ELSEVIER

Journal of Financial Markets 5 (2002) 57–82

Journal of FINANCIAL MARKETS

www.elsevier.com/locate/econbase

Intraday analysis of market integration: Dutch blue chips traded in Amsterdam and New York☆

Erik C.J. Hupperets[a], Albert J. Menkveld[b,*]

[a] HAL Investments B.V., P.O. Box 2001, 3000 CA Rotterdam, The Netherlands
[b] Tinbergen Institute, Erasmus University Rotterdam, P.O. Box 1738, NL-3000 DR Rotterdam, The Netherlands

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 or New York. © 2002 Elsevier Science B.V. All rights reserved.

JEL classification: G1; G12; G14; G15

Keywords: Market integration; Cross-list; Stock; Intraday; Amsterdam; NYSE

☆Gratefully acknowledged is the support from the Tinbergen Institute, KLM Royal Dutch Airlines, the Rodney L. White Center at Wharton, the Graduate School of Business at Stanford University, the IIE for a Fulbright grant, the Amsterdam Exchanges and the NYSE. Financial support is gratefully acknowledged from the D.N. Chorafas Foundation, Fundatie van de Vrijvrouwe van Renswoude, Moret Fonds, Stichting Dr. Hendrik Muller's Vaderlandsch Fonds, Stichting Fonds voor de Geld- en Effectenhandel, Stichting Hoogeschool-fonds, Stichting Organisatie van Effectenhandelaren te Rotterdam. For comments on an earlier draft, we are indebted to Marshall Blume, Karoy Hornyak, Frank de Jong, Jantiene T. Klein Roseboom, Roy Kouwenberg, Bruce Lehmann, George Sofianos, David Stolin, Ton Vorst and an anonymous referee.

*Corresponding author. Tel.: +31-10-408-8900; fax: +31-10-408-9031.

E-mail address: menkveld@few.eur.nl (A.J. Menkveld).

PII: S1386-4181(01)00019-2

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 June 1998. Included are two of the three stocks studied by Froot and Dabora (1999): Royal Dutch and Unilever. This paper 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 a stock, still relatively little is known about what happens afterwards when the stock is trading in a normal or "mature" way 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 a result the number of non-US companies listed at the NYSE has more than quadrupled over the last decade to 394 at the end of 1999. 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. The Dutch data set is tailored to a 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.

The Amsterdam stock exchange and the NYSE are both continuous, consolidated auction markets in the terminology proposed by Madhavan (2000). The main difference, however, is that the New York market is a hybrid market in the sense that it has both floor trading and electronic orders, whereas Amsterdam is a pure electronic market. These markets 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.

1.1. Indirect assessment of market integration

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 primarily 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.

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 for a single market as the best known stylised fact. This finding is the basis of an intuitive test on market integration. If an asset is traded in two markets that overlap in time then there is continued trading from the first market open to the last market close. If these markets are to be regarded as one market the intraday patterns for this trading period should have the U-shape. This hypothesis is depicted in Fig. 1. This idea was developed in Werner and Kleidon (1996) and the results rejected market integration for UK stocks cross-listed at the NYSE. Using the same approach based on the current dataset adds to academic debate since it generates evidence for both a different European market and a more timely dataset, 1997–1998 as opposed to 1991.

The empirical evidence for Dutch cross-listed stocks rejects the hypothesised market integration. In this respect the results do not differ from the Werner and Kleidon results. There are, however, two important differences. First, the shape of the patterns differs. For volatility and volume intraday jumps occur at the same time for both samples but are larger and more clear-cut for the current sample. For spreads the current sample shows significant intraday jumps that cannot be discerned in the Werner and Kleidon sample. The results for the current sample are consistent with strong price discovery due to increased informed trading for the overlapping hour. Second, whereas the London market in 1991 appears to be unaffected by macro-economic announcements one hour prior to the actual New York open, the Amsterdam market five years later clearly is affected. Volatility, for example, jumps by more than 50%! This is consistent with previous studies that show that news

