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# Before and after international cross-listing: an intraday examination of volume and volatility

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**Abstract**

It is known that intraday financial asset price volatility and volume are described typically by volatility that is high near the morning market opening and high again near the afternoon market closing. If European markets are integrated with USA, then the European afternoon volatility and volume peak should decline for firms that are cross-listed in the United States. Using data on German firms listed in USA, we are able to examine the issue of intradaily volatility along with volume in a time-series setting both before and after the listing date. We find the general result that the intradaily volume and volatility curves flatten after cross-listing. Afternoon volatility and volume should flatten due to the opportunity to trade in an overlapping market and extend the trading day beyond the German closing. Morning volatility and volume in Germany should flatten since there are fewer hours of non-trading once American depositary receipt (ADR) trading begins so there is more opportunity for price discovery prior to the German opening. The evidence is consistent with an integrated global trading environment rather than two segmented markets. 

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## 1. Introduction

What happens in the home market when a foreign firm lists its stock to be traded in the United States? Home market trading volume might rise if there is a liquidity effect of the listing. Home market volume might fall if trading migrates away from the home market to the United States. If the home market and USA can be thought of as one global market rather than two segmented markets, we would expect intradaily volatility and volume to flatten in the home market from the standard peaks that exist around the morning opening and afternoon closing in segmented markets. The answers to such volatility and volume questions will help us understand the extent to which national markets are integrated along with the benefits and costs of cross-listing. We will answer these questions for a sample of firms drawn from the leading industrial country in Europe, Germany. Our particular focus is on German firms due to the availability of intradaily transactions data from the German home market that allows a long enough time series to conduct a pre- and post-listing analysis.

The issue of market integration is still unsettled. We know that intradaily financial asset price volatility is described typically by a U-shape where volatility is high near the morning opening and high again near the afternoon closing. The morning volatility peak is thought to be due to the accumulation of new information that is revealed while the market is closed. The afternoon volatility peak is thought to be due to covering positions and exploiting any private information that was accumulated during the course of the day. If markets are integrated, then the afternoon volatility peak in European markets should decline once risk can be shared with traders in the overlapping USA market. Our analysis is motivated by the findings of Werner and Kleidon (1996) who use intradaily data to analyze UK cross-listed firms. Their results support the hypothesis of market segmentation as the intradaily U-shape of volatility seems to be unaffected by listing in the United States. If markets are integrated, one would expect the U-shape in London to flatten in the afternoon for firms that are also traded and listed in the United States. Werner and Kleidon compare a cross-section of cross-listed firms with a control group of firms not listed in the United States to make inferences regarding the market integration effect. Their surprising result is that cross-listed firms do not differ qualitatively from the locally-traded firm in terms of the intradaily U-shape. Using the German data, we are able to examine the issue of intradaily volatility in a time-series setting both before and after the listing date. A related issue is whether morning volatility and volume in Germany also declines once USA trading begins. Since there are fewer hours of non-trading for a cross-listed firm compared with a purely German-traded firm once a firm is cross-listed, there is more opportunity for price discovery prior to the German opening. Our results will shed additional light on this related issue of market integration.

Volume effects of cross-listing should be expected to follow a similar pattern as volatility. If the intradaily U-shape of volatility flattens due to foreign risk-sharing and price discovery after cross-listing, then we should expect similar outcomes for volume. The intradaily pattern of trading volume should flatten if there is less

home-market trading at the open resulting from information accumulation since the previous close and there is less home-market trading in the afternoon due to the extended trading opportunities made possible in the foreign market.

The remainder of the paper proceeds as follows. Section 2 discusses the issue of market integration versus segmentation and considers reasons why one or the other outcome might prevail. Section 3 discusses the data employed and provides new evidence supporting the hypothesis that the German and USA markets are integrated. Section 4 examines the evidence regarding volatility of cross-listing firms both pre- and post-American depositary receipt (ADR)-listing. Section 5 considers the pre- and post-listing evidence on volume. Finally, Section 6 offers a summary and conclusions.

## 2. Market integration versus segmentation

It has been well documented that intradaily volatility and volume are described by patterns where volatility and volume are relatively high following the morning opening (of the market) and high again prior to the afternoon closing.[1] According to Brock and Kleidon (1992), the morning and afternoon peak may be due to an increase in transactions demand and decrease in demand elasticity. If optimal portfolio shares are constant, then investor trades at the open are motivated by overnight price changes that require changes in quantities held to maintain constant portfolio weights. Trading prior to the close seeks to establish optimal portfolio shares based on prices in the late afternoon. In addition, outstanding broker orders that allow discretion in execution times need to be filled prior to the close. There also exist information-based theories of the U-shape as found in papers like Subrahmanyam (1991) where the approach of the close is associated with a clustering of trades.

Fig. 1 portrays the stylized U-shape of volatility between the open and close of the home market. If stocks are not cross-listed and there are no trading opportunities outside the home market, then the steeper curve prevails. After cross-listing, the theories cited above would imply that trading would be spread out over a longer period, as if the home market close was extended, and the intradaily volatility curve would flatten. Afternoon volatility flattens due to the overlapping trading hours between the home and foreign market. Morning volatility flattens due to the shorter period of non-trading during which price-relevant information may accumulate prior to the open. It is not necessary that the volatility curve for a local market lose its curvature entirely even if markets are integrated, as local insiders may trade largely during local business hours and local and foreign shares may not be perfect substitutes for reasons discussed below.

