IMPACT OF ARBITRAGE ON EUROPEAN FINANCIAL MARKET INTEGRATION

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Abstract

This paper examines the integration process for the difference between the prices of the siamese twin stocks of ABB/ASEA and Royal Dutch/Shell that cross-listed in Europe. A primary focus of this study is to examine the spillover effects (noise) for the difference between prices of the above siamese twin equities with the relevant foreign stock market indices on which these are traded. We investigate the relationship between spillover effects (noise) and arbitrage opportunities arising from daily stock price difference between the prices of twin equities that cross-listed in different European stock markets. The performance of the stock price difference of the examined siamese twin equities is compared with the relevant stock market indices to investigate the impact of price gap (arbitrage) on stock market integration. Overall, we find that arbitrage has a significant impact on spillovers (noise).

JEL classification: G15.

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1. Introduction

This paper examines the process of information transmission for cross-listed equities that are traded in European markets. Specifically, we examine 'Siamese-twin' company stocks or pairs of corporations whose charter fixes

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the division of current and future equity cash flows to each twin. The twins each have their own stock, with its own distinct trading habitat. In this study, we examine two examples of Siamese twins: Royal Dutch Petroleum and Shell Transport and Trading PLC; and ABB AB and ASEA. Other studies, such as Froot and Dabora (1995, 1999) examined three examples of siamese twins: Royal Dutch Petroleum and Shell Transport and Trading PLC; Unilever N.V. and Unilever PLC; and SmithKline Beecham. They point out that Siamese-twin stocks provide a more clear-cut of 'excess comovement' for several reasons. First, the twins they examine are among the largest and most liquid stocks in the world. Second, Siamese-twin stocks represent claims on exactly the same underlying cash flows. Thirdly, the stocks of the twins can be arbitraged easily. In the current study, we investigate empirically the level of integration between the difference of the stock price return of the twin equities and the stock market index in which they are traded. If there are arbitrage opportunities between the two stocks, we expect to find a low level of integration with the respective stock exchange on which they are traded.

In addition, Siamese twin stocks traded on major world stock exchanges, and they can both be purchased locally by many investors. For example, a U.S. (Dutch) investor can buy Royal Dutch and Shell in New York (Amsterdam). As a consequence, the additional costs and informational advantages commonly associated with cross-border trading cannot be used in the analysis of Froot and Dabora (1999) to explain their results. With respect to the above, we believe that the price difference of the Siamese twins that are bought locally could affect the level of integration with the respective market differently locally than internationally.

One interesting question which should be answered with regards to Froot and Dabora findings is what sources of segmentation might explain these findings. One hypothesis is that of cross-border tax rules. Withholding taxes on dividends differ across countries and investor clienteles, however the withholding taxes for any given investor are the same for stocks of any pair of twins. Thus, while helpful, tax-driven stories cannot fully account for their findings.

A second possible source of segmentation is country-specific noise. Suppose that a noise shock hitting, say, U.S. stocks, disproportionately affects the twin which trades relatively more in New York. In other words, stocks that trade more actively in the local market are more sensitive to local noise shocks and less sensitive to foreign noise shocks. This story has an interesting implication: the component of market movements explained by changes in twin's relative prices is likely to be noise. Twin price disparities, which are readily observable, may be informative about market-wide noise shocks, which are not directly observable.

Taking into account the above literature on 'Siamese twin' equities, the starting point in the current study is the extension of the above-mentioned research of Froot and Dabora (1995, 1999) to the European security market. In particular, instead of the Ordinary Least Squares (OLS) model that Froot and Dabora uses, we use the multivariate GARCH-BEKK model introduced by Engle and Kroner (1995) to control for systematic risk as in Bollerslev, Engle and Wooldridge (1988), Bodurtha and Mark (1991), and King, Sentana, and Wadhwani (1994). Hereafter we use the model known as the GARCH-BEKK-CAPM. In this respect, unanticipated returns are assumed to depend both on innovations in 'observable' noise and country-specific noise.

Overall, we find that the log price difference of the twin equities (Royal Dutch-Shell) and (ASEA-ABB) are correlated with the markets where they are listed and that explanatory variables such as local or global exchange rates can have an impact on the European integration process between 'arbitrage gap' and the respective stock indexes where a twin company is listed. The systematic beta effects found not to be important, as the covariane (1,2) / variance(1) found to be not statistically significant from the stock indexes back to the twin equity difference.

This paper is structured as follows. Section 2 provides a literature review with the main hypotheses that are tested. Section 3 outlines the research design and provides the siamese twin equity data, and Section 4 provides the empirical findings finally, the conclusions are summarised in Section 5.

2. Literature review

Previous studies on stock market integration concentrate on the level of integration between markets. A number of studies examine the transmission of news between markets for their market indexes. For example, Bennett and Kelleher (1988), Von Furstenberg and Jeon (1989), Hamao, Masulis and Ng (1990), King and Wadhwani (1990), Schwert (1990), Susmel and Engle (1990), Neumark, Tinsley, and Tosini (1991), Becker, Finnerty, and Tucker (1992) demonstrate this type of transmission of news. In their various analyses, they report that the transmission of volatility between markets is also time-varying, that lagged spillovers of price changes and price volatility exist between major stock markets, and that, when volatility is high, price changes in major stock markets tend to become highly correlated.

