Transmission of movements in stock markets

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The paper analyses the relationships between three stock markets: New York, Tokyo and Frankfurt. The non-simultaneity of the trading times in these three markets determines the results of cross-correlations and regressions with daily returns. To cope with this and other problems, an empirical model is proposed and estimated. This model allows the separation of the ability to influence and the sensitivity of the different markets, and New York is found to be the most influential market, with Tokyo the most sensitive.

Keywords: international linkages, stock markets, transmission of movements

1. INTRODUCTION

The relationships between international stock markets have received increasing attention since Grubel (1968) pointed out the benefits of international diversification. In order to ascertain the degree of integration of the different markets and, therefore, to evaluate the potential benefits, numerous researchers have studied these interrelationships. Several events have stressed this situation in recent years. These include the deregulation of financial markets and, in particular, the relaxation of controls on international capital movements and foreign exchange transactions; the technological revolution that has led to continued improvements in computer technology and telecommunications; the growing importance of institutional investors, such as pension funds and insurance companies which are very active in stock markets; and the increasing multinational operations of major firms, frequently listed on stock markets from different countries. The magnitude of the October 1987 crash, its world-wide occurrence and the absence of domestic causes intensified the interest in the transmission of movements across countries, to the point that it has become one of the major topics in empirical research.

The statistical and econometric methodology used in the research on this subject has been very diverse. Simple correlations (Becker *et al.*, 1992), regressions and causality tests (Malliaris and Urrutia, 1992), VAR analysis (Eun and Shim, 1989), cointegration (Corhay *et al.*, 1993), signal-extraction models with GARCH processes (Lin *et al.*, 1994), multivariate GARCH models (Karolyi, 1995) and other techniques have been used in studying the co-movements among the main world stock markets. Nevertheless, the conclusions are not unanimous at all, although the following result is present in most research: New York seems to be the most influential market, but is hardly affected by foreign movements.

Unfortunately, many contributions have one important limitation. The timings of the different markets are not always properly taken into account. The non-simultaneity of the trading intervals in the markets examined may substantially determine the results, especially when high frequency data are used. The conclusions regarding causation or leadership may simply reflect this non-simultaneity of trading times. For example, on a daily basis, if the trading time in a certain market antecedes the trading time in another market, price changes in the first market could affect those of the second on the same day, but the changes in the second market would affect those of the first on the following day. With daily data, many statistical methods would reflect a contemporaneous relationship, and, besides, an influence of the second market on the first with a lag of one day; however, the same statistical methods would be unable to reflect the possible influence of the first market on the second. Clearly, the conclusions regarding causation in these stock markets would hinge on the respective trading times.

To avoid these problems, several researchers have used intra-daily data. Thus, for example, Hamao *et al.* (1990) divide close-to-close stock index returns into their close-to-open and open-to-close components, and Susmel and Engle (1994) use hourly observations. While some problems are mitigated with this type of data, other problems arise. The higher the frequency of data, the more serious the problem of infrequent trading becomes. This problem may distort the results obtained, which, in fact, is one of the reasons why Susmel and Engle (1994, p. 5) use stock indexes and Booth *et al.* (1997, p. 1565) use stock index futures.

In addition to (and related with) this problem of trading times, there is the issue of the sources of movements in the different markets. Roughly speaking, two broad sources of movements can be distinguished.[1] On the one hand, there are global innovations whose influence is not restricted to just one market but affects different stock markets. On the other hand, there are specific innovations that affect only one market. Of course, these specific innovations, by their own nature, cannot account for the co-movements between different stock markets, which must originate exclusively from global factors. When studying these relationships, the investigation should focus on the global innovations and on the movements that they induce in the different stock markets. These global innovations are reflected in the stock prices immediately if the markets are open. But the markets are not open all day long and, therefore, cannot reflect these innovations until they open for trade. The response of the different markets to a certain global innovation occurs sequentially, according to the respective trading times. On a given day, a particular stock market will be affected by the global innovations that occurred since the preceding close until the current close, which will be reflected in the current price movement (close-to-close movement). Analogously, another market with different trading times will be affected by the global innovations that happened since its preceding close until its current close. Two possibilities arise when studying the