As mentioned in Section 1, Werner and Kleidon found a result that, in part, motivates the present work. They analyzed intradaily patterns of unconditional

[1] See French and Roll (1986), Jain and Joh (1988), Brock and Kleidon (1992), Werner and Kleidon (1996).

return volatility for UK and USA trading of British cross-listed stocks and found that for each market, the intradaily patterns for these stocks resemble closely those of an otherwise similar control group of non-cross-listed stocks. If the markets are integrated, then we would expect the London afternoon volatility to fall for stocks that are cross-listed in USA relative to stocks that are traded only in London. Rather than finding evidence of lower afternoon volatility in London for stocks that also are traded in the United States, Werner and Kleidon find that the return volatility of cross-listed firms is similar to that of non-cross-listed firms.

Our analysis differs in two important ways from that of the previous work. First, we use a time series sample that allows an analysis of the intradaily volatility before and after the cross-listing in the United States. Second, we examine conditional measures of volatility and also examine intradaily volume effects. In addition, German trading occurs via an electronic limit order book while the London Stock Exchange studied by Werner and Kleidon is a dealer market. If international financial market integration has grown over time, then it may also be relevant that we use more recent data in finding evidence of integration.

Aside from the Werner and Kleidon study, previous research on market integration has focused on specific barriers to capital flows and implications for integration.[2] Our analysis focuses on a specific event—the advent of ADR trading in the United States. We analyze the impact of this event on the intradaily volatility and volume patterns of stock price returns in the German home market.

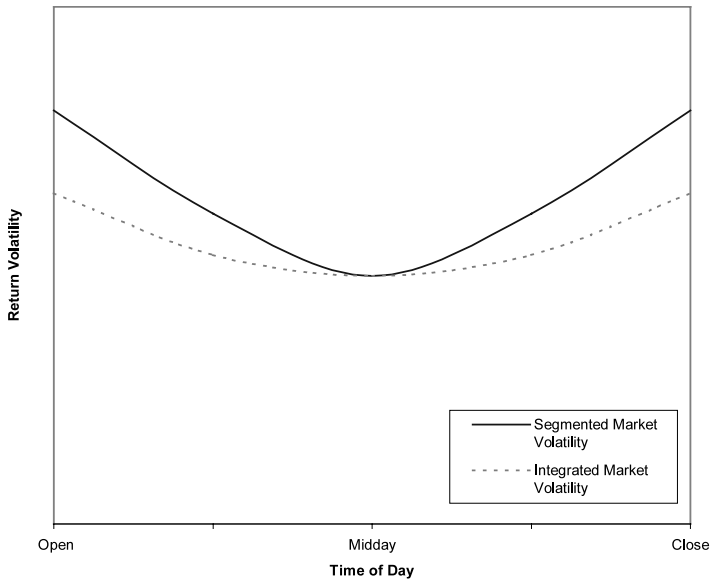


Fig. 1. Intradaily volatility for segmented and integrated markets.

[2] Examples include Alexander et al. (1987), Errunza and Losq (1985), Hietala (1989), Jorion and Schwartz (1986), Bekaert and Harvey (1995), Miller (1999).

Intuitively, there are several reasons why the trading of dual-listed stocks in Germany and the United States might be viewed as one integrated market. First, both Germany and the United States lack capital controls that erect barriers to foreign investors. Also, since Germany and the United States trade different claims on the same German firm for a common overlapping 1.5 h each day, dealers in cross-listed stocks potentially face cross-Atlantic competition for order flow.

There are also reasons why trading in the United States and Germany may be less than fully integrated. The first is that these stocks trade in the form of ADRs in the United States. An ADR is a security that combines the claim to shares of the underlying German firm with a service contract provided by the depositary bank. Consequently, the two securities are not perfect substitutes for all investors.[3] The second reason is the cost associated with cross-border arbitrage. ADRs are in principle fully convertible into underlying stock, but conversion is not costless. In practice, conversion is rare since large institutions trade on price differences between Germany and the United States without converting underlying stock into ADRs or vice versa.

Due to the fact that the ADR market might be less than perfectly integrated with German home trading, the question is to what extent does dual listing affect trading activity and price dynamics, as captured by intra-daily patterns? If the markets are completely segmented, trading of cross-listed stocks in each market would be characterized by a distinct intradaily pattern as in the steeper curve of Fig. 1. To determine whether cross-listing affects intradaily patterns, it is necessary to analyze German data both before and after the listing to see if there is a significant difference in the intradaily activity patterns as the firm begins an ADR program in the United States.

## 3. Data

In order to be included in our sample of ADRs, a firm must satisfy the following criteria:

- started a level I, II, III and/or 144a sponsored ADR program between 1991 and 1997.
- Listed on the integrated stock exchange trading and information system (IBIS).
- Have 3 months of intradaily data before and after the start of the level I, II, III and/or 144a sponsored ADR program.

The sample was formed by first identifying all German ADR programs in the United States. J.P. Morgan provides the master list of all ADRs on their ADR home page via the Internet.[4] Additional sources were used to cross-check that we had a complete list of current German ADRs, including Deutsche Bank, ADR-Net and Bankers Trust. It was determined that there were 52 German ADRs currently listed in the US markets.

[3] This is particularly true for level 1 and 144a as opposed to levels 2 and 3 ADRs.

