading overlap. The error correction model helps us detail this integrated price discovery.

Estimation results are tabulated in table 4. The strong positive contemporaneous correlation in the return series is picked up by the model in strong contemporaneous correlation in the error terms. This implies strong market integration since quotes in both markets move in the same direction in intervals as short as five minutes. Comparing R^2 for both markets shows that they are higher for New York, indicating that apart from contemporaneous adjustment, New York innovations depend to a larger extent on historical information. The error correction term is significant in all models, although sometimes significant for the Amsterdam equation only, sometimes for the New York equation only, and sometimes for both. For Ahold, KLM and KPN the error correction term is significantly positive for New York returns, which implies that New York adjusts to midquote differences with Amsterdam. For Aegon and Philips both Amsterdam and New York adjust for quote differences. For Royal Dutch and Unilever the error correction mechanism lets Amsterdam adjust to midquote differences with New York.

Before considering information shares of both exchanges as defined in Hasbrouck (1995), it is useful to discriminate between long term and transitional contributions to price discovery.

The long-term contribution is a straightforward expression after rewriting the error correction model to a Vector Moving Average (VMA) model.

$$\underline{r}_t = \Psi(L)\underline{\varepsilon}_t \qquad (4)$$

The stationarity conditions imply that the sum of all rows in $\Psi(1)$ constitute the long-term impact of a unit impulse on each of the midquote prices. The cointegration condition ensures that this sum is equal for both rows. The economic intuition is that prices on both exchanges can differ only temporarily and will revert to a common implicit price. The arbitrage mechanism brings both prices in line in the “long-term”.

The first two columns in table 5 document the long-term impact for all seven stocks. Consistent with the categorisation based on the error correction term, Ahold, KLM and KPN show that unit impulses in Amsterdam are permanent, whereas unit impulses in New York are temporary. For Aegon and Philips both unit impulses on Amsterdam and New York appear to have a permanent effect. Royal Dutch and Unilever in the long run incorporate unit impulses from New York, not from Amsterdam. Although these conclusions might be too black and white, they do point at the main differences.

The transitional properties of the model are best explored by drawing impulse response functions for all seven stocks. Figures 5a and 5b depict how AEX and NYSE midquotes are affected by unit impulses on one of the exchanges. The midquote value prior to the unit impulse is equal to the sample average. The response functions are strikingly similar across all stocks for both Amsterdam and New York. At the same time, they are different across both exchanges. Amsterdam tends to be overreacting to incumbent unit impulses, whereas New York tends to temper unit impulses originating in its own market. The adjustment process to a unit impulse on the other exchange is gradual for Amsterdam in reaction to New York, and relatively fast for New York in reaction to Amsterdam. The adjustment rate is quantified by documenting the time needed for the responding exchange to incorporate half of the long-term effect. The results in column 3 and 4 in table 5 show that in New York this takes less than fifteen minutes whereas in

Amsterdam this takes more than one hour. For Royal Dutch and Unilever, New York even overreacts to an impulse on Amsterdam. These patterns seem to indicate that Amsterdam traders are confident that quote changes in their own market reflect new, private information, whereas they slowly adept to the information in New York quote changes. In New York, traders interpret NYSE quote changes as only partially reflecting new, private information. The immediate adjustment downwards for all seven stocks supports this interpretation. For some stocks, this is a valid response since the long-term contribution of New York is nearly zero. For stocks such as Aegon, Philips, Royal Dutch and Unilever, however, this is not, since within twenty minutes quotes are adjusted upwards again.

Information shares measure the proportional contribution of innovations in one market to the innovation in the common implicit price. Hasbrouck (1995) calculates them based on the error-correction model. By construct, the information share cannot be pinned down to one number, but is contained in an interval. The lower and upper bound of this interval are tabulated in the last two columns of table 5 and depicted in figure 6. The intervals are relatively wide largely due to the high contemporaneous correlation in the error terms. In other words, both markets are integrated to such an extent that price adjustments take place *within* five minutes. This hampers the assignment of new information to Amsterdam or New York. The mere location of the intervals still is very informative on the relative position of the Amsterdam and New York market. Information for Ahold, KLM and KPN originates primarily in Amsterdam for the overlapping trading hour. Information for Aegon and Philips originates in both Amsterdam and New York. Information for Royal Dutch and Unilever originates primarily in New York. This categorisation is consistent with previous ones based on the error correction term coefficients and the long-term effect of unit impulses.

5 Intraday Patterns by Category

The intraday price discovery study based on the Hasbrouck model unambiguously shows that the Amsterdam and New York market are integrated, since they reflect the same fundamental information. Such unambiguous conclusion is not possible when looked at the origination of information. The sample can be categorised as Amsterdam led, mixed or New York led stocks. The first category contains Ahold, KLM and KPN, the second Aegon and Philips and the third Royal Dutch and Unilever. Based on these findings it is interesting to evaluate whether Amsterdam and New York trading patterns depend on the category the stock belongs to. To answer this question the Werner and Kleidon model is extended in the following manner.

$$Y_{s,d,t} = \left\{ \sum_{i \in A} \sum_{j=t_0}^{T} (I^i(s) \cdot I^j(t) \cdot \alpha_j) \right\} + \left\{ \sum_{i \in A} \sum_{j=t_0}^{T} (I^i(s) \cdot I^j(t) \cdot \sigma_j) \right\} \cdot \varepsilon_{s,d,t} \qquad (5)$$

$$A = \{AEX\_LEAD, MIX, NYSE\_LEAD\}$$

The additional variable $I^i(s)$ is one if stock s belongs to category i and zero otherwise. The estimation results are depicted in figure 7a and 7b. Although each category is thin, since it contains two or three stocks, the results are remarkable and patterns differ significantly, in particular during the overlapping trading hour.

The Amsterdam intraday patterns for each category do not deviate in shape from the overall pattern established in section 3, but differ in the size of the jumps throughout the day. The 14:30 effect for the different categories are not significantly different. This is consistent with the market wide, systematic information contained in the macro economic announcements. The 15:30 effects are more substantial the more information originates in New York. Volatility, volume and effective spread show significantly higher jumps upon the opening of New York.

In line with the findings for Amsterdam, the intraday patterns for New York are similar in shape to the documented overall pattern. Again, the differences are significant for volatility, volume and effective spread patterns. The intraday pattern differences in terms of jumps and drops are relatively small for volume and effective spread. The intraday volatility patterns on the other hand shows that stocks for which information originates in the Amsterdam market during the overlapping hour volatility drops just after the Amsterdam close. Stocks for which information solely originated in New York do not show such drop.

6 Conclusion

The question of market integration is increasingly relevant in a world where equity markets see more and more cross-listings. Werner and Kleidon (1996) studies UK stocks cross-listed in New York and answer this question by documenting intraday patterns in trade price volatility, volume and quoted spread. Contrary to the null hypothesis of market integration London volume and volatility increase at the end of the London trading day instead of staying at the lower levels while New York trading starts and then increase at the end of the New York trading day. London spreads, on the other hand, do not increase at the end of the London trading day, which is counter-intuitive given the results for volume and volatility. Updating this study with both a more recent sample, 1997 and 1998 as opposed to 1991, and a different market, Amsterdam instead of London, yields new insights. In short, the intraday patterns documented for Dutch stocks are significant and show some pronounced intraday jumps and drops that are not at all or to a lesser extent present in the Werner and Kleidon study. These differences suggest that either Dutch cross-listed stocks are more sensitive to US trading or cross-listed European stocks have become more dependent on the US market overtime.

Intraday jumps and drops in volatility, volume and spread are significant and occur at meaningful times. The most remarkable jump is at 14:30 CET when US macro economic announcements are published. In Amsterdam, volatility, volume and quoted spread jump significantly by 53, 26 and 10 percent respectively. The Werner and Kleidon study could not discriminate these jumps. At 15:30 CET NYSE trading starts and this is the start of one hour of synchronous trade at both sides of the Atlantic. Again, volatility, volume and quoted spread jump 47, 55 and 5 percent respectively, which suggests a start of informed trading. As soon as the Amsterdam stock exchange closes, volatility and volume for the Dutch shares drop in New York by 26 and 24 percent respectively. Remarkable is the jump in quoted spread by 9 percent. Apparently the competitive pressure, felt in New York during the hour of simultaneously trade with Amsterdam, eases. In the Werner and Kleidon study such drops existed for volatility and volume, 12 and 10 percent respectively, but did not exist for spread.

Although taken from the Werner and Kleidon study for comparability purposes, the proxies for volatility and spread are flawed. Improved proxies are midquote volatility and effective spread. The intraday patterns for these proxies yield the same picture.