There is some evidence that relates volatility spillovers to barriers on structural differences between markets for their stock market indexes. Specifically, Kanas (1998) shows that spillovers across markets with diverse structures are different to those with similar structures. While Kanas (1998) focuses on London, Paris, and Frankfurt, other studies (e.g. Hamao et al. (1990), Theodossiou and Lee (1993)) focus on the major stock markets (US, Canada, Japan, UK, and Germany). For example, Hamao et al. (1990), Koutmos and Booth (1995), and Susmel and Engle (1994) focus on spillovers across New York and London, and Theodossiou and Lee (1993) examine spillovers across US, Japan, Canada and Germany. In addition to the above, Hamao et al. (1990) find the existence of spillovers from the USA and UK markets to Japan. Koutmos and Booth (1995) find that the transmission of volatility is asymmetric and is more pronounced when news is bad and coming from either market. Other evidence from Susmel and Engle (1994) find that volatility transmission is short and small between New York and London, in contrast to Teodossiou and Lee (1993) who note that the US capital market is the major 'exporter' of volatility to other financial markets.

The research design of each of the above studies involves the use of GARCH models to examine transmission patterns. GARCH models with conditional correlation are developed extensively in the finance literature to model spillover effects. As research reveals, volatility spillovers from the US capital markets could lead the rest of the world (Eun and Shim, 1989) and also correlation between markets could increase over time (Koch and Koch, 1991; Von Furstenberg and Jeon, 1989). In particular, Eun and Shim (1989) study the change in daily stock returns across nine stock markets using a VAR approach adjusting for non-synchronous stock price trading hours in different markets. As already mentioned, these authors found that the US market is by far the most influential vis-à-vis other markets. On the other hand, Von Furstenberg and Jeon (1989) investigate the relationships between change in daily stock price returns in Japan, Germany, the UK, and the USA markets over the period 1986 to 1988. They find an increase in the correlation between the above markets especially after the October crash in 1987. Studies that have used the GARCH modelling framework in the past, however, have typically not used specifications that control for the impact of arbitrage (such as different stock price returns between Siamese twin equities) on stock market integration, the main focus of the current study.

As Karolyi (1995) has pointed out, barrier restrictions have an impact on interdependencies and these need to be taken into account using GARCH models in order to be able to draw correct inferences on such spillover relationships. In addition, such interdependencies may be related to the ongoing debate on arbitrage, and further on the impact of siamese twin 'cross-listing' equities on the market integration which is the empirical question in this study. The debate on market interdependence and its relation to arbitrage opportunities is also of particular importance in Europe where there have been departures from the law of one price for two merged equities that traded on different stock exchanges and moves to market segmentation and therefore market independence.

In this respect, an analysis of volatility spillovers between siamese twin cross-listed equities with the stock market indexes where these are traded may help to inform us more about the market integration process which arise as a result of arbitrage opportunities from merged equities. Maldonado and Saunders (1983) study the British regulatory restriction[1] on foreign investment and find little evidence or no impact. Foreign investors are not restricted in their investments in U.S. securities that sold in London. Thus, although British investors are not restricted in their arbitrage opportunities, U.S. investors are. Thus one-way arbitrage appears to be sufficient to maintain stock price parity.

To investigate how exchange rates impact on covariances between equities, we adopt King et al.'s (1994) suggestion[2] and use the GARCH-BEKK modelling approach to investigate the impact of exchange rates on the magnitude and persistence of volatility spillovers for our siamese twin cross-listed European equities. Studies that investigate the effects of exchange rate changes on volatility spillovers (e.g. Dumas and Solnik, 1995) find that the magnitude and persistence of spillovers are increased the higher the movement of the exchange rate changes. Previous studies (Dornbusch and Fischer, 1980; Cho, Eun, and Senbet, 1986; and Korajczyk and Viallet, 1989) also suggest a significant impact of exchange rates on stock price volatility.

In addition to the impact of exchange rate on stock price volatility, various studies have investigated a number of market anomalies (such as the size, the BE/ME, and the market beta) using a CAPM or APT modelling framework. For instance, Fama and French (1993) and Elton and Gruber (1997) extend the single factor model to a multi-factor model taking into account the arbitrage pricing theory by Ross (1976) identifying that common risk factors may explain stock price movements. Despite the extensive use of the CAPM framework for considering effects on the systematic risk of stocks, more recent studies use the CAPM-GARCH[3] model of Bollerslev, Engle, and Wooldridge, 1988; and Bodurtha and Mark, 1991.

This paper aims to address these issues by examining the influence that arbitrage opportunities and exchange rates have on volatility transmission of siamese twin cross-listed European equities. The following section 3 outlines the methodology adapted to investigate spillover effects for European siamese twin cross-listed companies. The analysis mostly aims to investigate volatility spillovers in a similar manner to the established literature and then to test to see how arbitrage such as price discrepancies of siamese twin equities influence such spillovers. Finally the paper examines how exchange rate changes impact on these spillover effects.