[4] See www.adr.com.

The next step was to identify those firms that started a level I, II, III and/or 144a sponsored ADR program between 1991 and 1997. It was determined that 23 firms fit this requirement. All 23 firms were listed on IBIS. Of the 23 firms, only 11 had sufficient historical data to be used for this empirical analysis.[5] For instance, Adidas, which is a 144a, went public in Germany around the same time they established an ADR program in the United States. Therefore, no historical data exist. The same problem occurs with Deutsche Telekom, Puma, Merck, and Mannesman. Schwarz Pharma presents a different problem. There is 1 year's worth of data but not enough observations to perform a detailed analysis of the shorter non-trading hours and risk sharing hypotheses.[6] Therefore, Schwarz Pharma is deleted from the sample. The breakdown of the final list of ADRs with their listing date in parentheses is the following.

- Level I sponsored ADR: Bayer (12/8/94), Bayerische Vereinsbank (10/22/97), Deutsche Bank (5/17/95), Dresdner Bank (4/18/94), Kloeckner Werke (10/31/97), RWE AG (3/17/95), and Thyssen (10/20/97).
- Level II sponsored ADR: Hoechst (9/24/97) and Veba (10/8/97).
- Level III sponsored ADR: Daimler Benz (10/5/93) and SGL Carbon (6/5/96).
- Rule 144a ADR: Dresdner Bank (5/11/92).

Since Dresdner Bank had two listings, we chose the level I rather than the 144a for our sample, since the latter is for the private placement market and is only available to 'qualified institutional buyers.' The data for the empirical analysis were supplied by the Karlsruher Kapitalmarktdatenbank (KKMDB).[7] The data are intradaily prices from Germany as quoted on the IBIS trading system. IBIS is an integral part of the Frankfurt Stock Exchange (FSE). It was introduced on April 5, 1991.[8] Trading takes place from 8:30 until 17:00 h. The IBIS data set contains time-stamped prices and volume for all trades since July 1, 1991. The time-stamp is accurate to the 100th second.

Before proceeding to the econometric analysis, it is useful to establish that there is, indeed, a U-shaped pattern of volatility and volume in our data. We define the morning period as the time from 8:30 to 11:30 h. Midday is from 11:30 to 14:00 h, and afternoon is from 14:00 to 17:00 h. In the 30-day period prior to listing in USA, the ratio of morning to midday variance measured using tick-by-tick observations (the ratio of morning to midday volume measured as number of shares traded) for each firm is: Bayer, 1.75 (1.96); Bayerische Vereinsbank, 1.84 (2.04);

[5] The empirical analysis requires at least 3 months of data before and after starting a sponsored ADR program.

[6] In communications with Torsten Lüdecke of the Institute Für Entscheidungstheorie und Unternehmensforschung (the source of the IBIS data on intradaily German stock prices) this is because of the lack of trading volume in Germany.

[7] A good discussion of the data is provided in Lüdecke (1997).

[8] On November 28, 1997, the IBIS system was replaced with the Xetra system. Xetra is a faster, more efficient trading system, but it essentially retains the same functionality as IBIS.

Daimler Benz, 1.17 (2.33); Deutsche Bank, 1.27 (2.00); Dresdner Bank, 1.21 (1.64); Hoechst, 1.37 (2.44); Kloeckner Werke, 1.37 (1.30); RWE, 1.38 (4.17); SGL Carbon, 1.54 (2.94); Thyssen, 1.46 (2.08); and Veba, 2.87 (2.56). All ratios are significantly greater than unity at the 5% level. The ratios of afternoon to midday variance (volume) are: Bayer, 1.38 (1.84); Bayerische Vereinsbank, 1.30 (2.21); Daimler Benz, 1.09 (1.70); Deutsche Bank, 1.25 (2.17); Dresdner Bank, 1.08 (1.83); Hoechst, 1.21 (2.68); Kloeckner Werke, 1.12 (2.45); RWE, 1.74 (2.62); SGL Carbon, 1.16 (2.84); Thyssen, 1.30 (2.28); and Veba, 1.91 (2.31). All ratios except the Dresdner Bank volatility are significantly greater than unity at the 5% level. In the Dresdner case, the lower limit on the 95% confidence interval is 0.96, so Dresdner just misses the 5% significance level cutoff for rejecting the null hypothesis of unity. The data clearly indicate that there exists a U-shape for volatility and volume over the trading day.

## 4. Cross-listed versus control sample volatility

Before examining the time-series evidence on German trading before and after listing in the United States, it is instructive to first examine a comparison of our sample of cross-listed German firms with a control group of German firms that are not listed in the United States. This analysis is analogous to that of Werner and Kleidon's comparison of firms traded in both the United Kingdom and the United States with a control group of firms traded solely in London. In their analysis, they found that the two groups of firms had similar intradaily volatility patterns.

In building our control group, we first searched for firms that were traded in Germany on the IBIS system and were in the same industry as our ADR firms. After having identified the target candidate firms, we matched as closely as possible our ADR firms in terms of market value and trading volume.[9] We then constructed a data set of tick-by-tick returns to compare the intradaily pattern of volatility for each group. Returns are calculated as:

$$R_{F,D,T} \equiv \ln(P_{F,D,T+1}) - \ln(P_{F,D,T}) \tag{1}$$

so the return on stock of firm $F$, on day $D$, and time interval $T$ is the change in the log of the price observed at each time interval. The sample period is October 23, 1997 (after the last of our ADR firms has listed in the United States) to November 28, 1997 (the end of our data set). To be clear, we use this 1997 sample period to see if the intradaily patterns of our cross-listed firms differs from that of the control group of firms.