These intraday patterns show that both markets are not perfectly integrated in that they resemble one market open from the Amsterdam start of trading to the New York close. Increased volatility, volume and spreads during the hour of overlap clearly are not consistent with the stylised U shape pattern for a single market. The Hasbrouck (1995) model is used to zoom in on price discovery for the overlapping trading hour. The error correction model clearly documents market integration, since price changes in both Amsterdam and New York temporarily differ but converge in the long-term. The adjustment rate is substantially higher for New York responding to Amsterdam as opposed to Amsterdam responding to New York. The origination of information differs from stock to stock. For some stocks price discovery is solely based on information originating in Amsterdam, for some information originates both in Amsterdam and New York and for some it originates solely in New York. Re-evaluating intraday patterns based on these different types of stock shows that the overall intraday shape is present in all stocks, but more pronounced jumps or drops are documented for the stocks where information primarily originates in the other market.

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Appendix: Variable Calculations

Variable	Definition
Trade Price Volatility	Volatility is proxied by the squared return for a specific fifteen minute interval. Returns are in basispoints. The interval return is calculated as the trade price prevailing at the start of the interval as is inferred from the last trade and the prevailing price at the end of the interval. Applying these rules without scrutiny will lead to arbitrary results for variance at the first fifteen minutes since trading does not start immediately at the open. The first fifteen minute return in the day is linearly extrapolated from the x-minute return from the first trade in the day to the prevailing trade fifteen minutes after the market open.
Midquote Volatility	The definition of midquote volatility is similar to trade price volatility. Midquotes are the average of the best bid and ask price.
Volume	Volume is calculated as the number of shares traded in a specific fifteen minute interval.
Quoted Spread	Quoted spread is calculated as the average difference between the best bid and ask price in a specific interval. The spread for a specific fifteen minute interval is a weighted average of all prevailing spreads in the interval.
Effective Spread	Effective spread is calculated as twice the difference between the transaction price and the mid-point of the prevailing bid and ask quote. Effectively, this spread metric measures ex-post cost of trading. The effective spread for a fifteen minutes interval is a weighted average of all observed effective spreads in the interval.

Table 1: Summary Statistics of Trading in Amsterdam and New York

Summary Statistics Data Set		Aegon	Ahold	KLM	KPN	Philips	R. Dutch	Unilever
Type of Listing in New York		NY reg	ADR	NY reg	ADR	NY reg	NY reg	NY reg
Outstanding Shares (mln)[a]		380	523	61	272	369	2,144	640
Outstanding New York (mln)[a]		4	8	12	8	76	859	218
%-age of total[a]		1%	2%	20%	3%	21%	40%	34%
Market Cap. (NLG bn)[a]		105	28	6	40	45	239	81
Average Number of Trades per Day	AEX	531	872	250	474	709	919	594
	NYSE	63	52	139	24	337	874	352
Average Number of Quotes per Day	AEX	665	916	282	542	1,021	1,111	830
	NYSE	91	48	464	37	189	329	322

Trading Statistics Full Day		Aegon	Ahold	KLM	KPN	Philips	R. Dutch	Unilever
Trade Price Volatility[b] (basispoints^2)	AEX	922	1,360	1,284	1,005	1,412	730	581
	NYSE	336	1,214	753	376	808	859	493
Midquote Volatility[b] (basispoints^2)	AEX	544	1,076	929	642	1,118	600	438
	NYSE	274	799	686	390	743	914	533
Volume (Number of Shares)	AEX	34,422	88,893	19,706	52,941	77,149	138,665	57,467
	NYSE	2,790	1,479	5,929	1,116	23,609	71,871	20,044
Quoted Spread (bp)	AEX	23	40	37	32	25	20	18
	NYSE	51	106	66	90	38	44	19
Effective Spread (bp)	AEX	18	26	28	25	18	15	14
	NYSE	19	49	32	35	15	15	13
Number of Observations[d]	AEX	7,308	7,308	7,308	7,308	7,308	7,308	7,308
	NYSE	6,786	6,786	6,786	6,786	6,786	6,786	6,786

Trading Statistics Overlapping Hour		Aegon	Ahold	KLM	KPN	Philips	R. Dutch	Unilever
TradePrice Volatility[c] (basispoints^2)	AEX	1,437	2,116	2,321	1,779	2,096	1,017	966
	NYSE	933	2,007	1,840	733	1,508	1,291	619
Midquote Volatility[c] (basispoints^2)	AEX	1,038	1,708	1,949	1,325	1,783	897	827
	NYSE	888	1,466	1,679	815	1,553	1,284	710
Volume	AEX	52,635	123,606	32,897	81,423	123,180	232,409	95,103
	NYSE	5,040	2,817	10,535	2,344	37,511	119,635	33,675
Quoted Spread (bp)	AEX	23	41	36	31	25	21	20
	NYSE	61	120	83	90	44	47	20
Effective Spread (bp)	AEX	20	28	32	28	20	17	16
	NYSE	51	82	58	83	33	17	21
Number of Observations[d]	AEX	1,044	1,044	1,044	1,044	1,044	1,044	1,044
	NYSE	1,044	1,044	1,044	1,044	1,044	1,044	1,044

[a]: as per 1/1/98

[b]: the first and last fifteen minutes of trading have been excluded because of extreme volatility

[c]: the first and last fifteen minutes of the overlapping hour were excluded due to extreme volatility at the opening of New York and the close of Amsterdam respectively, this way results are more comparable

[d]: valid for volume and spread, less observations for volatility because first and last fifteen minutes were excluded

The figures presented in this table are 15 minute averages. They are based on trading on both the Amsterdam Stock Exchange (AEX) and the New York Stock Exchange (NYSE) from July 1, 1997 until and including June 30, 1998. Variable definitions are to be found in the appendix.

Table 2: Intraday Jumps

Intraday Jumps in Amsterdam

	Macro Economic Announcements					Benchmark Werner and Kleidon (1996)		
	14:15	14:30	Δ	σ(14:30)	Δ/σ	14:15	14:30	Δ
Trade Price Volatility	0.73	1.13	53%	0.05	8.4	0.55	0.60	9%
Volume	0.80	1.01	26%	0.02	9.6	0.45	0.38	-17%
Quoted Spread	0.92	1.01	10%	0.01	12.1	1.01	1.01	0%
Quote Price Volatility	0.63	1.07	70%	0.05	8.9			
Effective Spread	0.91	1.00	10%	0.01	11.0			

	Start of NYSE Trading					Benchmark Werner and Kleidon (1996)		
	15:15	15:30	Δ	σ(15:30)	Δ/σ	15:15	15:30	Δ
Trade Price Volatility	0.90	1.31	47%	0.05	8.8	0.70	0.95	36%
Volume	0.95	1.48	55%	0.03	20.8	0.50	0.63	25%
Quoted Spread	0.96	1.01	5%	0.01	8.4	1.00	0.99	-1%
Quote Price Volatility	0.82	1.43	75%	0.06	11.1			
Effective Spread	0.95	1.00	5%	0.01	7.2			

Intraday Jumps in New York

	Amsterdam Close					Benchmark Werner and Kleidon (1996)		
	10:15	10:30	Δ	σ(10:30)	Δ/σ	11:15	11:30	Δ
Trade Price Volatility	2.15	1.60	-26%	0.08	-7.2	1.02	0.90	-12%
Volume	1.59	1.21	-24%	0.05	-7.8	1.00	0.90	-10%
Quoted Spread	1.03	1.12	9%	0.01	10.3	1.01	1.00	0%
Quote Price Volatility	1.99	1.54	-23%	0.06	-7.1			
Effective Spread	0.96	1.02	6%	0.01	5.5			

This table shows the size of intraday jumps in trade price volatility, volume, quoted spread, quote price volatility and effective spread. The size of the jump is compared to the standard deviation of the level estimate to enable judgement on statistical significance.

The patterns are based on a pooled regression after making up for stock specific means through scaling. Intraday heteroskedasticity is allowed for through standard deviations that depend on the time of day. The results are compared to jumps and drops in UK patterns that are taken from Werner and Kleidon (1996). The time line refers to Central European Time (CET) for the Amsterdam results and to Eastern Standard Time (EST) for the New York results. The sample period runs from July 1st, 1997 to June 30th, 1998.