3. Data and Sample Characteristics

We use daily stock returns for two Siamese twin equities listed in foreign stock exchanges of European countries. Our data source is the Datastream International and the sample extends from January 1987 to December 2000. Table 1 provides our cross-listing sample description for the twin equities of ABB/ASEA and Royal Dutch/Shell. This table shows the exchanges in which each of the Siamese twin equities is listed. More specifically, we observe that the Royal Dutch and Shell equities are commonly listed in the exchanges of Frankfurt, Brussels and Paris. This characteristic is a motivation to examine the spillover effects between these mentioned above stock exchanges and the price difference of (Royal Durtch – Shell). Because Royal Dutch only is additionally listed in the stock exchanges of Luxembourg and Zurich we investigate the spillovers between these exchanges and the price difference of the twin equity as mentioned above. We apply the same philosophy on the twin equities of ABB and ASEA and we examine the spillover effects between the exchanges where they are listed and the price difference of (ASEA–ABB).

Table 1: *Siamese Twins Stocks/Domestic and Foreign Interlistings for Stock Prices.*

	STO	FRANKF.	DEN	XSQ	XET	ZUR	AMS	LO	FRA	LU	BRU	AU
ABB	X		X	X(A+B)								
ASEA	X	X										
ROYAL DUTCH		X			X	X	X		X	X	X	
SHELL		X(ORD. + CE	RT.)					X	X		X	

Note: A means A shares, B means B shares, Ord. means ordinary shares, and Cert. means Certificates.

Table 2 provides descriptive statistics for the log price difference of the two twin equities the price indexes where they are listed and also some exchange rates such as the SEK TO SWISS (Swedish crone to Swiss franc), SEK TO U$ (Swedish Crone to US dollar), NLG TO GBP (Netherlands currency to Great Britain Pound), and NLG TO U$ (Netherlands currency to US dollar). In most of the series there is excess kurtosis and negative skewness and also there is a difference in the mean value of the log twin equity prices and the exchange rates. There is a similar characteristic in the value of standard error between the log price difference of the twin equities and the exchange rates.

Table 2: *Descriptive Statistics.*

	Mean	St. Error	T-Statistic	Skewness	Kurtosis
ASEAABB	0.00038	0.018	1.15	0.72	10.70
Copenhagen	0.00032	0.0096	1.56	−0.37	3.98
SEKTSWISS	0.000092	0.0059	0.57	0.40	2.068
SEKTU$	0.000034	0.0061	0.20	−0.12	1.26
Zurich	0.00051	0.010	2.65	−1.14	12.40
ROYLDS	0.00047	0.013	2.023	−0.060	3.099
Paris	0.00036	0.012	1.54	−0.33	5.15
German	0.00057	0.011	2.60	−1.18	13.99
Brussels	0.00041	0.0087	2.21	−0.13	5.46
NLGTGBP	−0.0000091	0.0047	−0.10	-0.80	7.98
NLGTU$	−0.000047	0.0071	−0.37	−0.049	2.96
Luxembourg	0.00075	0.0082	3.82	0.27	8.020

4. Methodology-Siamese twin cross-listed equities, and volatility spillovers

As noted already the main aim of this paper is to investigate both systematic and unsystematic spillovers relating to siamese-twin cross-listed companies in Europe. This requires us first to identify the relevant data sample, as outlined in the previous section, and then to model the interrelatedness of returns between the difference between the prices of the twin stocks and the stock market indices. In order to do the latter we follow Engle and Kroner (1995), but we modify their model to take into account systematic market beta effects as in Bollerslev, Engle, and Wooldridge (1988). Rather than examining spillovers between markets we narrow the focus by using Froot and Dabora (1999) specification[4] to examine the comovement between twins' log return difference and stock markets on which they are traded.

Froot and Dabora (1999) note that stock prices affected by the location of trade. They suggest that currency changes also affect the twins' log return difference. Specifically, stocks that are most intensively traded on a given market will co-move excessively with that market's return and currency.

As such, our analysis seeks to examine the magnitude and persistence of spillovers between the twins' return difference of cross-listed companies with the stock market indices in which they are traded. The main reason for examining spillover effects (systematic and unsystematic) between the twins' return difference and stock market indices is that we wish to investigate whether arbitrage (stock price discrepancies) change the direction in which information transfer between markets.

The broad methodological approach adapted takes the following steps:

STEP 1: We obtain data on European siamese twin cross-listed companies identifying the foreign location of trading for each siamese-twin equity (Table 1).

STEP 2: As in Froot and Dabora (1999) we examine spillovers between the stock markets in which the siamese twin equities are cross-listed and the difference between the prices of twin stocks. To do this, we use a GARCH-BEKK approach, similar to Engle and Kroner (1995) but we modify their model to take account of systematic risk effects, as in Bollerslev, Engle, and Wooldridge (1988). The modelling framework takes into account both systematic and unsystematic risk components. The aim is to see whether spillover effects between the stock markets and the difference between the prices of twin stocks influence capital market integration. The methodology also allows us to investigate the systematic spillover effect from the stock market index to the difference between the prices of the twin stocks.

STEP 3: Here, we use the GARCH-BEKK-CAPM modelling approach to investigate whether exchange rate changes influence the magnitude and persistence of spillovers. Kanas (2000) and Froot and Dabora (1999) have suggested that exchange rate changes have a significant influence on information transfer between markets and this will be investigated in our analysis.