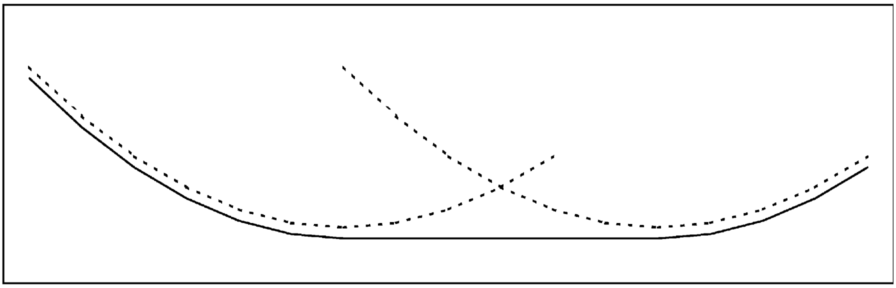


Fig. 1. Stylized intraday pattern. The solid line traces out the elongated U-shape that is the predicted intraday pattern for volatility, volume and spread under the hypothesis that Amsterdam and New York trading of Dutch cross-listed stocks is perfectly integrated. The dashed lines trace out two U-shape 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.

affecting the US market also affects other global markets, but not vice versa (e.g., Lin et al., 1991).

1.2. Direct assessment of market integration

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? 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 price series are indeed cointegrated for all shares. Interestingly, results on the origin of information are mixed. Some stocks are clearly driven by Amsterdam in the overlapping trading hour, which means that information primarily originates in the Dutch market, others appear to be driven by New York.

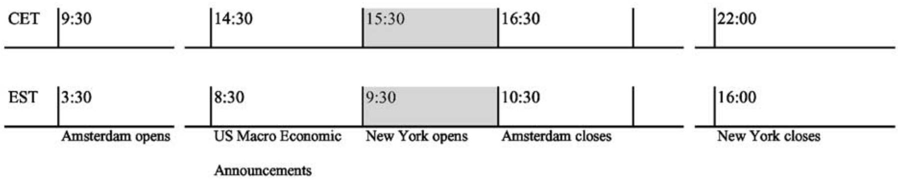
The results of both the indirect and the direct test on market integration can be reconciled by arguing that both markets cannot be viewed as one market open from 9:30 CET to 16:00 EST but are highly integrated when it comes to price discovery during the hour of trading overlap. The latter result appears to contradict the results reported by Froot and Dabora. They report up to 35% price differences for "twin" stocks trading in different markets. As opposed to the results documented in this paper, these differences do not disappear during synchronous trading in both markets. The key to understand these different results is in the arbitrage mechanism. Although "twin" stocks are claims on the *same* set of cash flows, they are not interchangeable. An arbitrage strategy therefore consists of buying the cheap claim and selling the expensive one and keeping this portfolio forever. This strategy is not feasible since it requires infinite horizons. Any real world arbitrageur has a finite horizon and since prices might drift further apart in any finite horizon this strategy is inherently risky. The only type of investor that could profit from this price difference is the long-term investor interested in the stream of future dividends. He will buy in the "cheaper" market. The resulting upward pressure in the price of the "cheaper" market is, apparently, too weak to drive the price difference to zero. The claims studied in this paper, however, are interchangeable. The "derivative" claim trading in New York, whether it is an ADR or a NY registered share, can be changed for the original share and vice versa at the Depositary Bank for a relatively small fee. If price differences exceed this fee and both markets are easily accessible an arbitrage strategy consists of buying in the "cheap market" and selling in the "expensive market" and changing the share at the Depository Bank to meet settlement. The horizon now is finite, relatively short and this strategy is therefore feasible. A more elaborate treatment of arbitrage mechanisms with reference to a.o. Froot and Dabora (1999) can be found in Shleifer (2000).

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 concludes the paper with a brief discussion of the results.

2. The setting: Amsterdam and New York

The volume of trading in non-US shares grew to more than 15% of total NYSE volume in 1999. European shares accounted for most of this volume, approximately one third. Amongst European shares, UK shares generated most NYSE volume and Dutch shares are second generating more volume than French and German shares combined.

The dataset used in this study consists of 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, daylight savings time in the Netherlands started one week before the US. This implies that there is no trading overlap from March 30 to April 3, 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 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. Based on this measure differences shrink and for some stocks New York spreads 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. In addition, relative midquote differences were calculated for this hour after converting NYSE midquotes to Dutch guilders using intraday exchange rates. Table 1 reports the maximum difference throughout the sample. It appears to be less than 4% for all stocks, contrasting sharply with differences of up to 35% reported by Froot and Dabora (1999).