Our hypothesis is that firms that are listed in the United States will tend to have a flatter intradaily volatility pattern than firms traded solely in Germany, along the lines of the two curves in Fig. 1. Intradaily volatility is measured as the morning to

[9] Of course, since the firms that trade as ADRs are the biggest German blue-chips, our control group firms will tend to have a smaller market capitalization. We find the best matches available among firms that are actively traded.

Table 1
Intradaily volatility patterns in German trading for cross-listed firms and locally-traded firms

| Firm pair | Morning/midday | Afternoon/midday |
|---|---|---|
| Bayer/Schering | 0.18* | 0.17* |
| Bayerische Vereinsbank/Bankgesellschaft Berlin | 1.24 | 0.68* |
| Deutsche Bank/Allianz | 0.31* | 0.29* |
| Dresdner Bank/IKB Deutsche Industriebank | 0.20* | 0.05* |
| Daimler Benz/Bayerische Moteren Werke | 0.46* | 0.29* |
| Kloeckner Werke/F. Krupp AG H. Krupp | 0.68* | 0.18* |
| RWE/Linde | 0.61* | 1.25 |
| Hoechst/Fag Kugelfischer G. Schaefer | 0.55* | 0.82* |
| Veba/Metallgesellschaft | 0.76* | 0.14* |
| SGL Carbon/Hochtief | 0.43* | 0.43* |
| Thyssen/Deutz | 0.30* | 0.74* |

The table provides estimates of intradaily stock return volatility ratios for a sample of German firms that are listed in the United States with a control group of German firms not listed in the United States. The hypothesis is that there should be a more pronounced intradaily U-shape of volatility for the firms that are only locally traded. Variance ratios were estimated for morning (8:30–11:30 h) to midday (11:30–14:00 h) volatility and afternoon (14:00–17:00 h) to midday volatility for each firm using tick-by-tick returns over the period from October 23, 1997 (after our last ADR listing) to November 28, 1997 (the end of the data set). The table reports the ratio for the (top-listed) cross-listed firm relative to the (bottom-listed) locally-traded firm. Asterisks denote ratios differ at a 95% level of confidence.

midday and afternoon to midday variance ratios. The periods are divided as morning, 8:30–11:30 h; midday, 11:30–14:00 h; and afternoon, 14:00–17:00 h. If the ADR sample firms have flatter morning and afternoon volatility than the control firms, then the variance ratios for the ADR sample should be lower than the ratios for the control sample or the values reported in Table 1 should be less than 1.[10]

Table 1 reports the intradaily variance ratios for each cross-listed firm relative to a matching control group firm. For instance, Bayer is cross-listed as an ADR and we identify Schering as the best industry match in Germany that is not traded in the United States. The value of 0.18 for morning/midday indicates that the variance ratio for morning to midday volatility for Bayer is 18% of Schering's morning to midday variance ratio and the difference is statistically significant at a 95% level of

[10] Variance ratios are distributed as $F$. Since the ratio of two $F$-statistics has no distribution, the use of confidence intervals is needed to make inference about the difference between two ratios. If the bounds for the two ratios do not overlap, then we can say they differ at the $\alpha$-level of significance. Consider a confidence interval for a variance ratio at the $\alpha$-level of significance:

$$Pr\left[F_{1-\alpha,n1,n2} \leq \frac{S_1^2/\sigma_1^2}{S_2^2/\sigma_2^2} \leq F_{\alpha,n1,n2}\right] = (1-2\alpha)$$

This may be rewritten in a form that bounds the true ratio:

$$Pr\left[\frac{S_1^2}{S_2^2} F_{\alpha,n1,n2} \leq \frac{\sigma_1^2}{\sigma_2^2} \leq \frac{S_1^2}{S_2^2} F_{1-\alpha,n1,n2}\right] = (1-2\alpha)$$

For a joint test involving two ratios, if one is interested in a 95% confidence interval, then we set $1-(1-2\alpha)^2 = 0.05$ so $(0.95)^{1/2} = 1-2\alpha$, or $\alpha = 0.01266$.

confidence. The value of 0.17 for afternoon/midday indicates that the variance ratio for afternoon to midday for Bayer is 17% of that of Schering and the difference is statistically significant at a 95% level of confidence.

Out of 11 paired firms in Table 1, ten cross-listed firms have a flatter morning volatility and ten cross-listed firms have a flatter afternoon volatility. Only the morning evidence for Bayerische Vereinsbank/Bankgesellschaft Berlin and the afternoon evidence for RWE/Linde does not support the hypothesis of lower volatility ratios for the cross-listed firms. Overall, the evidence presented in Table 1 meets our expectation that cross-listed firms will have flatter intradaily volatility patterns than firms that are traded solely in the home country.

We find these initial results instructive and interesting in comparison to the received literature. But we know that the variance ratios are plagued with problems since the underlying returns are not independent but have persistent volatility. For this reason we do not want to argue that these unconditional results are anything more than a first look at the issue in the spirit of the previous literature. Now, we want to move beyond the comparison of cross-listed and control group firms over a post-cross-listing sample period to examining the intradaily price and volume dynamics for each firm pre- and post-ADR-listing.

