Discussion Paper No. 98 - 13

Shock Around the Clock – On the Causal Relations Between International Stock Markets, the Strength of Causality and the Intensity of Shock Transmission. An Econometric Analysis.

Robert Dornau

Nontechnical Summary

This paper investigates empirically the interrelationships between the daily stock market returns of the stock exchanges of Tokyo (Japan), Frankfurt (Germany) and New York (USA). The respective stock exchanges are represented by the Nikkei 225, DAX and Dow Jones Industrial index. The observation period is October 1985 to October 1997 – the tenth anniversary of the October 1987 crash.

The nature of international transmission of stock returns has been a focus of extensive studies. Former works conclude that empirically, only uni-directional causality from the US to foreign markets can be shown. Many former articles have in common that the chronological order of the markets has not been used to model the system of variables correctly. To investigate the interactions correctly in an econometric model, we have to consider the fact that the stock markets are located in different time zones. This paper makes use of different models depending on when a shock/information enters the system of the three markets. Analysis of the structural properties leads to the examination of four separated periods. We find a changing causality structure between the markets. Therefore, we use a measure for the strength of causality and impulse response functions to facilitate an analysis of the changing structure. Throughout 1988-1997 the effect of other markets on the New York Stock exchange has been continuously decreasing, while the New York market's influence on DAX has been increasing. The intensity of the interrelationsships between the Nikkei on foreign markets has been decreasing.

The extension of Wallstreet's influence on German investors is well visible in the impulse response functions as well as the causality measure. Both increased particularly in the last observed period that ends just before the global market breakdown in October 1997. Despite an opposite economic movement – growing unemployment in Germany compared to stable growth in the USA – we observe rising stocks on Wall Street as well as in Frankfurt. This analysis reveals emperically the direction and strength of this interrelation.

Finally, the obtained relations are interpreted employing a model of different possible factors moving international stock markets. The analysis shows that in this context causality simply proofs that one market was useful for the prediction of another. Because of sudden structural breaks, it is not possible to use the models for ex ante prediction. The theory of global information does not support the theory of causality between the market returns. It has to be assumed that if new global information is available, the reaction of one market is not caused by the change of the previous index but by global information itself. On the other hand, if herd behavior exist, one market follows the other for psychological reasons without any economic or political background. Thus, the causality structures that were found would display cause and effect relations.

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February 1998

Abstract

This paper investigates empirically the interrelationships between the daily stock market returns of the Nikkei 225, DAX and Dow Jones Industrial index. Contrary to former work this paper uses the succession of the markets in time to form different econometric models. In this way it is possible to detect causality not only from the US to foreign countries but in some cases vice versa. The observation period is October 1985 to Ocotber 1997. Analysis of the structural properties leads to the examination of four separated periods. Results for Hosoyas measure of the strength of causality and impulse response analysis facilitate a dynamic analysis of the causal structure. Increasing influence from NYSE to foreign markets can be shown, whereas influence of the foreign markets on the Dow Jones is decreasing.

JEL-Classification: C32, G15

Keywords: Granger Causality, Causality Measure, Shock Transmission, International Stock Markets,VAR

Acknowledgments:
The author wishes to thank Frank Gerhard - University of Konstanz, Olaf Korn, Herbert Buscher - ZEW, and Hans Juergen v. Lengerke - City University London for helpful discussions and suggestion.