Following Werner and Kleidon (1996) 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 $\omega_{s,d}$:

$$Y_{s,d,t} \equiv \frac{X_{s,d,t}}{\hat{\omega}_{s,d}}. \tag{1}$$

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

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

The intraday patterns are incorporated in the α vector, $I^j(t)$ takes the value one if $j = t$ and zero otherwise. The error term $\varepsilon_{s,d,t}$ is identically and independently distributed with zero mean and unit variance. By construction, the intraday variance is allowed to be heteroskedastic and is reflected in the σ vector. Heteroskedasticity was found by Werner and Kleidon and was arguably due to the U-shape pattern. 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

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
Percentage of total[a]		1%	2%	20%	3%	21%	40%	34%
Market Cap. (NLG bn)[a]		105	2	2	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, $N = 7,308$ for AEX, $N = 6,786$ for NYSE[b]						
		Aegon	Ahold	KLM	KPN	Philips	R. Dutch	Unilever
Trade price volatility[c] (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[c] (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

Trading statistics overlapping hour, $N = 1{,}044$[b]

		Aegon	Ahold	KLM	KPN	Philips	R. Dutch	Unilever
Trade price volatility[d] (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[d] (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 (number of shares)	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
Maximum midquote difference (%)[e]		2.6	3.6	3.8	2.8	1.2	1.3	1.5

[a] As per 1/1/98.

[b] Valid for volume and spread, less observations for volatility because first and last fifteen minutes were excluded.

[c] The first and last fifteen minutes of trading have been excluded because of extreme volatility.

[d] 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.

[e] Midquotes calculated for five minute intervals, NYSE midquotes were converted to Dutch guilders using intraday exchange rates.

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 through June 30, 1998. Variable definitions are to be found in the appendix.

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 sample for Amsterdam consists of 261 trading days or 7,308 fifteen-minute intervals. A seven stock sample thus yields 51,156 observations. The intraday patterns are depicted in Fig. 2a. Statistics on intraday jumps and drops can be found 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 Fig. 2a, it has the U-shape, although somewhat distorted. The first remarkable difference with a pure "U" is the sudden 53% jump in volatility at 14:30 CET. This 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 volatility jump is at 15:30 and amounts to 47%. Volatility then steadily increases and jumps to record levels at the close, i.e. more than 250 times the average volatility in the day. The 99% confidence intervals show that the jumps in volatility are statistically significant results in the sense that these intervals are small compared to the size of the change.

Compared to the pattern documented for London 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. The jump in volatility at the New York open is evidenced in both studies, whereas Amsterdam is unique in showing a volatility jump one hour prior to the New York open.

3.1.2. Volume

The intraday pattern for volume as measured by the total number of shares traded is depicted in the second graph in Fig. 2a. It resembles the volatility pattern: a U-shape with jumps at 14 : 30 and 15 : 30 and a record volume at the close. Both jumps, again, are statistically significant. Although the jump at 14 : 30 is relatively small, 26%, the jump at 15 : 30 is comparable in size with the volatility jump, 55%.

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 Fig. 2a 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%. Both jumps are statistically significant. The spreads in the last two hours of trading are 5–10% higher than the previous hours. These results indicate that market participants in Amsterdam are quoting more carefully to protect themselves against informed trading.

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.

3.2. New York trading in Dutch stocks benchmarked against UK stocks

The sample for New York consists of 261 trading days or 6,786 fifteen-minute intervals. A seven stock sample thus yields 47,502 observations. The intraday patterns are depicted in Fig. 2b. Statistics on intraday jumps and drops can be found in Table 2.

3.2.1. Trade price volatility

As can be seen in the first graph of Fig. 2b, 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 significant 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 at the New York