4.1. The GARCH-BEKK-CAPM Model

Among GARCH models, multivariate GARCH approaches are the most widely used in time-varying (second moments) covariance studies. Such GARCH approaches include the Vector (VEC) of Bollerslev *et al.* (1988), the constant correlation (CCORR) of Bollerslev (1990), the factor ARCH (FARCH) of Engle *et al.* (1990) and the GARCH-BEKK of Engle and

Kroner (1995). The GARCH-BEKK model represents a successful attempt to overcome the various technical difficulties associated with previous approaches, such as the fact that the definite H_t matrix may not always be positive (a restriction imposed in the previous empirical approaches). Previous approaches impose the restriction for the estimated variance to be greater than zero when spillovers are examined. In contrast, the GARCH-BEKK parameterisation is specified in such a manner that no restrictions are required to ensure a positive definite H_t matrix.

Underlying these theoretical developments, the multivariate GARCH-BEKK [Berndt, Hall, Hall and Hausman (1974) and Engle and Kroner (1995)] model is written as follows:

$$r_t = \alpha + \sum_{p=1}^{n} \Phi_p r_{t-n} + e_t,\ e_t \mid \Omega_{t-1} \sim N(0, H_t) \tag{1a}$$

or

$$r_t = \alpha + \sum_{p=1}^{n} \Phi_p r_{t-n} + X_{t1}, X_{t2} + e_t,\ e_t \mid \Omega_{t-1} \sim N(0, H_t) \tag{1}$$

where,

r_t is the return series,

e_t is the error term of return equation,

α is the constant term in the above return equation,

X_1 and X_2 are the exogenous variables of the return equation,

Φ_p is the matrix of coefficients with the p lagged values of r_t

Ω_{t-1} is the matrix of conditional past information that includes the p lagged values of r_t.

To avoid the problems of dealing with normal distributions[5], the first moment of errors et is represented by a martingale process, as shown in Equation (2). It is assumed that et in Equation (1) follows a process of E (ε_t).

where,

$E(\varepsilon_t) = E(R_t - \beta_0 - \beta_1$* (covariance (1,2)/variance (1,1))), for the log price difference of the twin equity (2a)

and

$$E(\varepsilon_t) = E(R_t - \mu_0) \text{ for the stock indexes} \tag{2b}$$

β_0 is the long-term drift constant coefficient

β_1 is the long-term drift coefficient of covariance of the two series / variance of the first series

μ_0 is the long term drift coefficient and

$$H_{t+1} = CC' + B'H_tB + A'\varepsilon_t{}^*\varepsilon_t'A \quad (3)$$

Given a sample of T observations of the returns vector, r_{t+1}, the parameters of the bivariate systems are estimated by computing the conditional log-likelihood function for each time period as:

$$L_t(\Theta) = -\log 2\pi - \frac{1}{2}\log|H_{t+1}| - \frac{1}{2}E(\varepsilon_t)'(\Theta)H_t^{-1}(\Theta)E(\varepsilon_t)(\Theta)$$

and
$$L(\Theta) = \sum_{t=1}^{T} L_t(\Theta) \quad (4)$$

where Θ is the vector of all parameters. Numerical maximization of the log-likelihood function following the Berndt, Hall, Hall, and Hausman (1974) algorithm yields the maximum likelihood estimates and associated asymptotic standard errors.

An expansion of the GARCH-BEKK parameterisation equation for the bivariate GARCH (p, q) model takes the form:

$$\begin{pmatrix} h_{11,t+1} & \\ h_{12,t+1} & h_{12,t+1} \end{pmatrix} = \begin{pmatrix} c_{11} & c_{12} \\ c_{12} & c_{22} \end{pmatrix} * \begin{pmatrix} c_{11} & c_{12} \\ c_{12} & c_{22} \end{pmatrix} +$$
$$\begin{pmatrix} b_{11} & b_{21} \\ b_{12} & b_{22} \end{pmatrix} * \begin{pmatrix} h_{11,t+1} & \\ h_{12,t+1} & h_{22,t} \end{pmatrix} * \begin{pmatrix} b_{11} & b_{12} \\ b_{12} & b_{22} \end{pmatrix} + \quad (5)$$
$$\begin{pmatrix} \alpha_{11} & \alpha_{21} \\ \alpha_{12} & \alpha_{22} \end{pmatrix} * \begin{pmatrix} e_{1,t} \\ e_{2,t} \end{pmatrix} * \begin{pmatrix} e_{1,t} & e_{2,t} \end{pmatrix} * \begin{pmatrix} \alpha_{11} & \alpha_{12} \\ \alpha_{12} & \alpha_{22} \end{pmatrix}.$$

where h_{11},t + 1 is the volatility for the first series in period t + 1; $h_{22,t+1}$ is the variance of the return series in period t + 1; $h_{12,t+1}$ is the covariance between the first and the second series in period t + 1; c_{11} is the constant coefficient for the first series in period t; c_{12} is the constant coefficient for the covariance between the two series in period t, and c_{22} is the constant coefficient for the second series in period t; b_{11} is the volatility coefficient for the first series in period t; b_{21} is the volatility spillover coefficient from the first series to the second series in period t; b_{12} is the volatility spillover coefficient from the second series to the first series in period t; b_{22} is the volatility coefficient for the second series in period t; a11 is the coefficient of error term for the first series in period t; a_{21} is the coefficient of error transmission from the first series to the second series in period t; a_{12} is the coefficient of error transmission from the second series to the first series in period t; a_{22} is the coefficient of error term for the second series in period t; $e_{1,t}$ is the error term for the first series in period t, and $e_{2,t}$ is the error term for the second series in period t.