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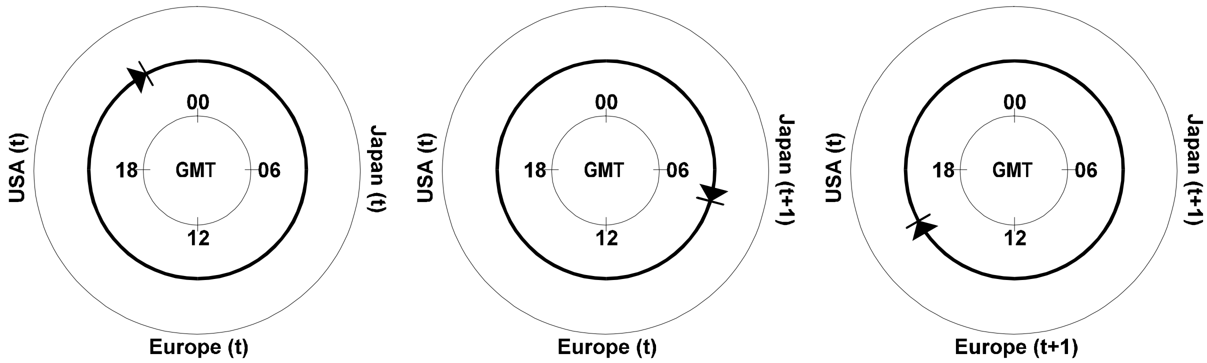
1 Introduction

The 1987 crash triggered the interest in the interrelation of global stock markets. Since then, the nature of international transmission of stock returns has been a focus of extensive studies. Von Fuerstenberg and Jeon (1989) investigated which factors move global markets and examined possible correlations between the New York, Tokyo, Frankfurt and London markets for the period 1986-88. Eun and Shim (1989) tested for Granger-causality between the US and nine foreign markets in the period 1979-85 finding dominant influence of the US market. Neumark, Tinsley, and Tossini (1991), Becker, Finnerty, and Gupta (1990), and Cochran and Mansur (1991) examined the period around the crash studying the correlation and causality between New York, Tokyo and other international stock markets. All these articles find increasing correlation between international markets after the crash and a dominant influence of the New York stock market. The studies also conclude that only uni-directional causality from the US to foreign markets can be shown empirically.

A common problem of the above studies is that the chronological order of the markets has not been employed to model the system of information flow in international stock markets. The special situation given by the chronological ordering of international stock markets was – among other things – a motive for the research addressed in this paper. We investigate empirically the relationships between the daily stock market returns of the stock exchanges of Tokyo (Japan), Frankfurt (Germany), and New York (USA). The respective stock exchanges are represented by the Nikkei 225, DAX and Dow Jones Industrial index. To investigate the interactions between these markets in an econometric model correctly, we have to consider the fact that the stock markets are situated in different time zones. Also, their floor trading hours do not overlap. The order of the markets – as given by time - also dictates the sequence in which each market can process new information. For this reason it is possible that the observation interval is inconsistent with the calendar date. The Tokyo stock market for example can not respond to a shock in the New York market on the same calendar date. When floor trading stops in New York at a local time of 4:00 p.m. on date *t*, local time in Tokyo is 06:00 a.m. on date *t+1*. Additionally, we have to be aware of the fact that if we investigate the transmission of shocks in global stock markets a shock can enter the system of markets at any time. The subsequent figures will illustrate the problem.[1]

Figure 1-1: Model of Information Flow



Model 1 **Model 2** **Model** 3

The arrows in the above figures represent the point in time at which the shock enters the system and thus indicates the start of the information flow. Only in Model 1 the information flow does not cross the date line. For this reason, we can not consider the data of two markets

[1] GMT: Greenwich Mean Time.

as a part of the same observation interval only because it is collected on the same calendar day. The attribution to one time interval (24h) depends on the flow of information. As long as a market was not able to process the relevant information it remains in the same observation interval *d*. This insight has to be taken into account when modeling the causal structure of international stock markets. Therefore, we construct a structural VAR to test for Granger-causality (see Granger (1969)).

When investigating relations between global stock markets we have to know the factors moving them. Following von Fuerstenberg and Jeon (1989) we can differentiate between three factors that influence international stock markets. Changes of an index can be caused by information of local or global relevance or by contagion effects. Only information of global relevance should have a worldwide impact on the stock markets. Lin, Engle, and Ito (1994), investigating correlations between Tokyo and New York markets, named the US Dollar as a global factor. The influence of changes in the exchange rate of the Dollar can have different implications. In one country, gains from changes in the exchange rate are made in the export sector whereas in another country they are made in the import sector. The effect on the stock index certainly depends on the relative weight of the appropriate sector in the index.