Table 3: Correlations Midquote Returns during Overlaping Trading Hour

		Aegon	Ahold	KLM	KPN	Philips	Royal Dutch	Unilever
Autocorrelations								
AEX								
5 min	$\rho(r_{AEX},r_{AEX}(-1))$	0.052*	0.049*	-0.002	0.022	0.119*	-0.007	0.070*
10 min	$\rho(r_{AEX},r_{AEX}(-2))$	0.015	-0.004	-0.004	0.002	0.069*	-0.032	0.033
15 min	$\rho(r_{AEX},r_{AEX}(-3))$	0.031	0.027	0.005	0.039*	0.049*	0.011	0.044*
20 min	$\rho(r_{AEX},r_{AEX}(-4))$	0.025	0.015	0.008	0.006	0.043*	-0.004	0.032
NYSE								
5 min	$\rho(r_{NYSE}(-1),r_{NYSE})$	0.044*	-0.058*	-0.069*	-0.048*	0.127*	0.001	0.000
10 min	$\rho(r_{NYSE}(-2),r_{NYSE})$	0.010	-0.009	0.004	-0.012	0.007	-0.067*	-0.009
15 min	$\rho(r_{NYSE}(-3),r_{NYSE})$	0.009	0.009	0.011	-0.004	0.020	-0.008	0.036*
20 min	$\rho(r_{NYSE}(-4),r_{NYSE})$	0.027	-0.028	-0.027	0.002	0.061*	0.003	0.019
Contemporaneous correlations								
0 lags	$\rho(r_{AEX},r_{NYSE})$	0.463*	0.273*	0.411*	0.286*	0.593*	0.700*	0.612*
Cross correlations								
NYSE lagged								
5 min	$\rho(r_{AEX},r_{NYSE}(-1))$	0.030	0.016	0.060*	0.011	0.137*	0.086*	0.079*
10 min	$\rho(r_{AEX},r_{NYSE}(-2))$	0.018	0.010	-0.010	-0.014	0.032*	-0.031	-0.037*
15 min	$\rho(r_{AEX},r_{NYSE}(-3))$	0.027	-0.023	-0.001	0.000	0.054*	-0.007	0.005
20 min	$\rho(r_{AEX},r_{NYSE}(-4))$	0.042*	0.013	0.000	-0.003	0.022	0.000	-0.009
AEX lagged								
5 min	$\rho(r_{AEX}(-1),r_{NYSE})$	0.308*	0.250*	0.159*	0.212*	0.326*	0.079*	0.124*
10 min	$\rho(r_{AEX}(-2),r_{NYSE})$	0.088*	0.073*	0.034	0.089*	0.065*	-0.037*	0.016
15 min	$\rho(r_{AEX}(-3),r_{NYSE})$	0.051*	0.057*	0.038*	0.040*	0.040*	0.005	0.015
20 min	$\rho(r_{AEX}(-4),r_{NYSE})$	0.037*	0.035	0.013	0.034	0.051*	-0.009	0.030*

*: Significant at a 95% significance level

This table contains the auto- and cross-correlations for the five minute midquote return series for the one hour period of simultaneous trading in Amsterdam and New York. Midquotes are based on best bid ask quotes on both the Amsterdam Stock Exchange and the New York Stock Exchange from July 1, 1997 until and including June 30, 1998.

Table 4: Vector Error Correction Results

		AEX lags				*NYSE lags*							
	$(P_{AEX} - P_{NYSE})$	-5 min	-10 min	-15 min	-20 min	-5 min	-10 min	-15 min	-20 min	n	R^2	σ^2	$\rho(\varepsilon_{AEX}, \varepsilon_{NYSE})$
Aegon AEX	-0.034*	0.045	0.009	0.019	-0.000	-0.002	0.027	0.047	0.081*	1666	0.01	0.0019	0.58
	(-2.54)	(1.39)	(0.26)	(0.54)	(-0.05)	(-0.05)	(0.71)	(1.23)	(2.40)				
Aegon NYSE	0.049*	0.390*	0.205*	0.147*	0.091*	-0.240*	-0.157*	-0.087*	-0.015*		0.19	0.0015	
	(4.77)	(15.7)	(7.64)	(5.34)	(3.35)	(-8.11)	(-5.43)	(-2.97)	(-5.71)				
Ahold AEX	0.002	0.055	0.003	0.067*	0.033	0.038	0.009	-0.048	0.014	1627	0.01	0.0023	0.30
	(0.18)	(1.94)	(0.11)	(2.20)	(1.12)	(1.23)	(0.29)	(-1.60)	(0.53)				
Ahold NYSE	0.052*	0.315*	0.139*	0.141*	0.079*	-0.190*	-0.109*	-0.039	-0.05*		0.18	0.0020	
	(5.22)	(12.7)	(5.32)	(5.29)	(3.05)	(-7.27)	(-4.12)	(-1.49)	(-2.10)				
KLM AEX	-0.014	0.003	-0.048	-0.006	-0.005	0.097*	0.053	0.037	0.002	1653	0.01	0.0024	0.46
	(-1.04)	(0.11)	(-1.39)	(-0.16)	(-0.14)	(2.87)	(1.55)	(1.17)	(0.09)				
KLM NYSE	0.060*	0.339*	0.141*	0.153*	0.104*	-0.240*	-0.140*	-0.060*	-0.082*		0.15	0.0020	
	(5.18)	(12.5)	(4.90)	(5.14)	(3.69)	(-8.37)	(-4.92)	(-2.27)	(-3.62)				
KPN AEX	-0.012	0.029	0.067*	0.109*	0.036	-0.026	-0.060	-0.029	-0.012	1563	0.01	0.0021	0.33
	(-0.92)	(0.94)	(2.04)	(3.27)	(1.06)	(-0.76)	(-1.68)	(-0.83)	(-0.36)				
KPN NYSE	0.079*	0.242*	0.184*	0.131*	0.102*	-0.253*	-0.164*	-0.083*	-0.042		0.17	0.0017	
	(7.64)	(9.82)	(6.96)	(4.86)	(3.73)	(-9.13)	(-5.68)	(-2.96)	(-1.61)				
Philips AEX	-0.041*	0.118*	124*	0.088*	0.081*	0.108*	-0.072	0.022	-0.036	1588	0.06	0.0023	0.59
	(-2.45)	(3.31)	(2.99)	(2.10)	(2.02)	(2.50)	(-1.58)	(0.51)	(0.95)				
Philips NYSE	0.047*	0.439*	0.245*	0.157*	0.102*	-0.190*	-0.207*	-0.117*	-0.013		0.23	0.0017	
	(3.84)	(16.6)	(8.01)	(5.06)	(3.47)	(-5.91)	(-6.15)	(-3.65)	(0.45)				
Royal Dutch AE	-0.078*	-0.030	-0.016	0.043	-0.018	0.119*	-0.011	-0.023	0.004	1759	0.03	0.0021	0.74
	(-5.26)	(-0.77)	(-0.38)	(1.00)	(-0.45)	(2.87)	(0.25)	(-0.55)	(0.11)				
Royal Dutch NY	-0.001	0.355*	0.189*	0.147*	0.004	-0.251*	-0.244*	-0.119*	-0.020		0.07	0.0019	
	(-0.08)	(10.2)	(4.93)	(3.85)	(0.11)	(-6.79)	(-6.33)	(-3.19)	(-0.61)				
Unilever AEX	-0.049*	0.063	0.100*	0.072	0.068	0.131*	0.002	0.021	0.015	1675	0.06	0.0018	0.64
	(-4.71)	(1.72)	(2.55)	(1.76)	(1.74)	(3.26)	(0.04)	(0.48)	(0.40)				
Unilever NYSE	-0.010	0.303*	0.170*	0.090*	0.087*	-0.218*	-0.168*	-0.069	-0.040		0.06	0.0015	
	(-1.15)	(9.87)	(5.14)	(2.63)	(2.63)	(-6.43)	(-4.68)	(-1.90)	(-1.26)				

*: Significant at a 95% significance level

This table summarises the results of Vector Autoregressive Model (VAR) estimations based on five minute midquote returns for the one hour period of simultaneous trading in Amsterdam and New York. Midquotes are based on best bid ask quotes on both the Amsterdam Stock Exchange and the New York Stock Exchange from July 1, 1997 until and including June 30, 1998.

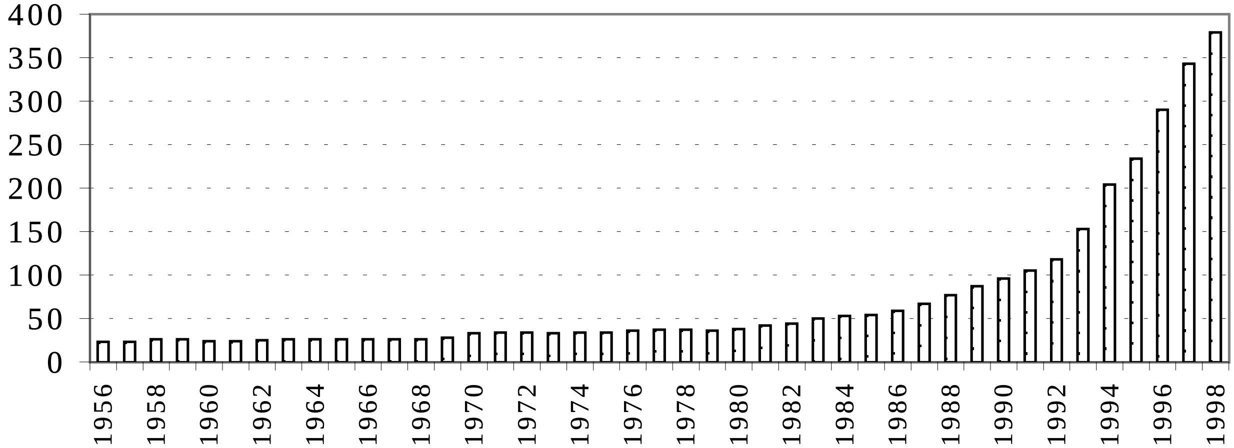
Table 5: Long Term Contribution to Price Discovery Process

	Long Term Effect (LTE) of a Unit Impulse		Time Needed to Incorporate Half the LTE		Information Share	
	Unit Impulse AEX	Unit Impulse NYSE	NYSE responding to AEX	AEX responding to NYSE	AEX	NYSE
Aegon	0.8	0.6	10 min	50 min	39 - 89	11 - 61
Ahold	1.2	0.0	20 min	NR	89 - 100	0 - 11
KLM	0.9	0.2	10 min	NR	66 - 98	3 - 34
KPN	1.0	0.1	15 min	NR	81 - 99	1 - 19
Philips	0.9	0.8	5 min	65 min	30 - 88	12 - 70
Royal Dutch	0.0	1.1	NR	70 min	0 - 54	46 - 100
Unilever	-0.3	1.4	NR	75 min	4 - 21	79 - 96

NR: not relevant, since long term effect to a unit impulse is negligble.