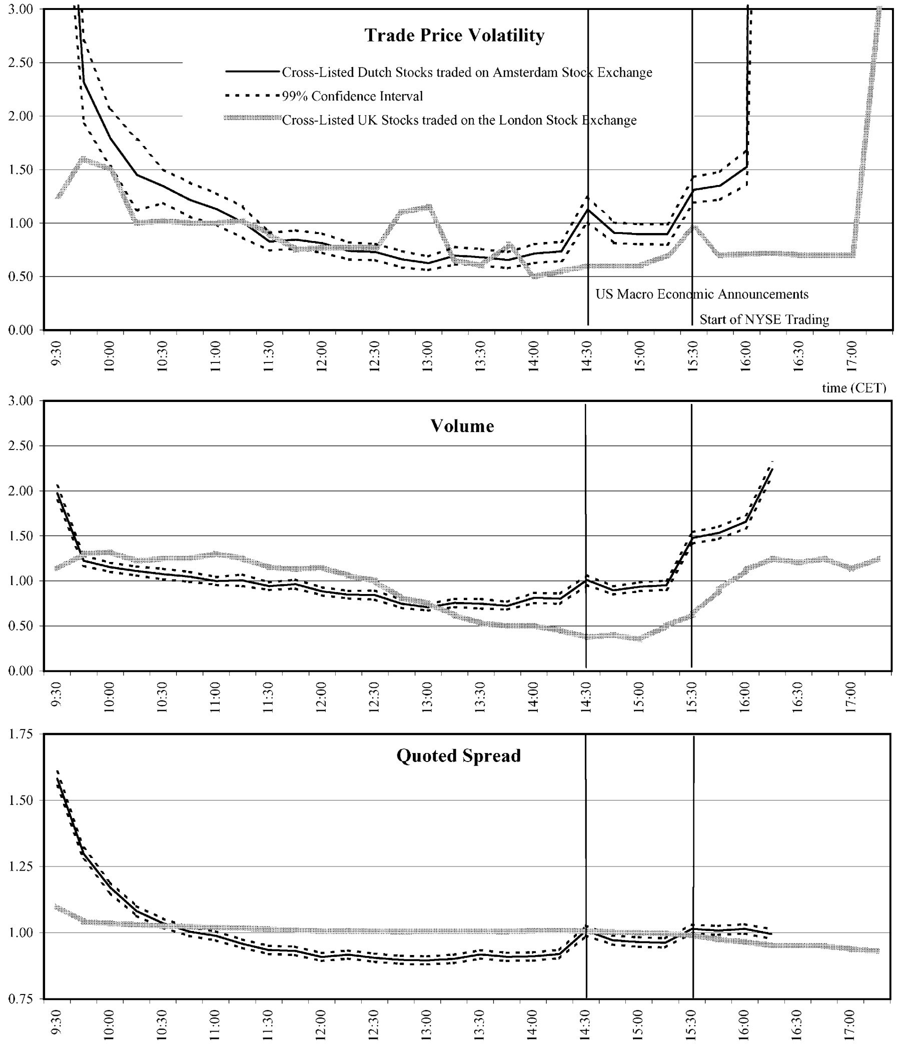


Fig. 2. (a) Intraday patterns for Amsterdam trading in cross-listed Dutch stocks. These figures depict the results of least squares regressions that establish the intraday patterns in trade price volatility, volume and quoted spread. The patterns are based on a pooled regression after making up for stock 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 1, 1997 through June 30, 1998.