Another global factor is the oil price. This was last observable during the Kuwait crisis 1990. Oil prices increased some 50% leading to globally declining stock markets. Finally, it is possible that shocks are transmitted through the markets as a result of so called ‘herd’ behavior or contagion effects. This means that one market follows the movement of another not for economic but for psychological reasons.

The different factors that drive the markets motivated the idea of a changing structure in the system of global stock markets. In the observation period from 1985 to 1997, international stock markets were subject to changes of economic background as well as a changing psychological behavior of investors. For this reason, we examined the 13-years observation period for possible structural breaks. Significant breaks were found for the 1987 crash, the breakdown of the Japanese bubble economy beginning 1990 and the stabilization of the Nikkei at the turn of 1992. The last period ends just before the market breakdown Oktober 1997, as we think it may turn out to be a structural breakpoint. This leads to the analysis of four separated periods. An interesting question that arises here is, whether there are fewer causal relations with a weaker impulse response structure when the markets move in opposite directions?

The structural breaks that were found gave rise to in-depth research about the strength of the causal structure. Knowing the causality structure between the observed markets is only the first step for a dynamic analysis of the system. However, this is not yet satisfying. Having found the same causality structure in more than one period we want to know if the strength of causality is constant over time. To be able to measure the strength of causality also enables a better interpretation of feedback situations. In this case it is of considerable interest to know the strength of influence between the variables and especially, whether it is stronger in one direction or not. Taking this into account, we will investigate the intensity of the causal structure. This is done using a measure of causality as introduced by Hosoya (1991) and extended by Granger and Lin (1995) as well as impulse response functions (Sims (1980), Lütkepohl (1990)). The use of a structural VAR is of advantage for impulse response analysis as this assures orthogonalization of the system.

The main results are as follows. By implementing the chronological order of the markets in the econometric models, we are able to find Granger-causality from foreign markets to the US in the periods after the 1987 crash. However, the strength of these causalities is not constant over time. The influence of foreign markets on Dow Jones decreases, whereas it increases in the opposite direction.

Organization of the paper is as follows. Section 2 introduces the econometric model under correct consideration of the information flow. A description of the data and analysis of structural changes is given in Section 3. Empirical results are given in Section 4. Section 5 offers an interpretation of the results that were obtained. A summary is given in Section 6.

2 Consideration of the Information Flow in the Econometric Model

2.1 The Vector Autoregressive Model

As shown above, international stock markets are subject to a certain order, which is given by the direction in which information flows through the markets. This has implications for the econometric models which are used to analyze the system of stock markets. If we want to model a system of variables without being able to make an a priori distinction between exogenous and endogenous variables, we make use of a Vector Autoregressive Model (VAR)[2]. In our case we construct a VAR consisting of the autoregressive processes of three time series (the daily returns of Nikkei 225 Index (*NIK*), DAX and Dow Jones Industrial index (*DOW*).

$$\begin{bmatrix} NIK_d \\ DAX_d \\ DOW_d \end{bmatrix} = \begin{bmatrix} c_1 \\ c_2 \\ c_3 \end{bmatrix} + \begin{bmatrix} \Theta_{11}(L) & \Theta_{12}(L) & \Theta_{13}(L) \\ \Theta_{21}(L) & \Theta_{22}(L) & \Theta_{23}(L) \\ \Theta_{31}(L) & \Theta_{32}(L) & \Theta_{33}(L) \end{bmatrix} \begin{bmatrix} NIK_d \\ DAX_d \\ DOW_d \end{bmatrix} + \begin{bmatrix} u_{1d} \\ u_{2d} \\ u_{3d} \end{bmatrix} \qquad \text{2-1}$$

where $\Theta_{ij}(L) = \Theta_{ij}^1 L^1 + \ldots + \Theta_{ij}^p L^p$ for *i,j=1,2,3* [3]