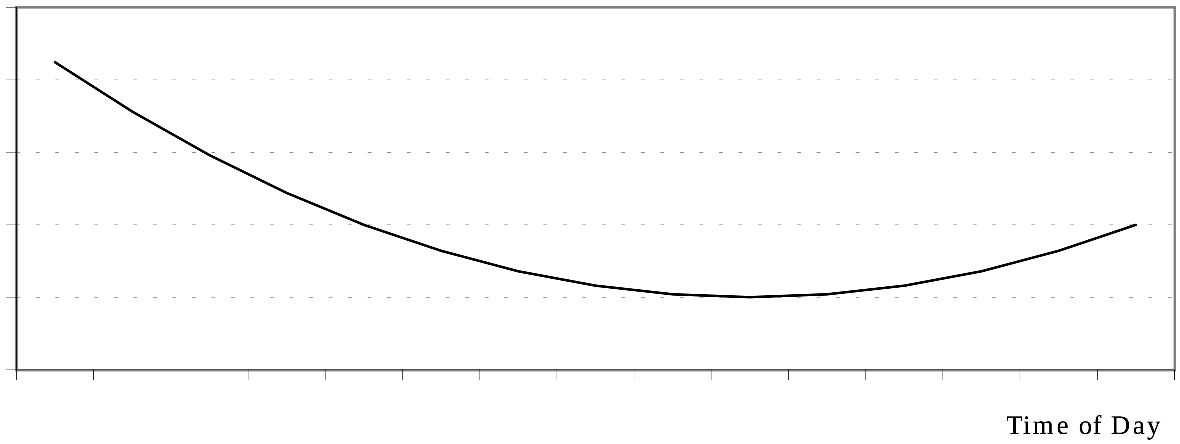
This table documents (i) the long term effect of a unit impulse in the midquote on both exchanges, (ii) the adjustment rate of the other exchange to this impulse and (iii) the information share of each of the exchanges.
(i) The long term effect is the contribution of a unit impulse to the common efficient price.
(ii) The adjustment rate is defined as the time needed by the other exchange to incorporate half of the long term effect.
(iii) The last four columns contain intervals that include the information share of each exchange in the overlapping trading hour. The metric 'information share' is developed in Hasbrouck (1995). It is defined as the proportional contribution of a market's innovations to the innovation in the common efficient price.
The long term effect, adjustment rate and information share are calculated based on Vector Autoregressive Model (VAR) estimations for five minute midquote returns. Midquotes are based on best bid ask quotes on both the Amsterdam Stock Exchange and the New York Stock Exchange from July 1, 1997 until and including June 30, 1998.

Figure 1: Non-US companies listed at the New York Stock Exchange

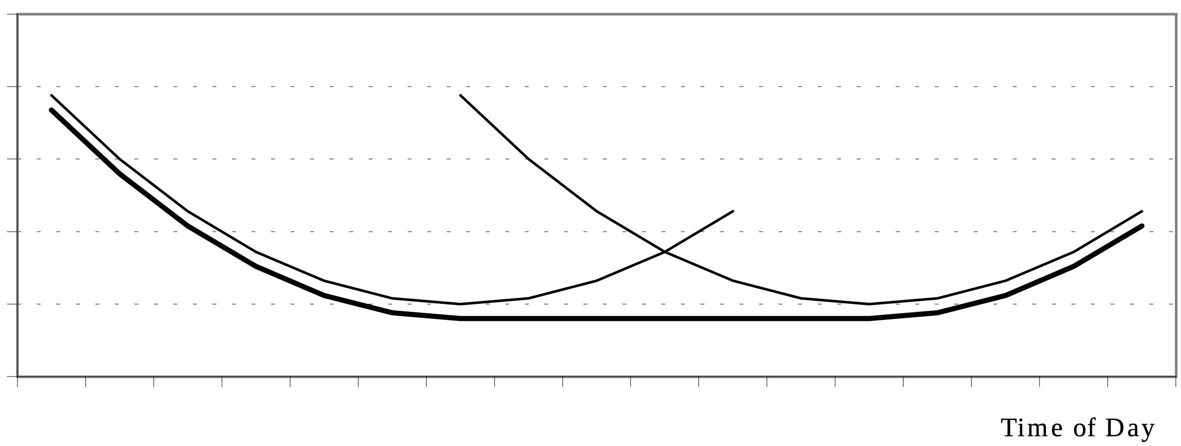


This graph depicts the number of non-US companies with common stock listed on the NYSE from 1956 through 1998. Soure: NYSE

Figure 2: Stylized Intraday Pattern

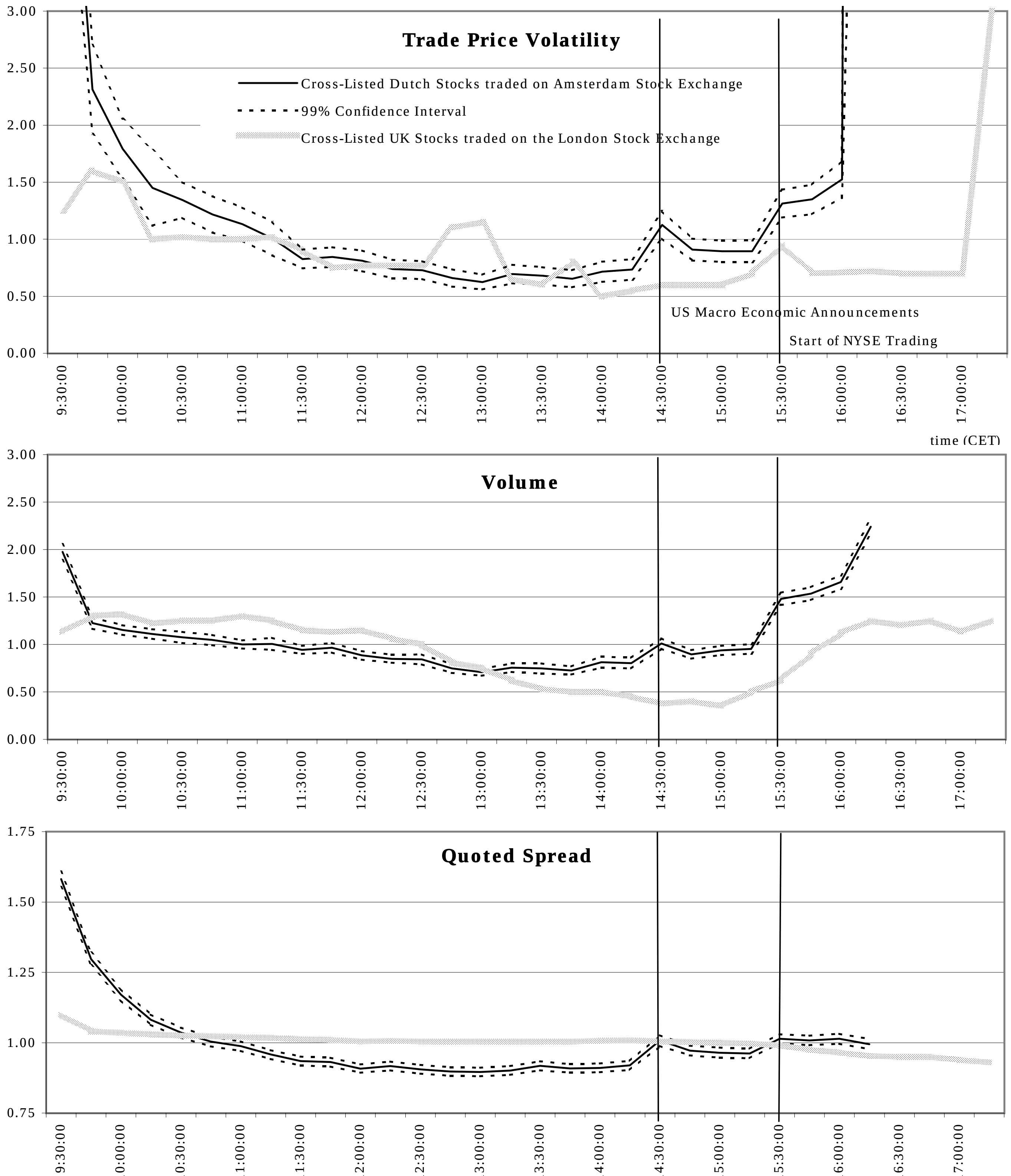


The thick solid black line traces out the stylized U-shape pattern for volatility, trading volume, and percentage quoted and effective spreads.