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[1] Similar distinctions have been made by other authors. See, for example, von Furstenberg and Jeon (1989), King and Wadhwani (1990) and Lin *et al.* (1994).

relationships of daily movements in these two markets. If both lapses of time (lapses of 24 hours, from the preceding close to the close on the day considered) are disjointed, their price movements will be independent, provided that the global innovations occur randomly. But if the lapses of time in the two markets do overlap, they will contain global innovations that affect both markets, generating the co-movements between them. Thus, it may be seen again that the trading times of the markets taken into account may play a decisive role.

Finally, most of the research on this topic evaluates the strength of the relationships between the different stock markets, and these evaluations are very often regarded as measures of leadership or causation. However, it would be desirable to dispose of measures of two aspects of these relationships that, to the best of our knowledge, have not yet been isolated: the influencing ability and the sensitivity of each of the markets. The effective influence of one market on another would arise from the interaction of the influencing ability of the first and the sensitivity of the second. The first factor would capture aspects like the valuation of global innovations by the corresponding market, and the second factor would reflect aspects like the degree of openness of the respective economy.

In this paper we propose an empirical model to cope with all these problems, and this model is applied to examine the daily interrelationships between the New York, Tokyo and Frankfurt stock markets. With that purpose, Section 2 presents the data used, stock price indexes from these three markets, and reports their trading times. In Section 3, some preliminary evidence consisting of cross-correlations and multiple regressions is shown, and their possible pitfalls are pointed out. In Section 4, a new model is proposed to determine these interrelationships. This model is estimated and the estimates obtained are commented on and interpreted. Finally, Section 5 summarizes the main results and conclusions.

2. DATA

Three stock markets, New York, Tokyo and Frankfurt, have been analysed. These have been selected from the world markets with the largest capitalizations because their trading times do not overlap, as shown in Fig. 1. Aside
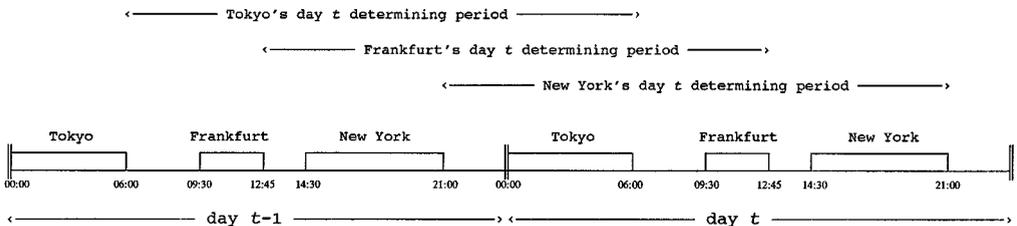

Fig. 1. Trading times in Tokyo, Frankfurt and New York

from holidays and weekends, the trading sequence in these three markets is as follows. When the day begins, Greenwich Mean Time (GMT), the Tokyo market opens for a six hour trading period with a two hour break in between. Three and a half hours after Tokyo closes, Frankfurt opens for a three and a quarter hour trading session; that is, from 9:30 to 12:45 GMT. One hour and three quarters later, at 14:30 GMT, New York opens for trade until 21:00 GMT. Three hours later a new day begins with the same sequence.

In order to measure the evolution of these stock exchanges, daily closing data for the Dow-Jones Industrial, Nikkei and Commerzbank indexes have been used. The Dow-Jones Industrial is an equally weighted index of 30 major industrial firms. This index adjusts for stock splits, but does not adjust for dividends. The Nikkei index is built in a similar way; it is also an equally weighted average of the largest 225 firms from all sectors traded in the first section of the Tokyo stock market. Finally, the Commerzbank index is a value weighted average of 60 major stocks traded on the Frankfurt stock market. It also adjusts for share issues, but does not adjust for dividends. The period considered extends from 2 January 1990 to 30 November 1993. This period was split into two subperiods: the sample period, from 2 January 1990 to 30 October 1992, and the post-sample period, from 2 November 1992 to 30 November 1993. Once Saturdays and Sundays were excluded from both periods, they cover 739 and 282 days, respectively. Thus, in the sample period, all the index series have 739 observations, some of which are missing values due to non-trading days. Close-to-close returns were obtained by logarithmic differences; that is, by $R_t = \log (I_t/I_{t-1})$ where R_t is the return for day t and I_t is the closing index for the same day computed at the closing times shown in Fig. 1. The returns whose calculation involved missing values have been considered missing values and, therefore, all the returns are one day returns, excluding all the Monday returns which are three day returns. In what follows NY_t, TO_t and FR_t denote the return on day t in New York, Tokyo and Frankfurt, respectively.