In this case the observation period is not the calendar date *t*, but a 24 hour period *d*. In order to employ the VAR(*p*) model we have to make some assumptions concerning the behavior of these time series. The considered VAR is said to be covariance stationary. The error term vector is independent, identically distributed with mean zero and unknown non-singular residual covariance matrix Σ_u and existing fourth moments:

$$u_d = \begin{pmatrix} u_{1d} & u_{2d} & u_{3d} \end{pmatrix}' \sim \text{IID}\,(0, \Sigma_u) \qquad \text{2-2}$$

where:

$$E\left[u_s u_t{}'\right] = \begin{cases} \begin{bmatrix} \sigma_{11} & \sigma_{12} & \sigma_{13} \\ \sigma_{21} & \sigma_{22} & \sigma_{23} \\ \sigma_{31} & \sigma_{32} & \sigma_{33} \end{bmatrix} = \Sigma_u & \text{for s = t} \\ \\ 0 & \text{for s} \neq \text{t} \end{cases} \qquad \text{2-3}$$

Consequently we allow for contemporaneous correlation in the residuals but no autocorrelation. No autocorrelation can be assured by using an appropriate lag order *p*.

[2] For a detailed look at VAR modells see for example Lütkepohl (1991).

[3] *L*= lag operator, *p* = lag order, *c* = constant, *u* = error term.

2.2 Implications for Tests for Granger-Causality

According to Granger's (1969) concept of causality, a test for causality should employ all relevant information. This of course is a very restrictive assumption. However, by using data of the major stock markets in Japan, Europe and the USA, we try to cover at least the most important sources of information in time. This leads to the examination of trivariate models.

Testing for Granger-causality we use a method introduced by Boudjellaba, Dufour, and Roy (1992). They give a formulation of the concept of Granger-causality in a general multivariate situation. Following Boudjellaba et al. (1992) a test for Granger-causality in equation [2-1] tests bivariate causality[4] and not block causality. This means that even in a trivariate VAR in each test only coefficients of one variable are considered.

Using the given order of the three markets and the different possibilities for the start of the information flow, we can construct three different VAR models. This is shown easily by replacing *d* in equation [2-1] by the relevant calendar date derived from the different models in figure [1-1]:

- If the relevant new information is accessible before the end of trading hours in Tokyo, all three markets can process the information on the same calendar date *t*. This leads to the estimation of the VAR-1 model:

$$\begin{bmatrix} NIK_t \\ DAX_t \\ DOW_t \end{bmatrix} = \begin{bmatrix} c_1 \\ c_2 \\ c_3 \end{bmatrix} + \begin{bmatrix} \Theta_{11}(L) & \Theta_{12}(L) & \Theta_{13}(L) \\ \Theta_{21}(L) & \Theta_{22}(L) & \Theta_{23}(L) \\ \Theta_{31}(L) & \Theta_{32}(L) & \Theta_{33}(L) \end{bmatrix} \times \begin{bmatrix} NIK_t \\ DAX_t \\ DOW_t \end{bmatrix} + \begin{bmatrix} u_{1t} \\ u_{2t} \\ u_{3t} \end{bmatrix} \qquad \textbf{VAR-1}$$

- If the news enters the system after Tokyo's trading hours, and before trading in Frankfurt ends, only *DAX* and Dow Jones can be affected by this information on the same calendar date (Model 2). The Japanese stock market can not make use of this information before the next day, leading to this model:

$$\begin{bmatrix} NIK_{t+1} \\ DAX_t \\ DOW_t \end{bmatrix} = \begin{bmatrix} c_1 \\ c_2 \\ c_3 \end{bmatrix} + \begin{bmatrix} \Theta_{11}(L) & \Theta_{12}(L) & \Theta_{13}(L) \\ \Theta_{21}(L) & \Theta_{22}(L) & \Theta_{23}(L) \\ \Theta_{31}(L) & \Theta_{32}(L) & \Theta_{33}(L) \end{bmatrix} \times \begin{bmatrix} NIK_{t+1} \\ DAX_t \\ DOW_t \end{bmatrix} + \begin{bmatrix} u_{1t+1} \\ u_{2t} \\ u_{3t} \end{bmatrix} \qquad \textbf{VAR-2}$$

- If the flow of Information starts before or during trading hours in New York, only the Dow Jones is able to display the news the same day. Tokyo's and Frankfurt's floor trading markets have to wait until the next day.