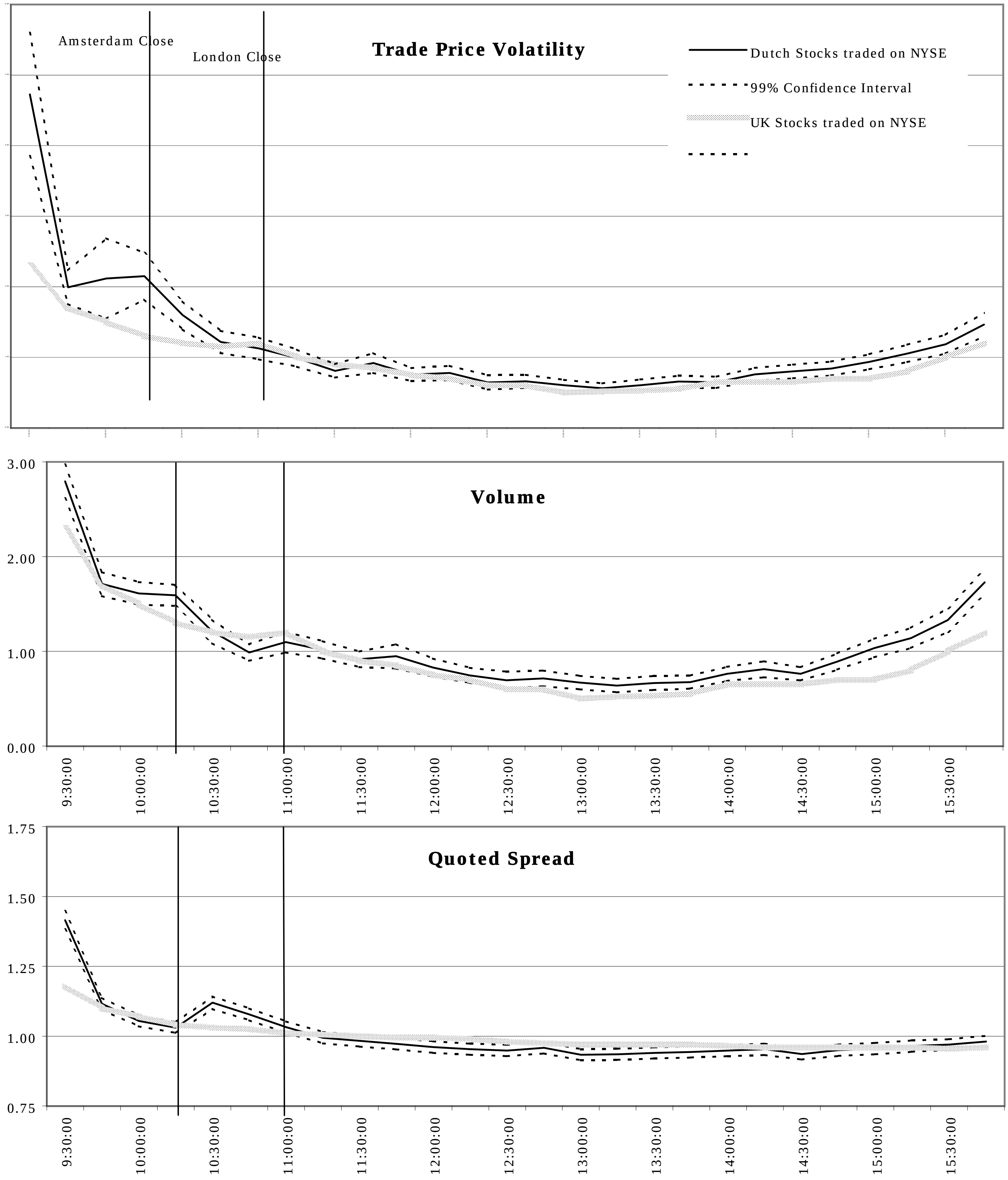
The thick solid black line traces out the elongated U-shape that is the predicted intraday pattern for volatility, trading volume, percentage quoted and effective spreads under the hypothesis that Amsterdam and New York trading of Dutch cross-listed stocks is perfectly integrated. The thin solid black lines trace out two U-shaped curves that represent the predicted intraday patterns for each market under the alternative hypothesis that trading of Dutch cross-listed stocks is not perfectly integrated.

Figure 3a: Intraday Patterns for Amsterdam Trading in Cross-Listed Dutch Stocks, Benchmark against London trading in similar UK Stocks



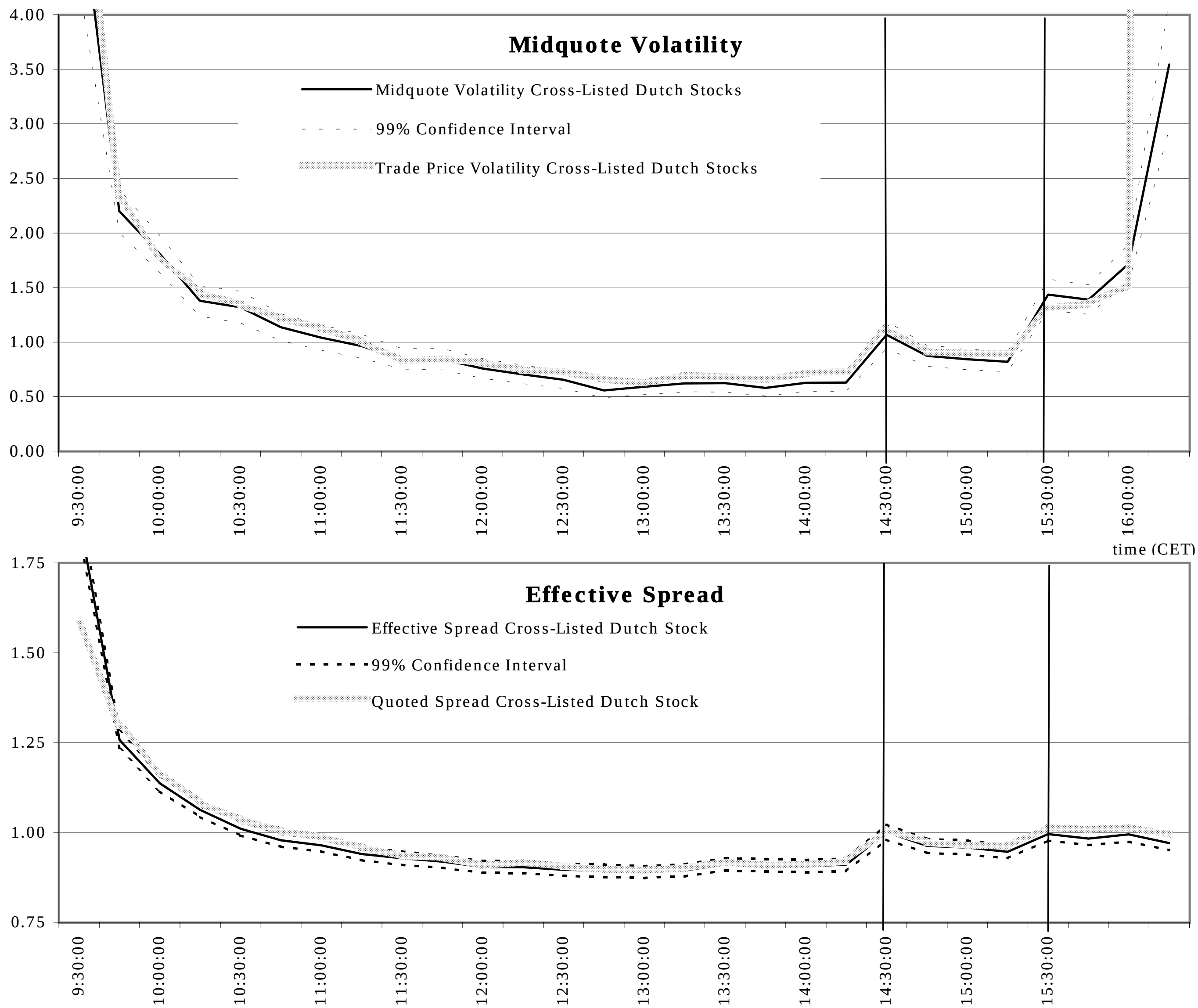
These figures depict the results of least squares regressions that establish the intraday patterns in trade price volatility, volume and quoted spread. The patterns are based on a pooled regression after making up for stock specific means through scaling. Intraday heteroskedasticity is allowed for through standard deviations that depend on the time of day. The results are compared to UK patterns that are taken from Werner and Kleidon (1996). The sample period runs from July 1st, 1997 to June 30th, 1998.