## 5. Intradaily volatility before and after cross-listing

We examine the pre- and post-listing stock return volatility patterns for individual German firms using two approaches. First, following the previous section and earlier literature, we examine unconditional volatility in terms of volatility ratios of morning-to-midday and afternoon-to-midday to gauge whether the typical morning and afternoon volatility peaks have flattened in Germany with the advent of ADR trading in the United States. We examine the volatility ratios relative to midday to account for any general change in the level of volatility. Second, knowing that volatility is unlikely to be a constant over time in financial asset pricing, we estimate conditional measures of volatility to allow inference on the change in morning and afternoon volatility after US ADRs begin trading. To anticipate the results, we find complementary evidence of morning and afternoon volatility in Germany dropping after US ADR trading begins.

### *5.1. Unconditional volatility and the start of ADR trading*

Volatility is calculated for the same three time intervals used in the previous section (morning, midday, and afternoon) for both 30 days before and after the start of ADR trading in the United States. We limit the window to 30 days in order to focus on the impact of cross-listing as a wider window would increase the likely contamination by other factors than the US listing event.

As in the prior section, overnight returns are excluded, so the first observation each day starts at 8:30 h and variance ratios for each firm are calculated for morning to midday volatility and afternoon to midday volatility. Now, rather than compare variance ratios between cross-listing firms and locally-traded firms we

want to compare the variance ratios for individual firms pre- and post-ADR listing. We expect that the intradaily pattern of volatility should flatten post-listing for two reasons.

1. There is a shorter period of nontrading between the US close and the German open once ADR trading begins. The shorter time for information to accumulate may reduce morning volatility relative to the period prior to ADR trading when the time from the German close to the German open is the relevant nontrading period.
2. Prior to the advent of ADR trading, the market closing in Germany will force information-based traders to trade before the German close to exploit any informational advantage they may have. In addition, position covering will occur prior to the close in order to avoid overnight exposure. After ADRs begin trading, there is an extended period of time for risk sharing as well as exploiting any private information so that the German afternoon volatility should drop relative to midday as trades are spread out over a longer period of time that reaches into the US market.

Table 2 reports the results for our variance ratio tests. The pre-listing variance ratio is divided by the post-listing ratio and the quotient is reported in the table. For instance, the morning/midday value of 1.09 for Bayer indicates that the pre-listing variance ratio was 109% of the post-listing ratio, or morning volatility flattened relative to midday after the Bayer ADR began trading in the United States. However, this difference between the pre- and post-listing ratios is not

Table 2
Intradaily unconditional volatility patterns in German trading pre- and post-ADR listing in the United States

| Firm | Morning/midday | Afternoon/midday |
|---|---|---|
| Bayer | 1.09 | 1.41* |
| Bayerische Vereinsbank | 1.42* | 6.19* |
| Daimler Benz | 1.03 | 1.20* |
| Deutsche Bank | 1.01 | 1.51* |
| Dresdner Bank | 0.63 | 1.21* |
| Hoechst | 0.68 | 1.25* |
| Kloeckner Werke | 0.68 | 1.18* |
| RWE | 1.17* | 2.32* |
| SGL Carbon | 0.66 | 2.90* |
| Thyssen | 0.69 | 1.59* |
| Veba | 1.91* | 2.15* |

The table provides estimates of German market intradaily stock return volatility ratios for a sample of German firms before and after they list as an ADR in the United States. The hypothesis is that there should be a more pronounced intradaily U-shape of volatility in German trading before the firms are also traded in the United States compared with the post-US-listing period. Variance ratios were estimated for morning (8:30–11:30 h) to midday (11:30–14:00 h) volatility and afternoon (14:00–17:00 h) to midday volatility for each firm using tick-by-tick returns for 30 days pre- and post-listing. The table reports the pre-listing variance ratio divided by the post-listing variance ratio. Asterisks denote the ratios differ at a 95% level of confidence.

statistically significant at a 95% level of confidence. In six cases, the morning/midday variance ratios fell in post-ADR trading. However, only in the cases of Bayerische Vereinsbank, RWE A.G., and Veba did the post-listing ratios indicate a statistically significant fall in the morning to midday volatility ratio. In the case of afternoon to midday volatility, there are no rejections of the hypothesis that afternoon volatility flattens relative to midday. Taken as a whole, the variance ratio test results provide some limited evidence of a drop in home-market morning volatility but strong evidence that home-market afternoon volatility tends to fall once ADRs start trading. One might conclude that the presence of overlapping trading hours in the German afternoon is much more important for the evidence of market integration than a shorter period of overnight non-trading prior to the German morning.[11]

### 5.2. Conditional volatility and the start of ADR trading

A robust finding in time series studies of high-frequency financial asset prices is that volatility tends to be persistent over time and clusters in periods of tranquility and turbulence. As a result, we view the prior results using unconditional volatility as instructive and representative of the past literature, but questionable and inconclusive. For this reason, we estimate GARCH models of the intradaily returns. In order to have equally-spaced time intervals between prices, we now define 15-min returns as the change in the log of the last price at each 15-min interval.