3.   PRELIMINARY EVIDENCE

Table 1 reports crossed correlations between the returns of these three markets. With the usual (Bartlett) asymptotic standard errors, $T^{-1/2}$, where T is the sample size, some of the correlation coefficients are significant. Thus, contemporaneous daily returns are correlated in all cases, with TO_t and FR_t presenting the largest correlation. NY_t is not correlated with TO_{t-1} or with FR_{t-1}, but TO_t and FR_t are correlated with NY_{t-1}. In addition, TO_t is correlated with FR_{t-1}. All other crossed correlations between markets for different lags and leads are not significant.

Before drawing some conclusions on the influence and leadership among these stock markets, it is important to notice that these results admit an explanation where the trading times play a crucial function. Under the efficiency hypothesis, daily returns (close-to-close returns) depend exclusively on the innovations occurring in the last 24 hours or, in the case of holidays or Monday returns, from the preceding close to the current close. Thus, for example, New York's return on day t, NY_t, depends exclusively on what happened from the

Table 1. Cross-correlations of returns

NY_t, TO_t	0.183*
NY_t, FR_t	0.267*
TO_t, FR_t	0.321*
NY_t, TO_{t-1}	−0.027
NY_t, FR_{t-1}	0.000
TO_t, NY_{t-1}	0.236*
TO_t, FR_{t-1}	0.128*
FR_t, NY_{t-1}	0.274*
FR_t, TO_{t-1}	−0.020

Cross-correlations between daily returns in different markets from 2 January 1990 to 30 October 1992. NY_t, TO_t and FR_t denote the returns on day t in New York, Tokyo and Frankfurt, respectively. The asymptotic standard error, $T^{-1/2}$, where T is the sample size, is equal to 0.037. The asterisk indicates that the corresponding correlation coefficient is different from zero at the 1% significance level.

close in the New York market on day $t-1$ until the close on day t. The same applies to the other stock markets. For a given day, these determining periods do overlap in different markets (see Fig. 1), and during these overlapping lapses global innovations surge that affect several stock markets, resulting in the co-movements and the positive correlations between returns in different markets, but on the same day. According to this hypothesis, the relationship between two markets should be more intense the longer the overlapping of the respective determining periods is. This hypothesis may be tested empirically, but two observations must be made. First, global innovations relevant for the stock market are not generated uniformly and, therefore, the different time intervals are not homogeneous throughout the day; the volume of world-relevant information generated in a certain daily lapse of time may differ substantially from the volume generated in another daily lapse of the same duration. Secondly, this approach does not exclude the possibility of a contagion effect, as proposed in King and Wadhwani (1990); one of the global innovations just mentioned may be the activity itself in one stock market.

These determining intervals and their overlapping can help to explain both the correlations between contemporaneous and between non-contemporaneous daily returns. With regard to the contemporaneous returns, they are correlated in the same way as the corresponding determining periods overlap. Additionally, it can be observed that the correlation estimates increase with the overlapping time. NY_t is more correlated with FR_t than with TO_t and, as can be appreciated in Fig. 1, the overlapping of the determining intervals is longer between New York and Frankfurt than between New York and Tokyo (in fact, the first overlapping includes the second).