Figure 3b: Intraday Patterns for New York Trading in Dutch Stocks
Benchmark against New York Trading in similar UK Stocks



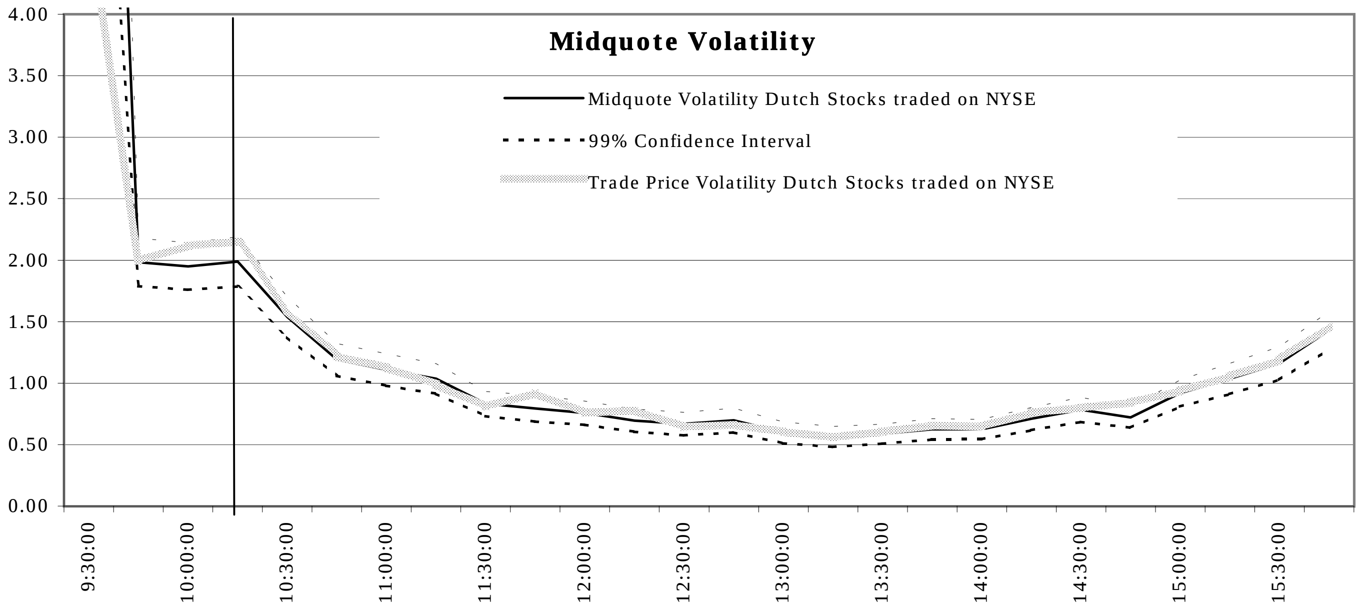
These figures depict the results of least squares regressions that establish the intraday patterns in trade price volatility, volume and quoted spread. The patterns are based on a pooled regression after making up for stock specific means through scaling. Intraday heteroskedasticity is allowed for through standard deviations that depend on the time of day. The results are compared to UK patterns that are taken from Werner and Kleidon (1996). The sample period runs from July 1st, 1997 to June 30th, 1998.

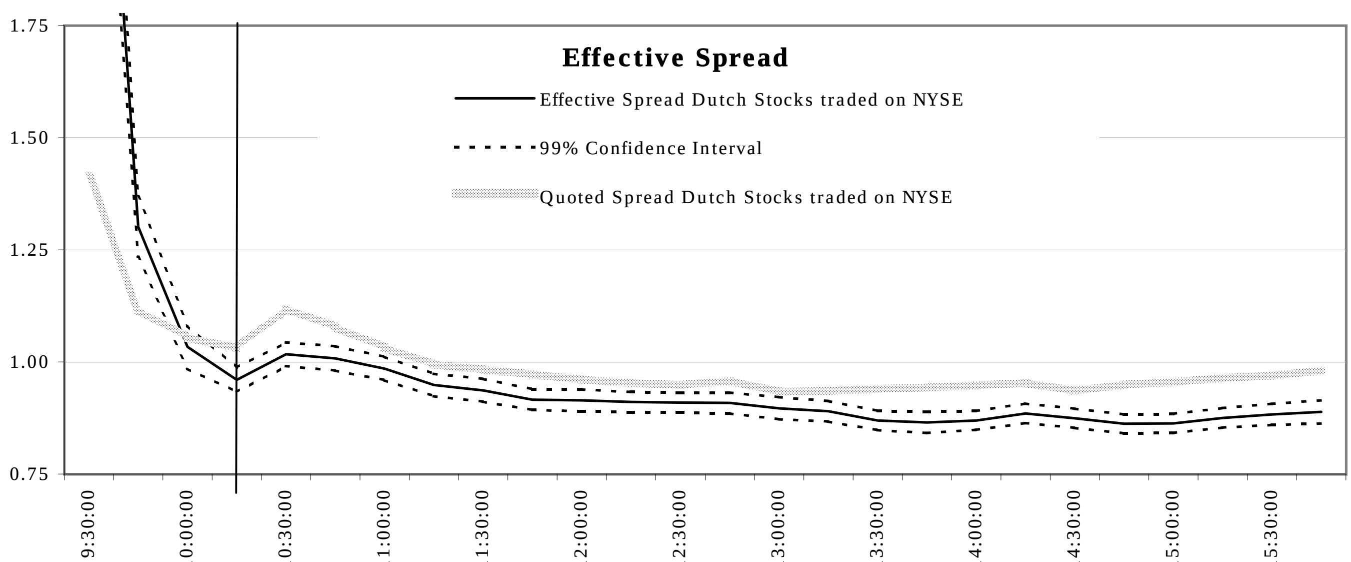
Figure 4a: Intraday Patterns for Amsterdam Trading for Cross-Listed Dutch Stocks: Improved Proxies for Volatility and Spread



These figures depict the results of least squares regressions that establish the intraday patterns in midquote volatility and effective spread. These are compared to the intraday patterns in trade price volatility and quoted spread which are reported in table 2. They are improved proxies for volatility and spread, since midquote volatility does not suffer from the bid-ask bounce and effective spread as opposed to quoted spread accounts for price improvement by traders. The patterns are based on a pooled regression after making up for stock specific means through scaling. Intraday heteroskedasticity is allowed for through standard deviations that depend on the time of day. The sample period runs from July 1st, 1997 to June 30th, 1998.

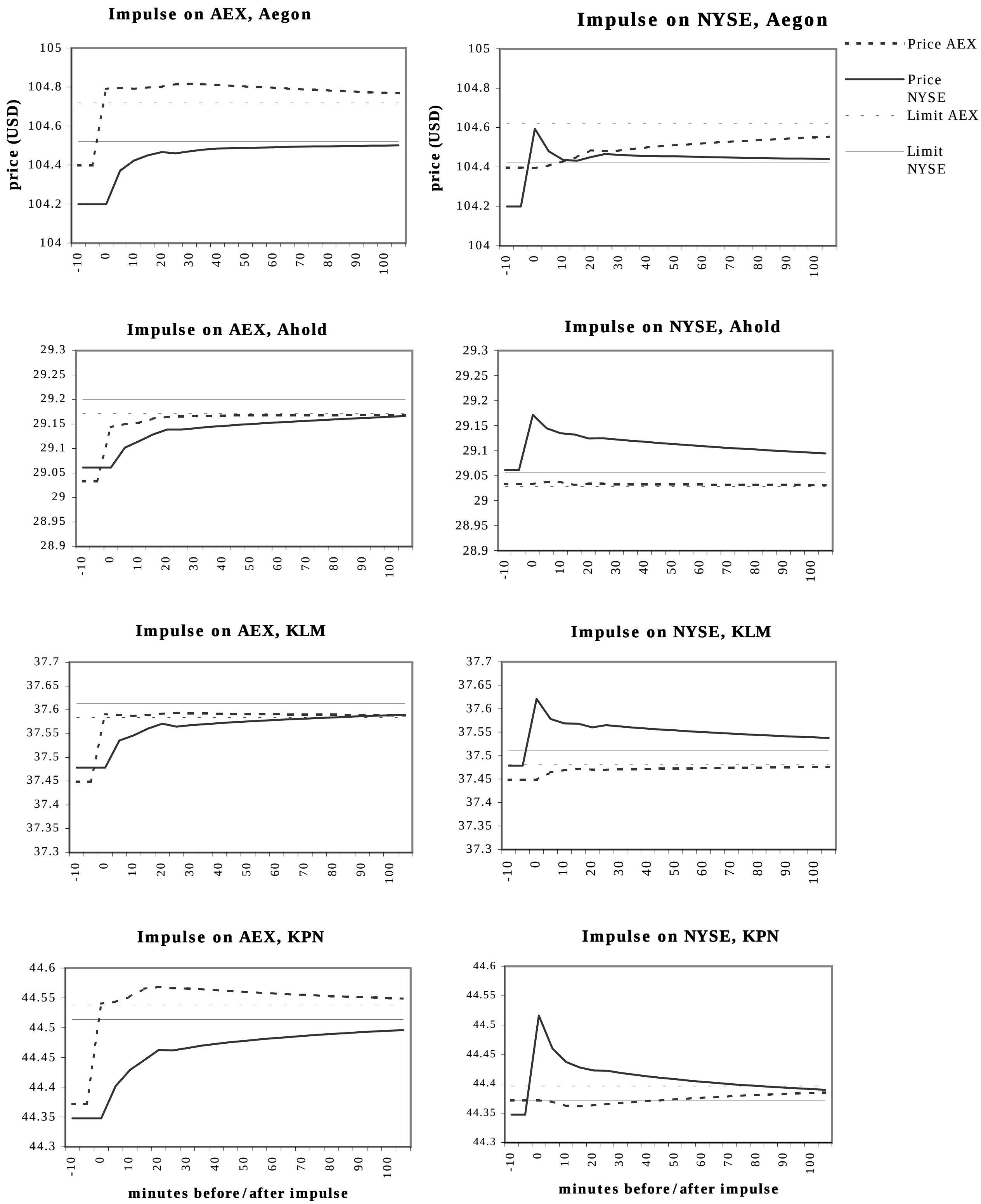
Figure 4b: Intraday Patterns for New York Trading in Cross-Listed Dutch Stocks: Improved Proxies for Volatility and Spread