$$\begin{bmatrix} NIK_{t+1} \\ DAX_{t+1} \\ DOW_t \end{bmatrix} = \begin{bmatrix} c_1 \\ c_2 \\ c_3 \end{bmatrix} + \begin{bmatrix} \Theta_{11}(L) & \Theta_{12}(L) & \Theta_{13}(L) \\ \Theta_{21}(L) & \Theta_{22}(L) & \Theta_{23}(L) \\ \Theta_{31}(L) & \Theta_{32}(L) & \Theta_{33}(L) \end{bmatrix} \times \begin{bmatrix} NIK_{t+1} \\ DAX_{t+1} \\ DOW_t \end{bmatrix} + \begin{bmatrix} u_{1t+1} \\ u_{2t+1} \\ u_{3t} \end{bmatrix} \qquad \textbf{VAR-3}$$

Testing for Granger-causality in VAR-1 does not make sense for all possible directions of causality. It is only possible to test whether *DAX* is not Granger-causal for *NIK* ($DAX \not\longrightarrow NIK$) or $DOW \not\longrightarrow NIK$. A closer look at each equation of the VAR-1 makes this clear. In VAR-1 today's observations are regressed on lagged observations. The influence on the Nikkei is portrayed correctly, as it can only react the next day. But today's Nikkei can

[4] Bivariate Granger-causality tests are described in standard econometric literature and are therefore not shown in detail (see e.g. Hamilton (1994) pp. 304).

influence *DAX* or *DOW* on the same day. As *DAX* or *DOW* is not regressed on today's Nikkei, this influence is not modeled correctly. The influence of today's *DAX* on today's *DOW* is not modeled correctly for the same reason. A test if $DOW \neq\rightarrow DAX$ is not possible because today's Nikkei is not included in the regression and as a result not all the necessary information as requested. We could derive spurious causalities inferring causality from *DOW* to *DAX* although yesterday's *DOW* has no useful information for a forecast of the *DAX*, which is not already contained in today's *Nikkei*. The same line can be drawn in the VAR-2 model. Here it is only possible to test if $NIK \neq\rightarrow DAX$ or $DOW \neq\rightarrow DAX$. In VAR-2 DAX_t is regressed on NIK_t and DOW_{t-1}, consequently using all relevant information for this direction of causality. The results for the three models are summarized in Table 2-1:

Table 2-1: Testable Hypotheses in the Different Models

Model	VAR-1	VAR-2	VAR-3
Possible tests	$DAX \neq\rightarrow NIK$	$NIK \neq\rightarrow DAX$	$NIK \neq\rightarrow DOW$
	$DOW \neq\rightarrow NIK$	$DOW \neq\rightarrow DAX$	$DAX \neq\rightarrow DOW$

2.3 Implications for Measures of Causality

Knowing the causality structure between the observed markets is a first step for the analysis of the system. However, it is not yet satisfying. Especially in feedback situations it is of considerable interest to know the strength of influence between the variables particularly if it is stronger in one direction.

Hosoya (1991) introduced a measure for the strength of causality that was extended by Granger and Lin (1995). Implementing Hosoya's idea to suit our model leads to the regression of equations [2-4] to [2-6]. As an example we derive a measure for the strength of Causality from *DAX* to *DOW*.

$$DOW_t = \sum_{i=1}^{p} a_i DOW_{t-i} + r_{1t} \qquad \textbf{2-4}$$

$$DAX_t = \sum_{i=1}^{p} a_i DOW_{t-i} + \sum_{i=1}^{p} b_i DAX_{t-i} + r_{2t} \qquad \textbf{2-5}$$

$$DOW_t = \sum_{j=1}^{p} \left(a_{1i} DOW_{t-i} + c_i r_{2t-i}\right) + r_{3t} \qquad \textbf{2-6}$$

where p is the lag order and r_{it} $i=1,2,3$ the error term

In order to reflect the information flow correctly, we have to transform Hosoya's model. In equation [2-5] we have to regress DAX_t on DOW_{t-i} where $i=1,\ldots,p$ and not $i=0,\ldots,p$, because of the sequence of the markets. Hosoya's measure of the degree to which DAX_t is causal for DOW_t is defined as:[5]:

$$M_{DAX \rightarrow DOW} = \log \frac{\mathrm{var}(r_{1t})}{\mathrm{var}(r_{3t})} \qquad \textbf{2-7}$$