Expanding the above equation to find the intercept terms, in particular the coefficients of lagged variance and covariance and the coefficients of lagged squared errors and lagged covariance of squared errors, this provides the following equation:

$$\begin{pmatrix} h_{11,t+1} & \\ h_{12,t+1} & h_{22,t+1} \end{pmatrix} = \begin{pmatrix} c_{11}^2 + c_{12}^2 & \\ c_{11}c_{12} + c_{12}c_{22} & c_{22}^2 + c_{12}^2 \end{pmatrix} +$$

$$\begin{pmatrix} b_{11}^2 h_{11,t} + 2b_{11}b_{21}h_{12,t} + b_{21}^2 h_{22,t} & \\ b_{11}b_{12}h_{11,t} + (b_{11}b_{22} + b_{12}b_{21})h_{12,t} + b_{21}b_{22}h_{22,t} & b_{22}^2 h_{22,t} + 2b_{12}b_{22}h_{12,t} + b_{12}^2 h_{11,t} \end{pmatrix} + \quad (6)$$

$$\begin{pmatrix} \alpha_{11}^2 \varepsilon_{1,t}^2 + 2\alpha_{11}\alpha_{21}\varepsilon_{1,t}\varepsilon_{2,t} + \alpha_{21}^2 \varepsilon_{2,t}^2 & \\ \alpha_{11}\alpha_{12}\varepsilon_{1,t}^2 + (\alpha_{11}\alpha_{22} + \alpha_{12}\alpha_{21})\,\varepsilon_{1,t}\varepsilon_{2,t} + \alpha_{21}\alpha_{22}\varepsilon_{2,t}^2 & \alpha_{22}^2\varepsilon_{2,t}^2 + 2\alpha_{12}\alpha_{22}\varepsilon_{1,t}\varepsilon_{2,t} + \alpha_{12}^2\varepsilon_{1,t}^2 \end{pmatrix}$$

Without using matrices, in a bivariate case, the GARCH-BEKK model takes the form:

$$h_{11,t+1} = c_{11}^2 + c_{12}^2 + \alpha_{11}^2\varepsilon_{1,t}^2 + 2\alpha_{11}\alpha_{21}\varepsilon_{1,t}\varepsilon_{2,t} + \alpha_{21}^2\varepsilon_{2,t}^2 + b_{11}^2 h_{11,t} + 2b_{11}b_{21}h_{12,t} + b_{21}^2 h_{22,t} \quad (7)$$

$$h_{12,t+1} = c_{12}c_{11} + c_{12}c_{22} + \alpha_{11}\alpha_{12}\varepsilon_{1,t}^2 + (\alpha_{21}\alpha_{12} + \alpha_{11}\alpha_{22})\varepsilon_{1,t}\varepsilon_{2,t} + \alpha_{21}\alpha_{22}\varepsilon_{2,t}^2 + b_{11}b_{12}h_{11,t} + (b_{12}b_{21} + b_{11}b_{22})h_{12,t} + b_{21}b_{22}h_{22,t} = h_{21,t} \quad (8)$$

$$h_{22,t} = c_{12}^2 + c_{22}^2 + \alpha_{12}^2\varepsilon_{1,t}^2 + 2\alpha_{12}\alpha_{22}\varepsilon_{1,t}\varepsilon_{2,t} + \alpha_{22}^2\varepsilon_{2,t}^2 + b_{12}^2 h_{11,t} + 2b_{12}b_{22}h_{12,t} + b_{22}^2 h_{22,t} \quad (9)$$

where a_{11} is the coefficient of noise for the first series of equities; a_{12} is the coefficient of noise transmission from the second series of equities to the first series of equities; a_{21} is the coefficient of noise transmission from the first series of equities to the second series of equities; a_{22} is the coefficient of noise of the second series of equities; is the coefficient of volatility for the first series of equities; . is the coefficient of volatility transmission from the second series of equities to the first ; b_{21} is the coefficient of volatility transmission from the first series of equities to the second; h_{11} is the estimated volatility of the first series of equities; h_{22} is the estimated volatility of the second series of equities; h_{12} is the covariance between the second series of equities and the first series of equities; e_1 is the error term in the first series of equities; e_2 is the error term in the second series of equities; c_{11} is the constant coefficient of covariance for the first series of equities; c_{12} is the constant coefficient of covariance between the second series of equities and the first series of equities.

This model can be economised by imposing the following restriction on the above equation: $B'H_tB = 0$. The main limitation to estimating bivariate GARCH type models is the large number of parameters that have to be estimated when the log-likelihood function is maximised; this number is equal to $n*(n + 1)/2 + (p + q)*n2*(n + 1)*2/4$. Two possible restrictions are suggested in the literature. The first one is suggested by Bollerslev *et al.* (1988), in particular, they set $p = q = 1$ and make the matrices A and B diagonal, reducing the number of parameters in the log-likelihood function to $3n*(n + 1)/2$. This restriction eliminates the possibility of capturing any transmission between pricing series with the GARCH–BEKK model. It also provides a means of estimating two univariate GARCH processes where in the second one only conditional covariance estimates are considered. In particular, this model takes the form:

$$h_{11,t+1} = c_{11}^2 + \alpha_{11}^2\varepsilon_{1,t}^2 + b_{11}^2h_{11,t} \tag{10}$$

$$h_{22,t} = c_{11}^2 + c_{22}^2 + \alpha_{22}^2\varepsilon_{2,t}^2 + b_{22}^2h_{22,t} \tag{11}$$