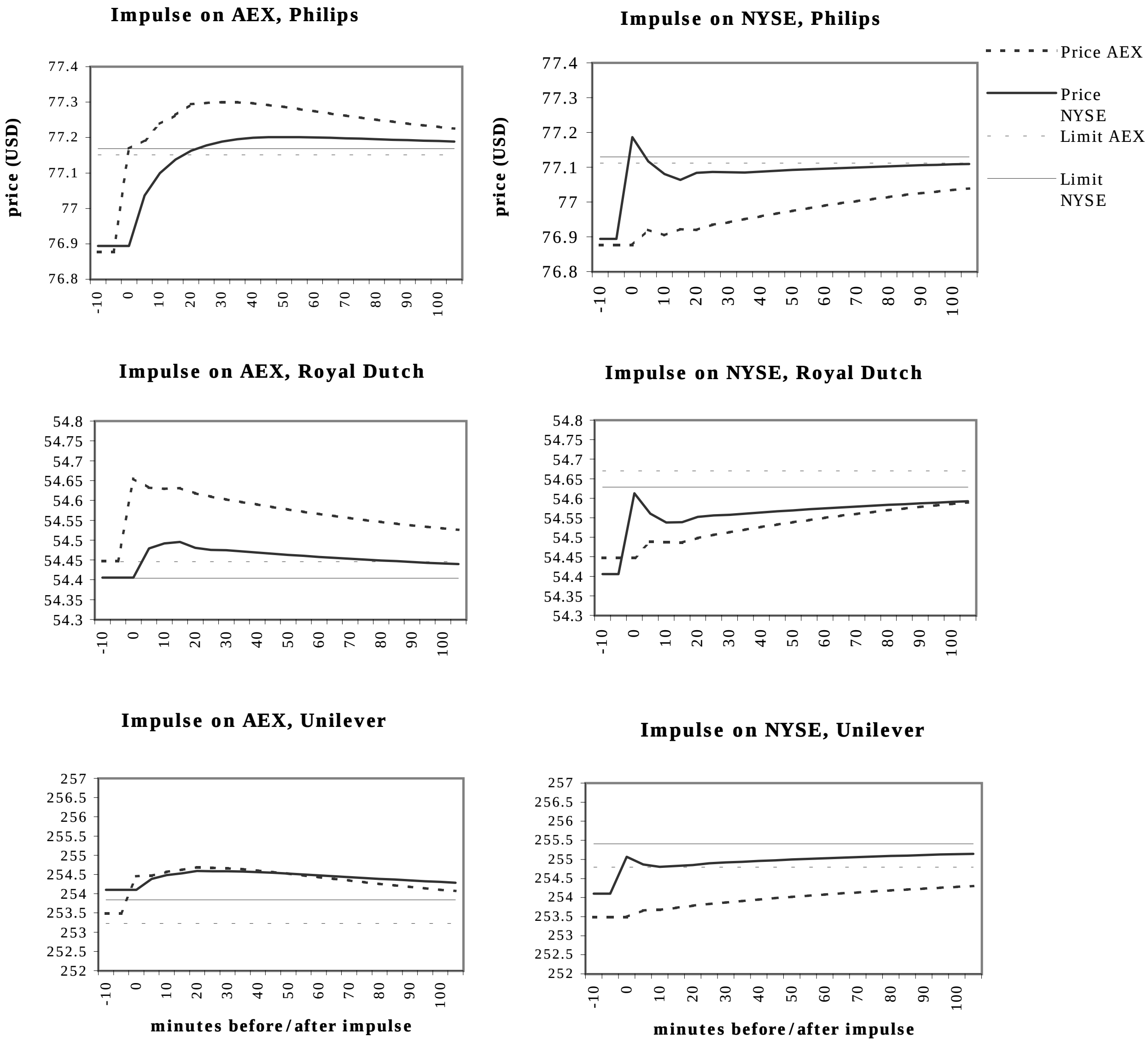
These figures depict the results of least squares regressions that establish the intraday patterns in midquote volatility and effective spread. These are compared to the intraday patterns in trade price volatility and quoted spread which are reported in table 2. They are improved proxies for volatility and spread, since midquote volatility does not suffer from the bid-ask bounce and effective spread as opposed to quoted spread accounts for price improvement by traders. The patterns are based on a pooled regression after making up for stock specific means through scaling. Intraday heteroskedasticity is allowed for through standard deviations that depend on the time of day. The sample period runs from July 1st, 1997 to June 30th, 1998.

Figure 5a: Impulse Response Functions for overlapping Trading Hour



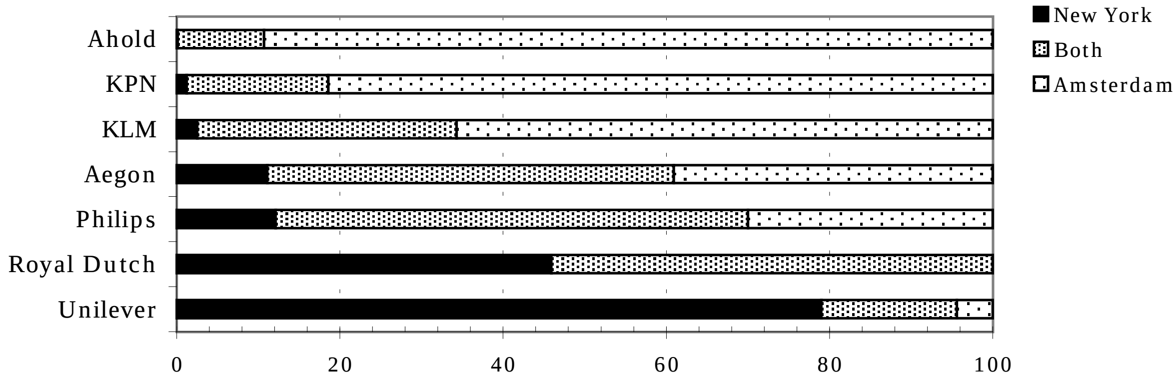
Impulse response functions show the average response to a unit shock in the midquote on one of the exchanges. The midquote value prior to the shock equals the average sample midquote in dollars. The functions are drawn based on Vector Autoregressive Model (VAR) estimates for five minute midquote returns. The sample is restricted to the one hour period of simultaneous trade in Amsterdam and New York. Midquotes are based on best bid ask quotes on both the Amsterdam Stock Exchange and the New York Stock Exchange from July 1, 1997 until and including June 30, 1998.