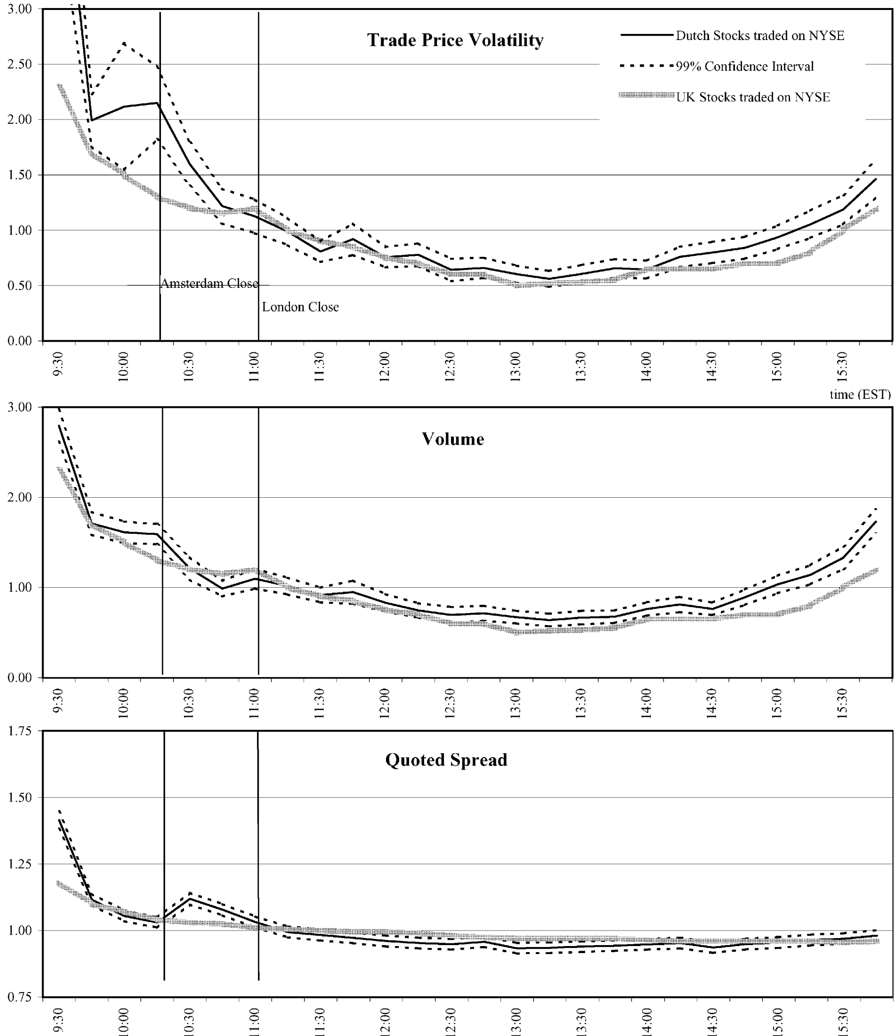


Fig. 2. (b) Intraday patterns for New York trading in Dutch stocks. These figures depict the results of least squares regressions that establish the intraday patterns in trade price volatility, volume and quoted spread. The patterns are based on a pooled regression after making up for stock specific 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 1, 1997 through June 30, 1998.

Table 2
Intraday jumps

Intraday jumps in Amsterdam								
	Macro-economic announcements					Benchmark (Werner and Kleidon, 1996)		
(CET)	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
Midquote 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)		
(CET)	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
Midquote 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)		
(EST)	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
Midquote 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, midquote 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 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 1, 1997 through June 30, 1998.

open 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. 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 jump immediately after the close.

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 Fig. 2b shows that the intraday volume pattern at the NYSE is similar in shape to the volatility pattern. The volume drops by a significant 24% at the time of the Amsterdam close. 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 "U" as can be seen from the third graph in Fig. 2b. The remarkable difference with the Werner and Kleidon pattern for UK stocks is the significant 9% jump in spreads upon the close of trading in Amsterdam. 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 a level even below the overlapping hour level 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. Apparently, such downward pressure 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. 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.

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 that create a stronger bid–ask bounce effect. An improved proxy for volatility is midquote volatility since it does not suffer from such bounce. 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 at less favourable bid prices. Second, trades might take place within the bid–ask spread, because both buyer and seller might give up some margin to establish a trade. These are the main reasons for studying the ex-post effective spread which is defined as twice the difference between the trade price and the midquote.

The intraday patterns for the improved proxies for volatility and spread are calculated and compared to the Werner and Kleidon proxies. The results show that these patterns are not significantly different at a 99% confidence level. This result strengthens confidence in the results documented in the previous sections.

The size and significance of intraday jumps for these proxies are tabulated in Table 2. The concern that trade price volatility jumps in Amsterdam are biased upwards is taken away since midquote volatility jumps are even larger. The volatility drop in New York is comparable in size for both proxies as are the spread jumps in Amsterdam. The effective spread jump in New York upon the Amsterdam close, however, is smaller than the quoted spread jump, 6% as opposed to 9%.

3.4. Impact of intraday exchange rate volatility

The intraday patterns for volatility are based on returns in Dutch guilders for Amsterdam and dollars for New York. The reason is that this makes results comparable to Werner and Kleidon (1996) that takes the same approach. The intraday patterns should nevertheless raise suspicion since they could be the result of an intraday pattern in exchange rate volatility. To address this issue the exchange rate volatility pattern was estimated for the sample period. Although higher exchange rate volatility in the period surrounding the overlap can account for some of the increased volatility, it can by no means account for the intraday patterns since it does not show any jumps throughout the 24-hour period.

3.5. 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 jumps are caused by the open or close of the other market. The results show they are, although the period is too short to find statistically significant results.

The results for Amsterdam and New York show that the null hypothesis of market integration has to be rejected since the intraday patterns for volatility, volume and spread have U-shapes for each market instead of a U-shape for the "aggregate" market.

4. Price discovery in the overlapping trading hour

The Amsterdam and New York market do not behave as one market open from the Amsterdam open to the New York close. 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. 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 during the overlap and if price discovery is integrated, arguably the most interesting question is: in which market does this new, private information originate? Hasbrouck (1995) proposes an error correction model that 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 denser 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 New York quote series are translated into Dutch guilders using intraday exchange rates.