An intuitive explanation for the measure is as follows: The variance of the residual r_{1t} of a regression of DOW_t on its own lagged values portrays the degree to which DOW_t is not explained by its own lagged values. The variance of residual r_{3t} reflects the degree to which DOW_t is not explained by lagged *DOW* and lagged *DAX*. If the inclusion of the lagged residual

[5] See Granger & Lin (1993), p. 532.

r_{2t} in regression [2-6] is of no advantage for the prediction of DOW_t, the variances of the error terms will be equal, Var(r_{1t})=Var(r_{3t}). In this case the measure is equal to zero. If r_{2t} is of advantage for the prediction of DOW_t, we observe a smaller variance so that Var(r_{1t}) > Var(r_{3t}). The value of the fraction in equation [2-7] will thus be greater than one and the measure *M* will be positive. Hence, the measure is either zero or positive without having an upper limit.

As the causality measure *M* is calculated using estimated figures, it is subject to statistical uncertainty. When using *M* for inference about the system we should be able to model this uncertainty. Unfortunately, Granger and Lin (1995) do not offer such a test in their paper. It may be difficult to present confidence intervals for the measure but as we show below, it can easily be tested whether *M* is significantly different from zero. As explained above, the measure will be zero if Var(r_{1t})=Var(r_{3t}). Therefore, the null hypothesis of a test if the measure is significantly different from zero is:

$$H_0: \mathrm{Var}(r_{1t})=\mathrm{Var}(r_{3t}) \qquad 2\text{-}8$$

Hamilton (1994) suggests testing this using a Wald-test. The test statistic is:[6]

$$\frac{T(\hat{\sigma}_{11}-\hat{\sigma}_{33})^2}{2\hat{\sigma}_{11}^2-4\hat{\sigma}_{13}^2+2\hat{\sigma}_{33}^2} \approx \chi^2(1) \qquad 2\text{-}9$$

where $\hat{\sigma}_{ij}^2$ *i,j=1,3* denotes the square of the estimated variance of the innovation in equation [2-4].

2.4 Implications for Impulse Response Functions

Sims (1980) first introduced impulse response analysis. He modeled the effects of 'typical shocks' to the system of variables. These typical shocks are positive residuals of one standard deviation unit in each equation of the system. Allowing contemporaneous correlation of the residuals as described in equation [2-3] has implications for impulse response analysis. In order to see the distinct patterns of movement that the system of markets may display, it is necessary to transform them into orthogonal form. Sims (1980) introduced a method of orthogonalization that is applicable to the case of international stock markets as these are subject to a given order. We triangulize the system with variables ordered as *NIK*, *DAX*, and *DOW*. Hence, the residuals whose effects are being tracked, are residuals from a system in which contemporaneous values of other variables enter the right-hand-sides of the regressions with a triangular array of coefficients. Hence we get a structural VAR in the form of [2-10], where e_{it} *i=1,2,3* are the orthogonalized residuals:

$$\begin{bmatrix} NIK_t \\ DAX_t \\ DOW_t \end{bmatrix} = \begin{bmatrix} c_1 \\ c_2 \\ c_3 \end{bmatrix} + \begin{bmatrix} 0 & 0 & 0 \\ B_{21}^0 & 0 & 0 \\ B_{31}^0 & B_{32}^0 & 0 \end{bmatrix} \begin{bmatrix} NIK_t \\ DAX_t \\ DOW_t \end{bmatrix} + \begin{bmatrix} B_{11}(L) & B_{12}(L) & B_{13}(L) \\ B_{21}(L) & B_{22}(L) & B_{23}(L) \\ B_{31}(L) & B_{32}(L) & B_{33}(L) \end{bmatrix} \begin{bmatrix} NIK_t \\ DAX_t \\ DOW_t \end{bmatrix} + \begin{bmatrix} e_{1t} \\ e_{2t} \\ e_{3t} \end{bmatrix}$$

$$\text{where } B_{ij}(L) = B_{ij}^1 L^1 + \ldots + B_{ij}^p L^p \text{ for } i,j=1,2,3 \qquad 2\text{-}10$$