Figure 5b: Impulse Response Functions for overlapping Trading Hour



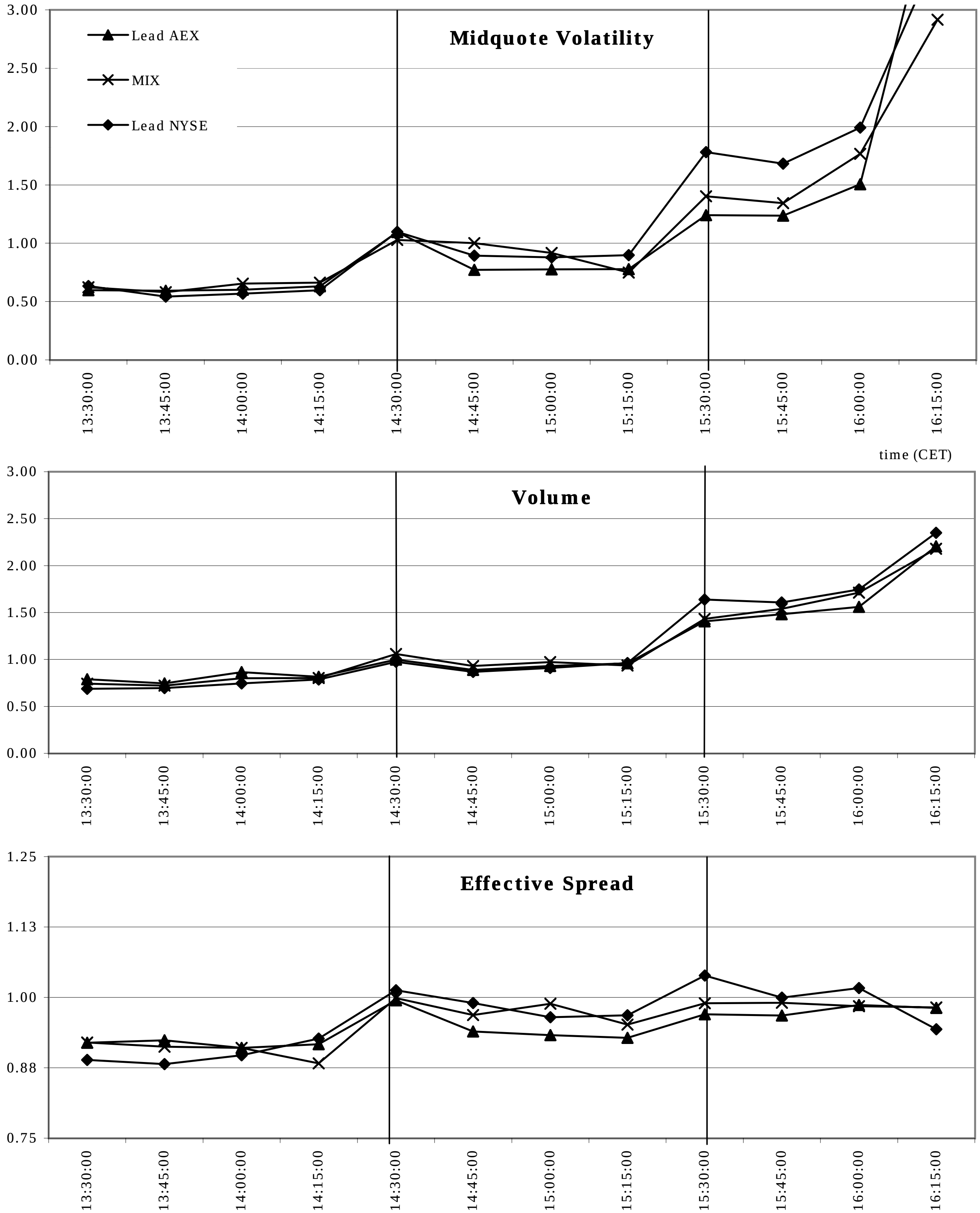
Impulse response functions show the average response to a unit shock in the midquote on one of the exchanges. The midquote value prior to the shock equals the average sample midquote in dollars. The functions are drawn based on Vector Autoregressive Model (VAR) estimates for five minute midquote returns. The sample is restricted to the one hour period of simultaneous trade in Amsterdam and New York. Midquotes are based on best bid ask quotes on both the Amsterdam Stock Exchange and the New York Stock Exchange from July 1, 1997 until and including June 30, 1998.

Figure 6: Information Shares for the overlapping Trading Hour



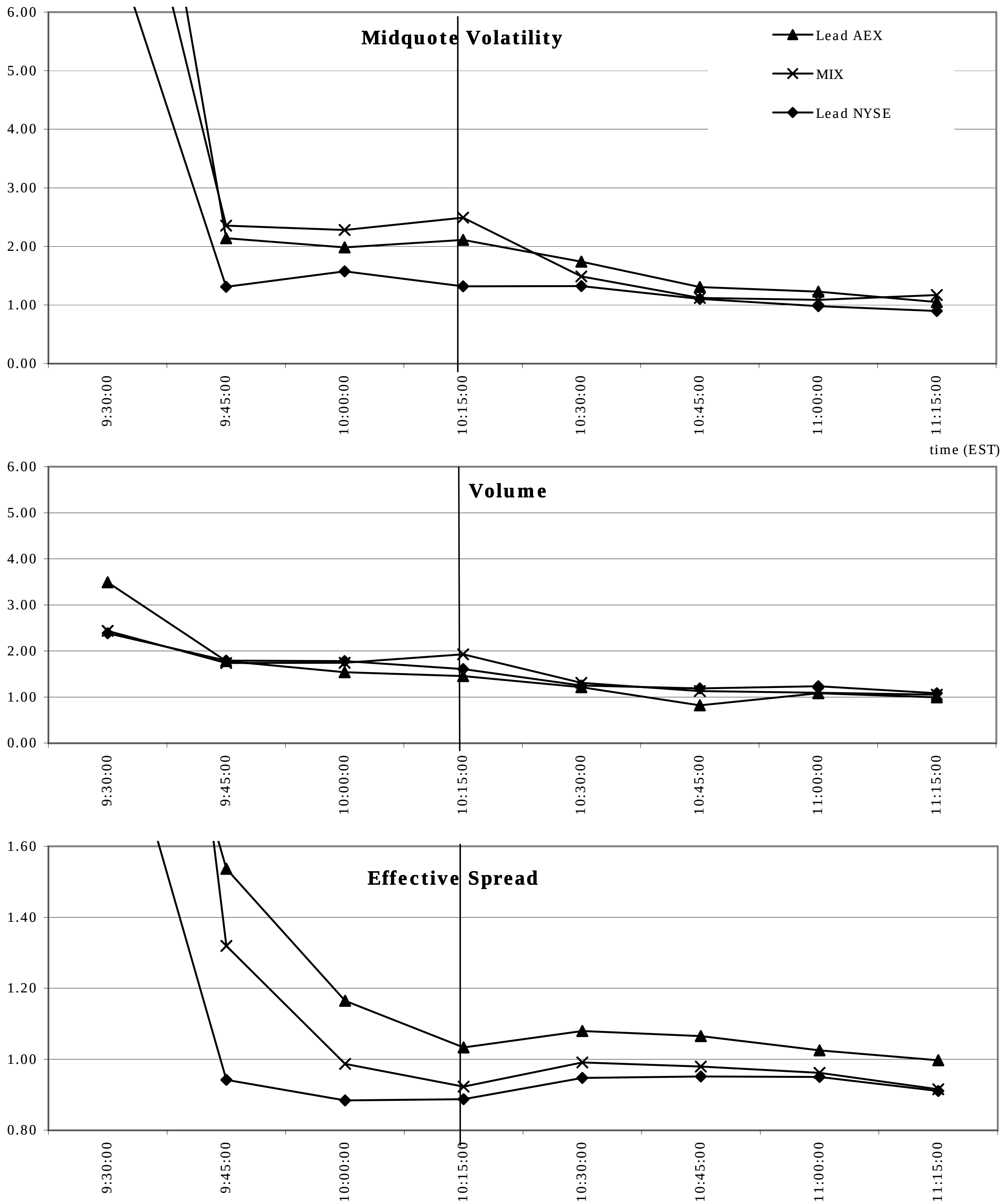
This figure depicts the information share of each exchange in the overlapping trading hour. The metric 'information share' is developed in Hasbrouck (1995). It is defined as the proportional contribution of a market's innovations to the innovation in the common efficient price. It is calculated using Vector Autoregressive Model (VAR) estimates for five minute midquote returns. Midquotes are based on best bid ask quotes on both the Amsterdam Stock Exchange and the New York Stock Exchange from July 1, 1997 until and including June 30, 1998.

Figure 7a: Intraday Patterns Amsterdam by Category



This figure summarises the results of least squares regressions that establish the intraday patterns in midquote volatility, volume and effective spread for three categories of stocks. The category of stocks clearly led by Amsterdam in the hour of trading overlap consists of Aegon, Ahold and KLM. The category of stocks with mixed results, both leads from Amsterdam and from New York, consists of Aegon and Philips. The final category consists of stocks that are clearly led by New York, Royal Dutch and Unilever. The time line refers to Central European Time (CET). The sample runs from July 1st, 1997 to June 30th, 1998.

Figure 7b: Intraday Patterns New York by Category



This figure summarises the results of least squares regressions that establish the intraday patterns in midquote volatility, volume and effective spread for three categories of stocks. The category of stocks clearly led by Amsterdam in the hour of trading overlap consists of Aegon, Ahold and KLM. The category of stocks with mixed results, both leads from Amsterdam and from New York, consists of Aegon and Philips. The final category consists of stocks that are clearly led by New York, Royal Dutch and Unilever. The time line refers to Central European Time (CET). The sample runs from July 1st, 1997 to June 30th, 1998.