With regard to the non-contemporaneous correlations, NY_t is not correlated with TO_{t-1} or with FR_{t-1} in the same way that the determining period

corresponding to NY_t does not overlap with the determining periods corresponding to TO_{t-1} or to FR_{t-1}. The contrary is true for TO_t and FR_t in relation with NY_{t-1}; in these cases the determining intervals for TO_t and FR_t do overlap with those corresponding to NY_{t-1}. Moreover, the correlation between TO_t and NY_{t-1} is higher than that between TO_t and FR_{t-1} in the same way that the first overlapping is longer than (in fact, it includes) the second. Looking at the correlations in Table l, a hasty analysis would conclude that the New York market affects the Tokyo and Frankfurt markets, but is not influenced by them. Nevertheless, as has been argued, it is possible to explain the magnitudes of daily correlations by means of the trading periods in the different markets.

A similar situation occurs when several markets are taken into account simultaneously. To see this, the regressions

$$TO_t = \gamma_0 + \gamma_1 NY_{t-1} + \gamma_2 FR_{t-1} + u_t \tag{1}$$

$$FR_t = \gamma_0' + \gamma_1' TO_t + \gamma_2' NY_{t-1} + u_t' \tag{2}$$

$$NY_t = \gamma_0'' + \gamma_1'' FR_t + \gamma_2'' TO_t + u_t'' \tag{3}$$

were estimated by ordinary least squares. In these equations, the return in each market on a certain day depends on the last daily returns in the other two markets. In addition, the same regressions were estimated excluding, in each equation, the market most recently closed. The results, shown in Table 2, present the following common features: (i) the regressors are clearly significant in all cases (with the only possible exception of Frankfurt's return in Tokyo's equation, whose t-statistic is 1.60); (ii) for all markets, the most significant (highest t-statistic) regressor is the return corresponding to the market most

Table 2. Regression of returns

$\hat{TO}_t = -0.001 + 0.516\ NY_{t-1} + 0.093\ FR_{t-1}$	
(−1.43) (5.99) (1.60)	$R^2 = 0.073$
$\hat{TO}_t = -0.001 + 0.196\ FR_{t-1}$	
(−1.75) (3.47)	$R^2 = 0.019$
$\hat{FR}_t = -0.0002 + 0.203\ TO_t + 0.293\ NY_{t-1}$	
(−0.45) (7.47) (5.11)	$R^2 = 0.155$
$\hat{FR}_t = -0.0005 + 0.413\ NY_{t-1}$	
(−1.10) (7.63)	$R^2 = 0.082$
$\hat{NY}_t = 0.0003 + 0.184\ FR_t + 0.053\ TO_t$	
(0.79) (6.37) (2.65)	$R^2 = 0.101$
$\hat{NY}_t = 0.0003 + 0.096\ TO_t$	
(0.87) (5.02)	$R^2 = 0.038$

Regressions of daily returns in each market on a constant and the last daily returns in the other markets from 2 January 1990 to 30 October 1992. NY_t, TO_t and FR_t denote the returns on day t in New York, Tokyo and Frankfurt, respectively. Values of t-statistics are in parenthesis.

recently closed; (iii) when excluding this most significant regressor, the significance of the other regressor increases remarkably.

Again, these results can be explained by taking the different trading times into account. The significance of the regressors is due to the fact that their determining intervals overlap with that of the regressand. In turn, the determining intervals of the regressors are overlapped among them. This means that common information is captured by both regressors, but, in all cases, the most significant regressor is the one whose determining interval overlaps the most with that of the regressand; it captures the same as the other regressor and more. When excluding this regressor, this sort of collinearity disappears and the other regressor reflects all the significance corresponding to its overlapping interval with an increase in its significance (*t*-ratios). This feature, it should be noted, is observed in the three markets.

The evidence reported in this section allows one to conclude that the results obtained with certain techniques regarding the relationships among stock markets depend critically on the different trading times and, specifically, on the position they occupy in a temporal sequence. The supposed relationships of influence and leadership could simply reflect the trading periods of the different markets.