Dickey Fuller tests show that both markets are integrated for each stock, since the midquote series are cointegrated of order one at a 99% confidence level. In other words, the midquote series are integrated of order one and the cointegrating relation, which is the difference between midquotes in Amsterdam and New York, is stationary.

To study 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 0.35 to 0.73. This shows that prices in both markets move in lockstep during the

Table 3
Correlations midquote returns during overlaping trading hour

	Aegon	Ahold	KLM	KPN	Philips	Royal Dutch	Unilever
Autocorrelations							
AEX							
5 min	0.055*	0.089*	−0.011	0.006	0.081*	0.025	−0.010
10 min	0.008	−0.022	0.026	0.006	0.064*	−0.044	−0.017
15 min	0.038	0.031	0.034	0.079*	0.055*	0.016	0.030
20 min	1.778	1.750	−0.025	0.005	0.070*	−0.005	0.056*
NYSE							
5 min	−0.018	−0.014	−0.076*	−0.063*	0.119*	0.027	−0.007
10 min	−0.025	−0.040	−0.068*	−0.020	−0.021	−0.084*	−0.056*
15 min	0.066*	−0.021	−0.011	0.000	−0.013	−0.039	0.004
20 min	0.003	−0.095*	0.022	0.032	0.066*	−0.021	0.029
Contemporaneous correlations							
0 lags	0.491*	0.353*	0.346*	0.342*	0.605*	0.727*	0.626*
Cross correlations							
NYSE lagged							
5 min	0.013	0.034	0.174*	−0.012	0.136*	0.091*	0.073*
10 min	0.014	0.035	−0.047	−0.036	0.045	−0.022	−0.008
15 min	0.036	−0.058*	0.013	0.012	0.057*	−0.018	0.037
20 min	0.115*	0.004	0.021	−0.029	0.020	−0.003	0.059*
AEX lagged							
5 min	0.312*	0.303*	0.120*	0.262*	0.345*	0.121*	0.155*
10 min	0.051*	0.087*	0.048	0.131*	0.054*	−0.048	−0.017
15 min	0.112*	0.026	0.041	0.050	0.012	−0.026	−0.003
20 min	0.034	0.038	0.040	0.021	0.044	−0.037	0.046
n	1,568	1,385	1,596	1,211	1,617	1,631	1,651

*: 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 through June 30, 1998. The New York quotes have been converted to Dutch guilders using intraday exchange rates.

hour of overlap. The significantly positive cross-correlations with either the AEX or the NYSE lagged five minutes are evidence of potential lagged response to price changes on the other exchange. First order autocorrelations are also significant but often 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 appears to be 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

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

The stationarity assumptions necessary for the application of this model are met since the midquote series are cointegrated of order one.

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 Aegon, Ahold, KPN and Philips the error correction term is significantly positive for New York returns, which implies that New York adjusts to midquote differences with Amsterdam. For KLM both Amsterdam and New York adjust to 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:

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

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

Table 4
Vector error correction results

	$(P_{\mathrm{AEX}} - P_{\mathrm{NYSE}})$	AEX lags (min) −5	−10	−15	−20	NYSE lags (min) −5	−10	−15	−20	n	R^2	σ^2	$\rho(\varepsilon_{\mathrm{AEX}}, \varepsilon_{\mathrm{NYSE}})$
Aegon AEX	−0.039	0.096*	0.008	0.004	−0.022	−0.077	0.009	0.046	0.127*	1,191	0.02	0.0019	0.55
	(−1.41)	(2.34)	(0.19)	(0.09)	(−0.54)	(−1.80)	(0.20)	(1.15)	(3.95)				
Aegon NYSE	0.113*	0.337*	0.124*	0.115*	0.051	−0.226*	−0.135*	−0.006	−0.013		0.19	0.0015	
	(5.00)	1.77778	1.75	(3.25)	(1.57)	(−6.37)	(−3.90)	(−0.18)	(−0.48)				
Ahold AEX	0.003	0.106*	−0.011	0.069	0.011	0.012	0.037	−0.059	0.004	1,061	0.02	0.0025	0.39
	(0.17)	(2.89)	(−0.30)	(1.77)	(0.29)	(0.31)	(0.98)	(−1.60)	(0.12)				
Ahold NYSE	0.104*	0.298*	0.096*	0.090*	0.062	−0.117*	−0.102*	−0.043	−0.100*		0.20	0.0022	
	(6.15)	(9.33)	(2.86)	(2.64)	(1.91)	(−3.57)	(−3.06)	(−1.35)	(−3.37)				
KLM AEX	−0.056*	−0.059	0.025	0.006	−0.053	0.231*	−0.009	0.042	0.042	1,200	0.08	0.0022	0.44
	(−2.77)	(−1.64)	(0.66)	(0.18)	(−1.43)	(6.86)	(−0.27)	(1.30)	(1.48)				
KLM NYSE	0.094*	0.186*	0.139*	0.106*	0.091*	−0.081*	−0.147*	−0.079*	−0.042		0.11	0.0019	
	(5.35)	(6.00)	(4.26)	(3.39)	(2.83)	(−2.80)	(−5.04)	(−2.87)	(−1.72)				
KPN AEX	−0.006	−0.019	0.087*	0.163*	0.069	−0.063	−0.134*	−0.059	−0.054	966	0.02	0.0021	0.39
	(−0.28)	(−0.49)	(2.09)	(3.87)	(1.61)	(−1.42)	(−2.92)	(−1.32)	(−1.40)				
KPN NYSE	0.145*	0.226*	0.164*	0.125*	0.035	−0.222*	−0.141*	−0.083*	−0.013		0.21	0.0017	
	(7.85)	(7.04)	(4.83)	(3.64)	(1.02)	(−6.14)	(−3.79)	(−2.29)	(−0.43)				
Philips AEX	−0.019	0.012	0.054	−0.002	0.048	0.146*	0.029	0.071	−0.010	1,178	0.04	0.0021	0.65
	(−0.54)	(0.25)	(1.10)	(−0.03)	(1.10)	(2.88)	(0.59)	(1.54)	(−0.25)				
Philips NYSE	0.123*	0.422*	0.266*	0.132*	0.119*	−0.202*	−0.193*	−0.103*	−0.034		0.20	0.0018	
	(4.10)	(10.22)	(6.28)	(3.18)	(3.16)	(−4.62)	(−4.50)	(−2.62)	(−1.02)				

Royal Dutch AEX	−0.137*	0.018	−0.019	0.049	−0.005	0.071	−0.015	−0.039	−0.011	1,318	0.03	0.0022	0.77
	(−3.99)	(0.35)	(−0.36)	(0.98)	(−0.11)	(1.40)	(−0.29)	(−0.81)	(−0.26)				
Royal Dutch NYSE	0.054	0.297*	0.123*	0.080	−0.048	−0.173*	−0.161*	−0.070	0.003		0.05	0.0021	
	(1.64)	(6.08)	(2.45)	(1.65)	(−1.07)	(−3.50)	(−3.22)	(−1.49)	(0.08)				
Unilever AEX	−0.090*	−0.070	−0.017	0.048	0.040	0.118*	0.010	−0.020	0.032	1,278	0.03	0.0016	0.69
	(−3.88)	(−1.68)	(−0.39)	(1.10)	(1.00)	(2.78)	(0.23)	(−0.48)	(0.85)				
Unilever NYSE	0.031	0.308*	0.177*	0.097*	0.082*	−0.224*	−0.182*	−0.094*	−0.039		0.06	0.0016	
	(1.35)	(7.47)	(4.06)	(2.25)	(2.04)	(−5.30)	(−4.22)	(−2.30)	(−1.05)				

*: Significant at a 95% significance level.

This table summarises the results of vector autoregressive (VAR) model estimates 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 through June 30, 1998. The New York quotes have been converted to Dutch guilders using the intraday exchange rates.

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 Aegon, Ahold, KPN and Philips show that unit impulses in Amsterdam are permanent in that the long-term impact is close to one. New York impulses for these stocks are temporary since the most part of the impulse is "corrected for". For Royal Dutch and Unilever the opposite is true, New York impulses are permanent and Amsterdam impulses are temporary. For KLM both unit impulses on Amsterdam and New York appear to have a permanent effect.

The transitional properties of the model are best explored by drawing impulse response functions for all seven stocks. Although not included in this paper, they are available from the authors upon request. 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 scale down 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 columns 3 and 4 in Table 5 show that in New York this takes fifteen minutes or less whereas in Amsterdam this takes up to forty minutes. 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 information. An immediate downward adjustment in New York supports this interpretation.