A GARCH specification of the 15-min returns for firm $f$, $R_{f,t}$ is:

$$R_{f,t} = C_f + \varepsilon_{f,t} \quad \text{where} \quad \varepsilon_{f,t} \sim N(0, h_{f,t})$$
$$h_{f,t} = cb_f + ca_f + \alpha_f \varepsilon^2_{f,t-1} + \beta_f h_{f,t-1} + \gamma_{f,1} DM_t + \gamma_{f,2} DA_t + \gamma_{f,3} DM1_t + \gamma_{f,4} DA1_t \quad (2)$$

In addition to the standard GARCH(1,1) terms, we allow the constant to shift for before and after the cross-listing ($cb$ and $ca$), $DM$ is a dummy variable for morning (prior to 11:30 h), and $DA$ is a dummy variable for afternoon (after 14:00 h). $DM1$ and $DA1$ are the $DM$ and $DA$ dummies interacted with a dummy that switches from zero to one once ADR trading in firm $f$ begins. The hypothesis of interest is that the morning and afternoon volatility fall once ADR trading begins in the United States. Thus, we focus on whether the coefficients on $DM1$ and $DA1$ are negative.

[11] We considered the possibility that this limited evidence of morning volatility falling in the post-ADR listing period may be related to the fact that some of the firms are also listed in Tokyo, so that the non-trading period prior to the US listing is shorter for these firms. If this factor is relevant, we would expect those firms not listed in Tokyo to be more likely to experience a morning volatility drop. According to data provided by Torsten Lüdecke and his student Wilhelm Kürfgen, the following firms were not listed in Tokyo prior to the US listing: Bayerische Vereinsbank, Hoechst, Kloeckner Werke, RWE A.G., SGL Carbon, Thyssen, and Veba. Note that the three firms that do experience a significant drop in morning unconditional volatility are on this list, but so are five others. Thus, we do not think the Tokyo listing is a useful explanation for the results.

Table 3
Intradaily conditional volatility patterns in German trading pre- and post-ADR listing in the United States

| Firm | $DM$ | $DA$ | $DM1$ | $DA1$ | $Q(12)$ |
|---|---|---|---|---|---|
| Bayerische Vereinsbank | 0.48 (0.06) | 0.24 (0.06) | −0.12 (0.04) | −0.47 (0.02) | 25.24 (0.51) |
| Bayer | 0.12 (0.05) | 0.08 (0.05) | −0.07 (0.01) | −0.07 (0.01) | 18.91 (0.54) |
| Daimler Benz | 0.15 (0.10) | 0.10 (0.05) | −0.08 (0.01) | −0.02 (0.02) | 6.52 (0.88) |
| Deutsche Bank | 0.37 (0.07) | 0.22 (0.06) | −0.22 (0.02) | −0.38 (0.01) | 10.54 (0.57) |
| Dresdner Bank | 0.76 (0.12) | 0.17 (0.05) | −0.49 (0.02) | −0.86 (0.00) | 12.01 (0.45) |
| Hoechst | 0.04 (0.02) | 0.08 (0.03) | −0.42 (0.01) | −0.48 (0.00) | 13.04 (0.37) |
| Kloeckner Werke | 0.91 (0.05) | 0.68 (0.06) | −0.63 (0.53) | −0.44 (0.01) | 9.28 (0.68) |
| RWE | 0.01 (0.10) | 0.09 (0.18) | −0.03 (0.03) | −0.13 (0.02) | 10.72 (0.55) |
| SGL Carbon | 0.82 (0.00) | 2.55 (0.01) | −0.59 (0.05) | −0.66 (0.01) | 12.74 (0.39) |
| Thyssen | 0.24 (0.27) | 0.16 (0.51) | −0.57 (0.00) | −0.35 (0.02) | 14.03 (0.70) |
| Veba | 0.11 (0.13) | 0.11 (0.10) | −0.36 (0.02) | −0.43 (0.02) | 19.26 (0.58) |

The table reports coefficient estimates on dummy variables from the following GARCH model:

$$R_{f,t} = C_f + \varepsilon_{f,t} \quad \text{where} \quad \varepsilon_{f,t} \sim N(0, h_{f,t})$$

$$h_{f,t} = cb_f + ca_f + \alpha_f \varepsilon^2_{f,t-1} + \beta_f h_{f,t-1} + \gamma_{f,1} DM_t + \gamma_{f,2} DA_t + \gamma_{f,3} DM1_t + \gamma_{f,4} DA1_t$$

where $R$ is the 15-min stock price return for firm $f$; $DM = 1$ from 8:30 to 11:30 h, 0 otherwise; $DA = 1$ from 14:00 to 17:00 h, 0 otherwise; $DM1$ is $DM$ interacted with a dummy = 1 post-listing, 0 otherwise; and $DA1$ is $DA$ interacted with a dummy = 1 post-listing, 0 otherwise. The sample period includes 30 days pre- and post-listing. $P$-values are reported in parentheses. The $Q$-statistic and related $P$-values are tests of white noise residuals out to 12 lags.

Estimates of the model are reported in Table 3. In order to conserve space, only the dummy variable results are reported. However, the significance of the lagged volatility terms in each case underscores the need for conditional volatility modeling rather than the unconditional variance ratios presented earlier. In all cases, the coefficients on $DM1$ and $DA1$ are negative. Robust S.E. were estimated and $P$-values reported for each coefficient. Based on these $P$-values, there is evidence of a statistically significant drop in morning volatility for ten of the 11 firms at the 5% level of significance once ADR trading begins. This supports the hypothesis that the shorter nontrading hours for each firm is associated with lower morning volatility in Germany. For afternoon volatility, all of the 11 firms have a statistically significant volatility drop at the 5% level of significance once ADR trading begins.