$$h_{12,t} = h_{21,t} = c_{11}c_{22} + \alpha_{11}\alpha_{22}\varepsilon_{1,t}\varepsilon_{2,t} + b_{11}b_{22}h_{12,t} \tag{12}$$

$$h_{21,t} = h_{12,t} \tag{13}$$

The second restriction is suggested by Bollerslev (1990) who proposes that the correlation between variables to be time-invariant and, therefore, allows the covariance of equities to change and be equal to:

$$h_{ij,t} = p_{ij}\,(h_{ii,t} * h_{jj,t})^{1/2} \tag{14}$$

This could reduce the number of parameters in the log-likelihood function, allowing each individual variance to behave as a univariate GARCH (p, q) process and also resulting in a small number of $3n + n*(n + 1)/2$ parameters. In this case, the GARCH-BEKK model takes the form:

$$h_{11,t} = c_{11} + \alpha_{11}\varepsilon_{1,t}^2 + b_{11}h_{11,t} \quad (15)$$

$$h_{22,t} = c_{22} + \alpha_{22}\varepsilon_{2,t}^2 + b_{22}h_{22,t} \quad (16)$$

$$h_{12,t} = h_{21,t} = c_{12}\sqrt{h_{11,t} * h_{22,t}} \quad (17)$$

$$h_{21,t} = h_{12,t} \quad (18)$$

where,

$c_{12} = Q(1,2)/\sqrt{(c_{11} * c_{22})}$ and $Q(1,2)$ is the covariance matrix. (19)

The above three models govern a different covariance equation. Hence, it is not clear whether the parameters for h_{12} are just the result of the parameter estimates for h11 and h_{22} or if the covariance equation alters the parameters estimates of the variance equations for the above equations.

5. Empirical Results

In this section we present and discuss the findings of our empirical analysis. We employ multivariate GARCH–BEKK–CAPM models to explore the dynamic of spillovers between the log difference of twin equities and their respective stock exchanges where they are listed. We examine this issue having or not as explanatory variables in the return equations of the models the exchange rates between the currencies in which locally these twin equities are traded and also the exchange rate of one of the local currency of the twin equities against the US dollar currency. In addition, we take into account in the residual equation of the return series the impact of systematic betas on the log price difference of the twin equity. For more details in this specification, see the section above where this is shown with specific equations.

5.1. Results of spillovers between Royal Dutch-Shell and the respective exchange

Table 3, Panel A and B report the results from estimating the multivariate GARCH-BEKK-CAPM model without and with explanatory variables of two exchange rates, a local and a global one. We test the null hypothesis of no spillovers and systematic beta effects against the alternative that there are spillovers and systematic beta effects. The null hypothesis is equivalent to a segmented European stock market where there is no link between arbitrage and stock exchanges and the alternative is that there is an integrated stock market where there is a link between arbitrage and stock exchanges. The T-Statistic is used to employ this hypothesis.

Table 3: *Information Transmission Results from a CAPM-GARCH multivariate framework for Royal Dutch price premium, Paris, German and Brussels stock exchanges:*

		ROYLDS Paris German Brussels
	Coefficient (Std. Error)	T-Statistic (Signif. Level)
Panel A: A Simple Approach		
	Systematic Beta Effects	
From Paris to ROYLDS	0.001 (0.004)	0.34 (0.73)
From German to ROYLDS	0.001 (0.005)	0.22 (0.83)
From Brussels to ROYLDS	−0.002 (0.005)	−0.47 (0.64)
	Error Transmission	
From Paris to ROYLDS	0.089 (0.031)	2.86 (0.004)
From German to ROYLDS	0.12 (0.027)	4.47 (0.00)
From Brussels to ROYLDS	0.10 (0.019)	5.49 (0.00)
From ROYLDS TO German	0.16 (0.057)	2.91 (0.004)
From ROYLDS to Brussels	0.17 (0.073)	2.37 (0.018)
Log-Likelihood	50054.83	

Panel B: Considering Two	Explanatory Variables in the OLS: NLGTGBP and NLGTU$	
	Systematic Beta Effects	
From Paris to ROYLDS	0.008	1.20
	(0.007)	(0.23)
From German to ROYLDS	−0.001	−0.31
	(0.004)	(0.76)
From Brussels to ROYLDS	−0.008	−2.81
	(0.003)	(0.005)
	Error Transmission	
From Paris to ROYLDS	−0.078	−3.093
	(0.025)	(0.002)
From German to ROYLDS	0.097	5.062
	(0.019)	(0.00)
From ROYLDS to Paris	0.13	2.89
	(0.044)	(0.004)
From ROYLDS to German	0.33	7.19
	(0.046)	(0.00)
From ROYLDS to Brussels	0.26	4.61
	(0.055)	(0.00)
Log-Likelihood	49561.85	

Notes: ROYLDS means Royal Dutch-Shell. NLGTGBP means the exchange rate of Netherlands currency to Great Britain Currency and NLGTU$ means the exchange rate of Netherlands currency to US dollar currency.