4. A NEW MODEL

This evidence has shown that the trading times may play a critical role when studying the relationships between markets. It would be desirable to evaluate the ability of a given market to transmit information that can affect the other markets, independently of the overlapping of the determining intervals. Analogously, it would also be desirable to dispose of a measure of the sensitivity of a given market to global innovations first captured by other markets, independently the overlapping of the determining periods. Then, the effect of one market on another would be the joint result of the influencing ability of the first and the sensitivity of the second. A model that would allow this possibility is

$$TO_t = \alpha_{TO} + \beta_{NY} \cdot \lambda_{TO} \cdot NY_{t-1} + \beta_{FR} \cdot \lambda_{TO} \cdot FR_{t-1} + u_{TO,t} \tag{4}$$

$$FR_t = \alpha_{FR} + \beta_{TO} \cdot \lambda_{FR} \cdot TO_t + \beta_{NY} \cdot \lambda_{FR} \cdot NY_{t-1} + u_{FR,t} \tag{5}$$

$$NY_t = \alpha_{NY} + \beta_{FR} \cdot \lambda_{NY} \cdot FR_t + \beta_{TO} \cdot \lambda_{NY} \cdot TO_t + u_{NY,t} \tag{6}$$

This model is formed by three equations, one for each market. In each equation, the return in a stock market on date *t* depends linearly on the last returns in the other markets. These last returns may correspond to the same day *t* or to day $t-1$, but, in any case, their determining periods overlap with the return that appears as regressand. The effect of one market on another is the product of two factors: one factor depends on the influencing market and the other factor on the market being examined. Thus, for example, in (4), the return in Tokyo on day *t*, TO_t, depends on the returns in New York and Frankfurt on the preceding day, NY_{t-1} and FR_{t-1}, respectively. The influence of New York on Tokyo is the product of two parameters: β_{NY} and $\lambda_{TO} \cdot \beta_{NY}$ measures the ability of New York to

affect other markets; this ability depends on the volume of global innovations that occur from the close of Frankfurt to the close of New York, and these innovations are first captured by the New York market. λ_{TO} measures the sensitivity of Tokyo to movements in other markets. The interpretation for β_{NY} originates from the fact that, when the New York returns appear as regressors, they are always accompanied by this parameter, whatever the equation. The interpretation for λ_{TO} follows from the fact that this parameter always appears accompanying the regressors in Tokyo's equation. Analogously, the influence of Frankfurt on Tokyo on the following day is the product of β_{FR} and λ_{TO}; β_{FR} measures the influencing ability of Frankfurt, while λ_{TO} measures the sensitivity of Tokyo, as previously explained. The interpretation of the other two equations is entirely similar, where, as in the first equation, the β measures the influencing abilities and the λ measures the sensitivity in the corresponding markets. One important point that can be observed is that the sensitivity factor depends exclusively on the stock market receiving the influence, irrespective of the influent market. Conversely, the influencing ability of a given market does not depend on the markets receiving the influence.

In order to estimate the previous model, several problems must be faced, like the possible cross-correlation of error terms, the equality of some parameters in different equations, the non-identification of these equations and their non-linearity. Correlation of error terms in different equations would suppose a situation similar to a SURE (seemingly unrelated regressions model). This possibility was examined with the Breusch and Pagan (1980) test. The test statistic is $T(r^2_{45} + r^2_{46} + r^2_{56})$, where T is the number of observations and r_{ij} is the correlation coefficient of the least square residuals of equations i and j. Under the null hypothesis of absence of correlation, this statistic asymptotically follows a χ^2 distribution with three degrees of freedom. The value obtained for this statistic (0.49) means a *P*-value higher than 90%, so there is no statistical evidence of cross-correlations of the error terms. It is interesting to observe that this result is in accordance with the approach followed. The error terms reflect specific innovations occurring during the corresponding determining period, or global innovations occurring in lapses of the determining periods that do not overlap with those of the regressors. Thus, $u_{TO,t}$ would reflect the effect of Tokyo-specific innovations and the effect of the global innovations that are not contained in NY_{t-1} and in FR_{t-1} (that is, global innovations that occur between the close of New York on day $t-1$ and the close of Tokyo on day t). Analogously, $u_{FR,t}$ would capture the effect of Frankfurt-specific innovations and the effect of the global innovations that are not contained in TO_t and in NY_{t-1} (that is, global innovations that occur between the close of Tokyo on day t and the close of Frankfurt on the same day). Finally, u_{NYt} would reflect the effect of the New York-specific innovations and the effect of the global innovations that are not contained in FR_t and in TO_t (that is, global innovations that occur between the close of Frankfurt on day t and the close of New York on the same day). As the error terms reflect specific innovations or global innovations in non-overlapping but sequential time periods, there are no reasons to have cross-correlated error terms.