Taken together, the unconditional and conditional volatility results provide evidence of a flattening of the intradaily volatility pattern after cross-listing. The results cause us to question seriously the hypothesis that markets are segmented and should be thought of as independent. Beyond the implications for volatility patterns, cross-listing should also have implications for intradaily volume. The next section examines the evidence on this issue.

## 6. Intradaily volume and the start of ADR trading

The effects of cross-listing on trading volume have been studied before. Foerster and Karolyi (1998) argued that if markets are integrated, then we may expect to see volume migrate from the home market to US market once ADR trading begins. We examined average daily volume for our sample of German firms for 30 days pre- and post-listing and found a statistically significant drop in volume only for Bayerische Vereinsbank, Dresdner Bank, and Kloeckner Werke. Based on daily volume, we would find limited support for any significant net effect of volume migration. It is important to think in terms of a net effect on volume, because in addition to the volume migration effect of cross-listing in an integrated setting, there may also be a liquidity effect. The liquidity effect should lead to greater home-market volume after cross-listing. Evidence that the liquidity effect dominates is provided by Smith and Sofianos (1997) who show that volume increases on the home market after cross-listing. While the effects of cross-listing on home-market daily volumes is important, we want to examine the intradaily evidence. There are certainly other determinants of trading volume besides international listing, and it is difficult to hold such effects constant as the window of time studied widens. For this reason, we examine 30 days pre- and post-listing to infer volume effects. In addition, cross-listing should have implications for volume analogous to the volatility effects discussed earlier and shifts in intradaily volume patterns provide an independent view of cross-listing and integration apart from shifts in volume at the daily level. The volume migration effect should be most obvious during the period of trading overlap between the German and US markets. Even if average daily volume does not fall significantly for the majority of German firms in our sample, this does not rule out the intradaily shifting of trading volume post-ADR-listing compared with pre-ADR-listing in the home market. We expect an intradaily U-shape of volume for the same reasons as the intradaily U-shape of volatility discussed earlier. However, if the markets are integrated and considered more as one global trading venue than segmented individual markets, the migrating-volume hypothesis would suggest a flattening in the afternoon volume peak post-listing.

Individual volume (shares traded) data from the IBIS data set were aggregated over 15-min intervals for each firm in our sample. To explore the impact of an ADR listing, time series models are estimated for each firm. We began by estimating simple OLS models of time-of-day effects on volume of the following form:

$$V_t = ab_0 + aa_0 + a_1 DM_t + a_2 DA_t + a_3 DM1_t + a_4 DA1_t + \varepsilon_t \tag{3}$$

where *ab* and *aa* represent a constant for before and after cross-listing, $V_t$ represents volume for 15-min interval $t$ and the dummies are: $DM = 1$ for 8:30–11:30 h, 0 otherwise; $DA = 1$ for 14:00–17:00 h, 0 otherwise; $DM1 = 1$ for 8:30–11:30 h post-ADR listing, 0 otherwise; $DA1 = 1$ for 14:00–17:00 h post-ADR listing, 0 otherwise. The initial OLS estimates indicated autocorrelation problems in all cases. We then constructed an appropriate time-series model for each firm. In most cases, an LM test for ARCH indicated the presence of autocorrelated heteroskedasticity,

which was then modeled. Table 4 reports the final functional form estimated for each firm along with the dummy variable coefficients and $P$-values.

Our focus is on the coefficients estimated for $DM1$ and $DA1$. Listing in the United States results in fewer hours of non-trading in each stock prior to the German-market opening and less time for information to accumulate, so we expect less information-based trading at the open. Based upon the shorter hours of non-trading, we hypothesize that post-ADR-listing morning volume falls relative to midday, or $DM1$ coefficients should be negative. Listing in the United States also provides an alternative trading venue for European traders and allows a longer trading opportunity each day. For these reasons, we hypothesize that post-ADR-listing afternoon volume falls relative to midday, or $DA1$ coefficients should be negative.

Table 4 reports that all coefficients for $DM1$ and $DA1$ are negative and all are seen to be statistically significantly negative. Based on the estimation results reported in Table 4, we infer that cross-listing in the United States has significant effects on the intradaily pattern of volume in the home market. This is an important result in contrast to the finding that there was no significant shift in average daily volume for eight of the eleven firms after ADR listing.

Of course, examining average daily volume allows for more contamination of the listing event effect due to other factors. By examining the intradaily pattern of volume in terms of morning relative to midday and afternoon relative to midday, we allow for overall shifts in volume and ask the questions of whether morning volume falls due to shorter hours of non-trading after US listing and whether afternoon volume falls due to a new overlapping trading venue and longer hours to trade beyond the German-home-market close. The affirmative answers to these two questions led us to conclude that we should think of these markets more as one integrated trading opportunity rather than two segmented, independent markets.

## 7. Summary and conclusions

The primary hypotheses addressed in this paper include, (1) the shorter period of overnight non-trading once an ADR is listed will reduce morning volatility and volume traded in the German home market; and (2) the opportunity to share risk and trade for an extended period of time in the German evening, once American trading in the ADR begins, will reduce afternoon volatility and volume in the German home market. Using time-series data at the level of the individual firm, both before and after the US listing, we analyze the evidence on both unconditional and conditional volatility and volume.