In Panels A and B, we report that the log-likelihood value of the multivariate GARCH-BEKK-CAPM models is almost equal, 50054.83 (in Panel A) and 49561.85 (in Panel B). This shows that the variance between the two Panels is equal. Significant spillovers exist only for the noise changes and not for the price changes as it is shown from the results of Table 3. In particular, Panel A shows that there is spillovers from Paris (German or Brussels) to (Royal Dutch–Shell) twin difference and only German and Brussels is influenced by the twin equity difference of (Royal Dutch-Shell). This means that the difference in stock price of (Royal Dutch-

Shell) is well integrated with the foreign stock exchanges where there is a listing. A similar result is observed in Panel B. In particular, there is spillovers from Paris (German) to (Royal Dutch – Shell) twin difference and Paris, German and Brussels is influenced by the twin equity difference of (Royal Dutch-Shell). Again, this is supportive of a well integrated European stock market.

In addition, the systematic beta effects are not significant in Panel A while in Panel B is significant for the Brussels stock exchange. This means that the covariance ((Royal Dutch-Shell), stock index of Brussels) / Variance (Royal Dutch-Shell) affects the variance of the twin equity of (Royal Dutch-Shell) in Panel B. This also means that there is country-specific risk from Brussels stock exchange which affects the arbitrage difference of the twin equity difference of (Royal Dutch-Shell) in Panel B.

To sum up, taking the results of the two cases, Panel A and Panel B, we could say that there are no extremely significant differences for the direction of spillovers and also the systematic beta effects which arise from the covariance (1,2) / variance (1,2) of the two variables under investigation. This means that the inclusion of the two explanatory variables of exchange rates (one local and one global) do not add new value in the market integration process and systematic beta. There are only few changes in the integration process and systematic beta effects but these are minor taking into account the whole integration process under consideration. Therefore, the results between the two panels (A and B) are quite similar.

Table 4 (Panels A and B) report the results of spillovers between the log price difference of (Royal Dutch-Shell) and the stock exchanges of Luxembourg and Zurich and also the systematic beta effects from Luxembourg and Zurich to (Royal Dutch-Shell) difference without and with explanatory variables of exchange rates. In contrast to the results of spillovers of the log price difference of (Royal Dutch-Shell) and the stock exchanges of Paris, German and Brussels, here we have found that the explanatory variables of the exchange rates of Netherlands currency to Great Britain pound and the Netherlands currency to US dollar add value on the European integration process. This happens because the transmission of volatility from Luxembourg (Zurich) to (Royal Dutch-Shell) and also from (Royal Dutch-Shell) to Zurich found to be significant in Panel B of Table 4, while previously in Panel A of table 4 these effects do not exist. Therefore, we can conclude here that the explanatory variables of exchange rates are important in order to understand the dynamics of spillovers between markets.

Table 4: *Information Transmission Results from a CAPM-GARCH multivariate framework for Royal Dutch price premium, Luxembourg and Zurich stock exchanges:*

		ROYLDS Luxembourg Zurich
	Coefficient (St. Error)	T-Statistic (Signif. Level)
Panel A: A Simple Approach		
	Systematic Beta Effects	
From Luxembourg to ROYLDS	0.001	0.50
	(0.002)	(0.61)
From Zurich to ROYLDS	−0.001	−0.073
	(0.003)	(0.94)
	Error Transmission	
From Luxembourg to ROYLDS	0.051	3.41
	(0.015)	(0.00)
From Zurich to ROYLDS	0.10	7.71
	(0.013)	(0.00)
From ROYLDS to Zurich	−0.23	−6.68
	(0.034)	(0.00)
Log-Likelihood	38018.84	

Panel B: Considering Two Explanatory Variables in the OLS:	NLGTGBP	NLGTU$
Systematic Beta Effects		
From Luxembourg to ROYLDS	−0.002	−1.15
	(0.001)	(0.25)
From Zurich to ROYLDS	−0.001	−0.43
	(0.002)	(0.25)
Volatility Transmission		
From Luxembourg to ROYLDS	−0.64	−8.95
	(0.071)	(0.00)
From Zurich to ROYLDS	0.66	5.077
	(0.13)	(0.00)
From ROYLDS to Zurich	−0.36	−4.74
	(0.075)	(0.00)
Error Transmission		
From Zurich to ROYLDS	−0.15	−4.82
	(0.031)	(0.00)
From ROYLDS to Zurich	0.15	3.29
	(0.045)	(0.001)
Log-Likelihood	37882.88	

Notes: ROYLDS means Royal Dutch-Shell. NLGTGBP means the exchange rate of Netherlands currency to Great Britain Currency and NLGTU$ means the exchange rate of Netherlands currency to US dollar currency.

5.2. Results of spillovers between (ASEA-ABB) and the respective exchanges

Following our previous findings that there is a well integrated European market considering the spillovers between the variables of (Royal Dutch-Shell) and the respective stock markets in which the above mentioned twin equity is listed, we further also consider a GARCH-BEKK-CAPM model to measure the level of integration of the (ASEA-ABB) and their respective stock markets in which the above mentioned twin equity is listed. In addition, we also measure the systematic beta effects which arise from the relevant stock exchanges in which the twin equity is listed to the log stock price difference of (ASEA-ABB). We also employ a similar analysis for the difference of the twin equity of (ASEA-ABB) and the respective stock markets on which is listed taking into consideration two explanatory variables of exchange rates (Swedish Crone to Swiss franc and Swedish crone to US dollar) in the return equation (1).