Another problem is the equality of some parameters in (4), (5) and (6). To incorporate this restriction of equal parameters across equations, the system (4)–(6) should be estimated jointly. Therefore, these equations were stacked obtaining the following regression.

$$
\begin{bmatrix} TO_2 \\ TO_3 \\ \vdots \\ TO_T \\ FR_2 \\ FR_3 \\ \vdots \\ FR_T \\ NY_1 \\ NY_2 \\ \vdots \\ NY_T \end{bmatrix}
=
\begin{bmatrix}
1 & NY_1 & FR_1 & 0 & 0 & 0 & 0 & 0 & 0 \\
1 & NY_2 & FR_2 & 0 & 0 & 0 & 0 & 0 & 0 \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
1 & NY_{T-1} & FR_{T-1} & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & TO_2 & NY_1 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & TO_3 & NY_2 & 0 & 0 & 0 \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
0 & 0 & 0 & 1 & TO_T & NY_{T-1} & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & FR_1 & TO_1 \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & FR_2 & TO_2 \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & FR_T & TO_T
\end{bmatrix}
\begin{bmatrix} \alpha_{TO} \\ \beta_{NY}\cdot\lambda_{TO} \\ \beta_{FR}\cdot\lambda_{TO} \\ \alpha_{FR} \\ \beta_{TO}\cdot\lambda_{FR} \\ \beta_{NY}\cdot\lambda_{FR} \\ \alpha_{NY} \\ \beta_{FR}\cdot\lambda_{NY} \\ \beta_{TO}\cdot\lambda_{NY} \end{bmatrix}
+
\begin{bmatrix} u_{TO,2} \\ u_{TO,3} \\ \vdots \\ u_{TO,T} \\ u_{FR,2} \\ u_{FR,3} \\ \vdots \\ u_{FR,T} \\ u_{NY,1} \\ u_{NY,2} \\ \vdots \\ u_{NY,T} \end{bmatrix}
\tag{7}
$$

Of course, neither the system (7) nor any of the single equations (4), (5) and (6) are identified. Nevertheless, we are not interested in the β or the λ, but in their relative values. So, λ_{FR} was fixed equal to 1, with the implication that the values of the other parameters should be understood as their ratios to this one. Identical ratios would be obtained if, alternatively, any other parameter were equalled to any arbitrary value.

Finally, given the non-linearity in parameters of model (7), it was estimated by non-linear least squares, applying the method of Gauss–Newton.

Table 3 shows the results of the estimation, and suggests a rather different behaviour of the three markets in their interrelationships. The β as well as the λ are clearly significant in all cases. As mentioned above, the interest does not lie in their absolute values, but rather in their relative values. These relative values indicate that New York is the most influential market; its estimate of β approximately doubles that of Tokyo and is more than three times the estimate of Frankfurt. On the other hand, the estimate of β corresponding to Tokyo is almost twice that of Frankfurt. Even admitting an intrinsic leadership of the New York market, other economic explanations must be considered. The co-

Table 3. Joint estimation of model (4), (5) and (6)

$\hat{\beta}_{NY}$: 0.341 (5.47)	$\hat{\lambda}_{NY}$: 0.600 (3.68)
$\hat{\beta}_{TO}$: 0.181 (6.09)	$\hat{\lambda}_{TO}$: 1.377 (4.53)
$\hat{\beta}_{FR}$: 0.103 (2.69)	$\hat{\lambda}_{FR}$: 1.000 (——)