We first examine the evidence regarding unconditional volatility for our German ADR-listing firms compared with a control group of firms that are not traded in the United States. This approach follows the spirit of the previous literature. We find evidence that the intradaily pattern of volatility flattens for the cross-listed firms. Next we examine the pattern of unconditional volatility for our cross-listed firms before and after cross-listing. The unconditional volatility evidence from

Table 4
Intradaily volume shifts in German trading pre- and post-ADR listing

| Firm | $DM$ | $DA$ | $DM1$ | $DA1$ | $Q(12)$ | Model |
|---|---|---|---|---|---|---|
| Bayer | 0.93 (0.04) | 1.76 (0.00) | −1.65 (0.00) | −2.99 (0.00) | 20.66 (0.82) | GARCH(1,1) |
| Bayerische Vereinsbank | 2.59 (0.06) | 2.31 (0.05) | −1.59 (0.01) | −4.77 (0.00) | 14.18 (0.43) | GARCH(1,1) |
| Daimler Benz | 1.07 (0.02) | 1.63 (0.00) | −0.70 (0.00) | −2.16 (0.00) | 31.68 (0.41) | ARCH(1), AR(1), MA(1) |
| Deutsche Bank | 0.17 (0.00) | 0.10 (0.00) | −1.86 (0.00) | −2.13 (0.00) | 8.97 (0.67) | ARCH(1), MA(1) |
| Dresdner Bank | 0.94 (0.12) | 7.13 (0.00) | −4.03 (0.00) | −5.57 (0.00) | 9.57 (0.61) | GARCH(1,1), MA(1) |
| Hoechst | 2.79 (0.01) | 6.77 (0.08) | −4.56 (0.00) | −1.53 (0.01) | 6.91 (0.69) | OLS, ARMA(1,1) |
| Kloeckner Werke | 5.12 (0.10) | 2.70 (0.05) | −5.96 (0.01) | −10.96 (0.00) | 3.09 (0.96) | ARCH(1), AR(1), MA(1) |
| RWE | 0.70 (0.00) | 0.43 (0.02) | −4.30 (0.01) | −5.27 (0.03) | 4.89 (0.86) | GARCH(0,1) |
| SGL Carbon | 0.30 (0.01) | 1.66 (0.01) | −1.23 (0.00) | −3.88 (0.00) | 15.12 (0.18) | GARCH(0,1) |
| Thyssen | 0.13 (0.06) | 0.66 (0.00) | −0.56 (0.01) | −0.70 (0.00) | 13.74 (0.28) | GARCH(1,2) |
| Veba | 2.99 (0.05) | 7.84 (0.00) | −1.35 (0.00) | −2.98 (0.00) | 10.25 (0.55) | GARCH(1,1), MA(12) |

For each firm, an initial OLS model of the following form is estimated:

$$V_t = ab_0 + aa_0 + a_1 DM_t + a_2 DA_t + a_3 DM1_t + a_4 DA1_t + \varepsilon_t$$

where $V_t$ denotes volume over 15-min interval $t$; $DM = 1$ from 8:30 to 11:30 h, 0 otherwise; $DA = 1$ from 14:00 to 17:00 h, 0 otherwise; $DM1$ is $DM$ interacted with a dummy = 1 post-listing, 0 otherwise; and $DA1$ is $DA$ interacted with a dummy = 1 post-listing, 0 otherwise. Estimates of this base model are then used to identify appropriate time-series specifications for each firm that yield white-noise residuals. The final functional form estimated for each firm is reported. $P$-values are given in parentheses. The sample period is 30 days pre- and post-listing. The $Q$-statistic and related $P$-values are tests of white noise residuals out to 12 lags.

variance ratios provides limited evidence of morning volatility flattening but strong support for a flattening of afternoon volatility. However, we should regard unconditional volatility evidence as suggestive but not conclusive, as we know that volatility in these markets involves time-dependencies. So we next estimate models of conditional volatility for each firm pre- and post-ADR-listing. The conditional volatility evidence indicates morning volatility flattening for ten out of our 11 firms and afternoon volatility flattening for all firms. Taken as a whole, the volatility results offer considerable support for a flattening of the intradaily pattern of volatility following a listing in the US market.

Finally, we examine the evidence regarding German-home-market volume effects of listing in the United States. We first examined the average daily volume for 30-days before and after ADR listing and found that only three firms had a statistically significant change (a volume drop). However, it is possible for other effects to contaminate the listing-event effect on volume at the daily level. As an alternative, we examine the intradaily pattern of volume pre- and post-ADR-listing to allow the daily level of volume to shift while still permitting a focus on the listing-event effect on morning and afternoon volume relative to midday volume. We expect a volume drop in the German morning trading after the US listing as there is less time for information to accumulate prior to the German open. We also expect a volume flattening in the German afternoon due to the migration of trading to the new ADR and the opportunity to trade over a prolonged period of time beyond the German close. The estimation results for each firm support both morning and afternoon volume flattening. It appears that when examined in an intradaily setting, there is a significant volume effect of the cross-listing.

Considering the overall evidence regarding the effect of ADR listing on German home-market volatility and volume over the trading day, we believe that the data support the hypothesis of trading taking place in an integrated global setting rather than in segmented market intervals associated with the home and US market.

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