Table 5, Panel A reports the results for the GARCH-BEKK-CAPM model without including in the return equation (1) any exlanatory variables. This panel testing for volatility and error spillovers between the above mentioned variables, where the null hypothesis is of no volatility transmission, error dependence and systematic beta effects and the alternative is that there is volatility transmission, error dependence and systematic beta effects. The null hypothesis of no error dependence is rejected in favour of the alternative of error dependence on the basis of the significantly unilateral transmission of noise from (ASEA-ABB) to Copenhagen (German) stock exchange. However, we can not reject the null hypothesis of no volatility transmission between the above mentioned variables and systematic beta effects from the stock indexes to the log price difference of (ASEA-ABB). This means that there is partly noise dependence (partly integration), which is well captured by the GARCH-BEKK-CAPM technique.

Table 5: *Information Transmission Results from a CAPM-GARCH multivariate framework for ASEA-ABB price premium, Copenhagen, and German stock exchanges:*

		ASEAABB Copenhagen German
	Coefficient (St. Error)	T-Statistic (Signif. Level)
Panel A: A Simple Approach		
	Systematic Beta Effects	
From Copenhagen to ASEAABB	−0.001 (0.038)	−0.001 (0.99)
From German to ASEAABB	0.001 (0.028)	0.001 (0.99)

	Error Transmission	
From ASEAABB to Copenhagen	3.66	4.17
	(0.88)	(0.00)
From ASEAABB to German	1.33	4.054
	(0.33)	(0.00)
Log-Likelihood	23577.15	
Panel B: Considering Two	**Explanatory Variables in the OLS: NLGTGBP and NLGTU$**	
	Systematic Beta Effects	
From Copenhagen to ASEAABB	0.002	0.71
	(0.003)	(0.47)
From German to ASEAABB	0.001	0.015
	(0.005)	(0.98)
Volatility Transmission		
From Copenhagen to ASEAABB	−0.18	−2.31
	(0.077)	(0.021)
From ASEAABB to Copenhagen	0.34	2.52
	(0.14)	(0.012)
From German to ASEAABB	0.24	1.97
	(0.12)	(0.049)
From ASEAABB to German	−1.43	−5.028
	(0.28)	(0.00)
	Error Transmission	
From Copenhagen to ASEAABB	−0.16	−13.24
	(0.012)	(0.00)
From ASEAABB to Copenhagen	−0.23	−2.52
	(0.089)	(0.012)
From ASEAABB to German	0.33	3.56
	(0.093)	(0.00)
Log-Likelihood	35348.39	

Note: ASEAABB means ASEA-ABB. SEKTSWISS means the exchange rate of Swedish crone currency and the Swiss franc currency and SEKTU$ means the Swedish crone currency to the US dollar currency.

The results for testing for transmission spillovers and systematic beta effects between the above mentioned variables with explanatory variables of exchange rates (see above) in the return equation (1) are reported in Panel B. Not only can the null hypothesis of no error dependence be rejected but also the null hypothesis of volatility transmission. The results of the null hypothesis of no systematic beta effects can not be rejected here as well. Comparing this result with the results from Panel A with respect to the level of integration process, we observe that in Panel B the integration process defined well and not only partly as mentioned for Panel A. This result here suggests that there are bilateral volatility and noise spillover effects and therefore a different level of integration is evident. The Log-likelihood value of Panel A and B further supports this finding.

To sum up, table 5 (Panel A and B) shows that there is a lower level of integration between the log difference price of (ASEA-ABB) and the stock markets of Copenhagen and German without any explanatory variables of exchange rates in the return equation 1 than with explanatory variables. These results provide evidence of co-movement between relative twin prices and the market indexes for long horizons.

6. Conclusions

This paper presents evidence that stock price differences (arbitrage) affected by the location of trade. The co-movements between price differentials (arbitrage) and market indexes are present at long horizons. Here we examined the volatility and noise spillovers and also the systematic beta effects which might arise between the log price difference of (Royal Dutch-Shell) and the respective stock market indices where the twin equity is listed and we also did the same for the (ASEA-ABB) twin equity difference and their respective stock indexes where the twin equity is listed.

The results reveal that the level of integration is affected by both the location of trade and the explanatory variables of exchange rates which are included in the return equation (1) of the GARCH-BEKK-CAPM model. Evidence on volatility and noise spillovers indicate that the relation between arbitrage and stock market integration is well captured showing a well integrated market in most of the cases where examined here. In addition, the systematic beta effects which might arise from the stock exchanges back to the twin price difference (arbitrage) is not present. Our results are in line with those of Froot and Dabora (1999) who found that the difference between the prices of twin stocks appears to be correlated with the markets on which these are listed.

NOTES

1. To make foreign investment for British investors even more disadvantageous, the British government impose an implicit tax on foreign investment in 1965. This so=called 'surrender rule' requires 25 percent of all foreign security sales, dividends, and interest to be surrendered at the existing (lower) noninvestment spot rate of exchange. These restrictions end on October 23, 1979.
2. King et al. (1994) suggest that the construction of covariance between markets on the basis of economic data is difficult.
3. This model takes into account the autocorrelation factor for returns and resuduals.
4. To measure the relative comovement of twin prices, Froot and Dabora (1999) regress the twin's log differential on US, UK, and Dutch market index log returns plus the relevant log currency changes.
5. This is important for smoothing the series for calculating the conditional volatility of returns according to the data. In this way, we transform the non-linear GARCH-BEKK model into a stochastic model.

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