Estimates of model (4), (5) and (6). The system was estimated jointly, as shown in (7), by non-linear least squares from 2 January 1990 to 30 October 1992. λ_{FR} was set equal to 1. The values in parenthesis are the t-ratios of the corresponding estimates. The coefficient of determination is $R^2 = 0.096$.

movements between different stock markets must originate exclusively from global innovations, and the influencing ability of one market should depend on the volume of those innovations first captured by this market. Among the markets analysed, New York is the first market to respond to global innovations occurring during eight hours and a quarter (from the close of Frankfurt, 12:45, to the close of New York, 21:00). Tokyo first captures nine hours (from the close of New York, 21:00 to the close of Tokyo, 06:00) and Frankfurt six hours and three quarters (from the close of Tokyo, 06:00, to the close of Frankfurt, 12:45). But global innovations are not generated uniformly throughout the day. From an economic point of view, some lapses of time are much more relevant than others of the same duration. Surely, the volume of global innovations generated from, say, 13:00 to 14:00 GMT is much larger than the volume generated from 05:00 to 06:00 GMT. This different density of global innovations could also help to explain the different influencing abilities.

With regard to the sensitivity of the markets, New York seems to be the most insensitive market, while Tokyo seems the most sensitive with a λ-value that more than doubles New York, and is higher than that of Frankfurt. These results are in accordance with the nature of the respective economies. The degree of openness of the Japanese and German economies is much higher than that of the US economy. This fact is reflected in the companies included in the indexes considered and, therefore, it is not surprising that the Tokyo and Frankfurt stock markets are much more sensitive to global factors.

It is interesting to compare equations (1), (2) and (3), estimated separately, with model (4)–(6), estimated jointly. This is accomplished in Table 4, where the product of the estimates with a multiplicative interaction in model (4)–(6) has been performed; that is, for example, the value that accompanies NY_{t-1} in Tokyo's equation is the result of the product of $\hat{\beta}_{NY}$ and $\hat{\lambda}_{TO}$ ($0.341 \times 1.377 = 0.470$). It can be observed that, in (4)–(6), the estimate corresponding to the first regressor (the market that has closed most recently) diminishes in comparison to equations (1), (2) and (3), while the estimate corresponding to the last regressor (the market that closed earlier) increases.

Table 4. Comparison of estimates

Estimates of equations (1), (2) and (3):

$$\hat{TO}_t = -0.0010 + 0.516\ NY_{t-1} + 0.093\ FR_{t-1}$$
$$\hat{FR}_t = -0.0002 + 0.203\ TO_t + 0.293\ NY_{t-1}$$
$$\hat{NY}_t = \ \ 0.0003 + 0.184\ FR_t + 0.053\ TO_t$$

Estimates of model (4)–(6):

$$\hat{TO}_t = -0.0010 + 0.470\ NY_{t-1} + 0.142\ FR_{t-1}$$
$$\hat{FR}_t = -0.0002 + 0.181\ TO_t + 0.341\ NY_{t-1}$$
$$\hat{NY}_t = \ \ 0.0003 + 0.062\ FR_t + 0.109\ TO_t$$

Comparison of equations (1), (2) and (3), estimated separately, with model (4)–(6), estimated jointly. Both estimations are from 2 January 1990 to 30 October 1992.

Table 5. Mean squared errors

	Observations	Equation (1)	Model (4)–(6)
Tokyo	191	0.014526%	0.014504%
	Observations	Equation (2)	Model (4)–(6)
Frankfurt	191	0.008133%	0.008034%
	Observations	Equation (3)	Model (4)–(6)
New York	194	0.003052%	0.002912%

Mean squared errors of the out-of-sample forecasts of equations (1), (2) and (3), estimated separately, and of model (4)–(6), estimated jointly as shown in (7), from 2 November 1992 to 30 November 1993.