The information share of a market is defined in Hasbrouck (1995) as the proportional contribution of innovations in this market to the innovation in the common implicit price. As a result it cannot be pinned down to one number but can only be specified in terms of an interval. The lower and upper bound of this interval are tabulated in the last two columns of Table 5 and depicted in Fig. 3. The intervals are relatively wide largely due to 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. For Ahold and KPN more than 80% of the information can be attributed to Amsterdam. For Aegon, KLM and Philips Amsterdam contributes roughly half of the information, the other half

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	0.9	0.3	10 min	20 min	50–96	4–50
Ahold	1.2	0.0	15 min	NR	87–100	0–13
KLM	0.8	0.5	10 min	5 min	47–87	13–53
KPN	1.0	0.0	10 min	NR	82–100	0–18
Philips	1.3	0.2	10 min	NR	48–99	1–52
Royal Dutch	0.3	0.8	NR	25 min	4–77	23–96
Unilever	0.3	0.9	NR	40 min	4–67	33–96

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

This table documents (i) the long term effect of a unit impulse in the midquote, (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 (VAR) model 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 through June 30, 1998. The New York quotes have been converted to Dutch guilders using intraday exchange rates.

is primarily generated in both markets. For Royal Dutch and Unilever, however, Amsterdam contributes less then 5% whereas the contribution of New York is over 20%. This result is remarkable given that trading volume in New York during the overlap is smaller than volume in Amsterdam.

5. 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 answers 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. 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. The intraday patterns documented for Dutch stocks are smoother 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% 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% respectively and stay at the levels. As soon as the Amsterdam stock exchange closes, volatility and volume for the Dutch shares drop in New York by 26% and 24% respectively. Remarkable are the jumps in quoted and effective spread by 9% and 6% respectively. Apparently the competitive pressure, felt in New York during the hour of simultaneous trade with Amsterdam, eases. In the Werner and Kleidon study such drops existed for volatility and volume, 12% and 10% respectively, but not for spread.

Increased volume, volatility and spread during the overlapping hour suggests informed trading. The Hasbrouck (1995) model is used to zoom in

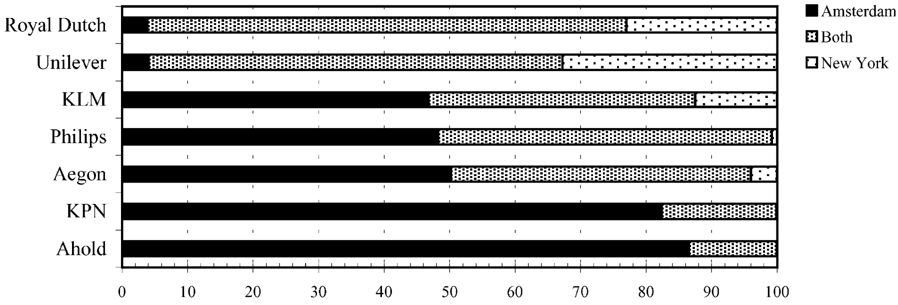


Fig. 3. Information shares for the overlapping trading hour. This figure depicts the information share of each exchange in the overlapping trading hour. The metric "information share" is developed in Hasbrouck (1995). It is defined as the proportional contribution of a market's innovations to the innovation in the common efficient price. It is calculated using vector autoregressive (VAR) model 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

on price discovery for this 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 higher for New York responding to Amsterdam than for 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 others it originates in New York more than in Amsterdam.

Appendix

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. Prices are in original currency, i.e. dollars for New York and Dutch guilders for Amsterdam.

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.

References

Froot, K.A., Dabora, E.M., 1999. How are stock prices affected by the location of trade? Journal of Financial Economics 53, 189–216.

Goodhart, C.A.E., O'Hara, M., 1997. High frequency data in financial markets: issues and applications. Journal of Empirical Finance 4, 73–114.

Hasbrouck, J., 1995. One security, many markets: determining the contributions to price discovery. Journal of Finance L (4), 1175–1199.

Lin, W.L., Engle, R.F., Ito, T., 1991. Do bulls and bears move across borders? International transmission of stock returns and volatility as the world turns. NBER Working Paper No. 3911.

Madhavan, A., 2000. Market microstructure: a survey. Journal of Financial Markets 3 (3), 205–258.

Roll, R., 1984. A simple implicit measure of the effective bid–ask spread in an efficient market. Journal of Finance 39 (4), 1127–1140.

Shleifer, A., 2000. Inefficient Markets: An Introduction to Behavioral Finance. Oxford University Press, Oxford.

Werner, I.M., Kleidon, A.W., 1996. UK and US trading of British cross-listed stocks: an intraday analysis of market integration. Review of Financial Studies 9 (2), 619–664.