This behaviour occurs for all the markets. In Tokyo's equation, the estimate that accompanies NY_{t-1} diminishes slightly, but the estimate that accompanies FR_{t-1} increases substantially. The changes in Frankfurt's equation are somewhat weaker but in the same direction: the estimate corresponding to TO_t diminishes while the estimate corresponding to NY_{t-1} increases. Finally, New York's equation varies most drastically; the estimate that accompanies Frankfurt's returns reduces to one third while the estimate that accompanies Tokyo more than doubles. As a result, the relative influence of these two markets on New York's returns reverses. When equation (3) is estimated separately, the influence of Frankfurt on New York is more than three times the influence of Tokyo (0.184 versus 0.053). But, when model (4)–(6) is estimated jointly, the influence of Tokyo almost doubles the influence of Frankfurt (0.109 versus 0.062).

In Section 3, it was shown that, in equations (1), (2) and (3), the most significant regressor is the return corresponding to the market most recently closed, and that, when excluding this regressor, the significance of the other regressor increases remarkably. The explanation proposed for this fact pointed out that common information is captured by both regressors, but, in all cases, the most significant regressor is the one with the longest overlapping determining interval. If this regressor is excluded, the collinearity disappears and the other regressor reflects all the significance corresponding to the extension of its overlapping intervals with an increase in its significance. Model (4)–(6) can be regarded as an attempt to overcome this problem. The relationships between stock markets must be analysed in a multivariate framework, but, in this setting, serious problems arise. The timings in the different markets originate specific estimation problems. In particular, the collinearity among the regressors seriously affects the estimates of the influence of one market on another. Model (4)–(6) aims properly to isolate and evaluate both the influencing abilities and the sensitivities in a multicountry setting.

Perhaps the most important criterion for judging the appropriateness of different models is their predictive power, and, in this respect, out-of-sample forecasts must be preferred to in-sample forecasts. To evaluate the predictive ability of equations (1), (2) and (3) compared with model (4)–(6), the estimates reported in Table 4 have been used to compute the forecasts of daily returns in

the three markets from 2 November 1992 to 30 November 1993. For all markets, model (4)–(6) presents lower mean squared errors than those obtained with equations (1), (2) and (3). The improvements are rather modest, but two remarks must be made. First, they occur in all markets (0.15% in Tokyo, 1.2% in Frankfurt and 4.5% in New York). Second, these small improvements must be seen from the perspective of stock markets, where the accuracy of forecasts is usually low. Of course, this does not necessarily mean that model (4)–(6) can be used to better the forecasts and obtain abnormal profits; doubtless, the predictable movements are already reflected in the opening prices, and, therefore, this superior predictive power could not be exploited. The important point to be stressed here is that the forecasts made with model (4)–(6) are more accurate in each case than those made with single equations (1), (2) and (3). In addition, model (4)–(6) yields sensitivity and influential measures for each market.

Further research should extend this model in several directions. First, it would be interesting to examine other stock markets with this model, and, particularly, markets with overlapping trading times. Second, in an increasingly related world, other economic variables may be examined in the light of this model.

5. CONCLUSIONS

The interrelationships between world stock markets have received increasing attention in recent years. To cast some light on this issue, several statistical and econometric methods have been used. However, the non-simultaneity of trading times in the markets examined may originate specific problems, especially when high frequency data are used; the conclusions obtained with regression- or correlation-based methods may simply reflect the different trading times, instead of real relationships of influence.

This study has investigated the relationships between daily returns in the New York, Tokyo and Frankfurt stock markets, from January, 1990 to September, 1993. For the purpose, an empirical model is proposed that presents the following distinctive features: (i) it decomposes the relationship between markets into two factors, ability of influence and sensitivity, and the exact relationship between them arises from the interaction of these factors; (ii) both factors remain constant when examining the interrelationships with other markets, irrespective of their trading times; (iii) as a result of the preceding points, the model provides the relative influencing measures and sensitivities of the markets analysed.

The results obtained with this model present some differences from those obtained with regressions- or correlations-based methods. The relative importance of the markets are modified, and in one case the changes are drastic. New York is found to be the most influential market, with an influence ability that almost doubles that of Tokyo and triples that of Frankfurt. On the other hand, Tokyo is found to be the most sensitive market, with a level of sensitivity that more than doubles that of New York, with Frankfurt between the two. Finally, out-of-sample forecasts with this model outperform, slightly but in all

cases, those made with more conventional methods for each of the three markets considered.

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