The *NIK* equation is left unaltered, while the *DOW* equation includes contemporaneous values of the two remaining variables. A shock in the *NIK* equation, represented by the residual e_{1t} is assumed to disturb instantly all other variables of the system, according to the strength of the

[6] See Hamilton (1994) p. 301.

contemporaneous correlation of other residuals with the *NIK* residual. The *DAX* residual can not affect the *NIK* of the same day and the *DOW* residual is only allowed to affect the *DOW* variable of the same day. This way of modeling the system is consistent with the information flow methodology.

The given order of the variables has two additional implications for the impulse response analysis:

- Hamilton (1994) shows that in the special case of ordered variables the structural VAR represented by equation [2-10] can be derived easily using the orthogonalized form of VAR-1. In this case, the orthogonalized impulse-response coefficients give the dynamic consequences of the structural events represented by e_t. The only necessary assumptions are that the coefficient matrix B_o in equation [2-10] is lower triangular and that the residual covariance matrix Σ_e is diagonal. OLS estimation of the single equations in [2-10] leads to biased coefficients but the residuals of these estimations can be used to test the hypothesis „Cov(e_{it}, e_{jt})=0, $i,j=1,2,3$". Following Hamilton (1994)[7] the responding test statistic is:

$$\frac{\sqrt{T}\hat{\sigma}_{\mathrm{ij}}}{(\hat{\sigma}_{ii}\hat{\sigma}_{jj}+\hat{\sigma}_{\mathrm{ij}}^{2})^{1/2}} \approx N(0,1) \qquad 2\text{-}11$$

  where $\hat{\sigma}_{ij}$ $i,j=1,2,3$ are the elements of the covariance matrix Σ_e .

- The impulse response function plots have to be interpreted in a different manner. A shock in the *NIK* equation, represented by the residual e_{1t}, is assumed to disturb all other variables instantly. In our specific case "instantly" has the meaning of "in the same interval *d* (24h)". The succession of the markets in one interval *d* leads to the distinction of direct and non-direct impulse responses (IR) instead of contemporaneous and lagged IR, respectively. Following the information flow methodology a direct IR is specified independent of the calendar date. As long as the response is within a period of 24 h after the initial impulse, it is a direct response.

3 Data

The data used for estimation consist of the daily floor trading closing values of the stock indices of Tokyo (Nikkei 225 index), Frankfurt (DAX) and New York (Dow Jones Industrial). Country specific bank holidays led to the omission of these dates from the whole sample. We measure the stock return as the change in the logarithm of the stock index. Using first differences of the data assures stationarity, which is required for estimation of the VAR. Johansen tests for cointegration of the VAR models in levels show rank zero, hence proofing stationarity and no cointegration of the first differences of the time series.[8] The observation period is 10/15/1985 to 20/10/1997, representing a sample size of 3057 observations.

Determining the order *p* of a VAR we are facing a trade-off. On the one hand the order should be high enough to assure that the residuals are not autocorrelated and hence all necessary information is used in the regression. On the other hand the order of the VAR can be determined by optimizing the forecast behavior of the VAR(*p*). Unfortunately, these two alternatives do not necessarily lead to the same results. We minimized the Schwartz

[7] see. Hamilton (1994) , p. 301
[8] Test results are not shown in the appendix but can be supplied on demand.

Information Criterion to optimize forecast behavior and then ran Portmanteau Tests[9] to check for autocorrelation of the residuals. This led to the analysis of VAR(3) models including a constant term. The VAR models were estimated running ordinary least squares (OLS) regressions for each equation of the VAR. White-Heteroscedasticity tests and perusal of the CUSUMQ plots led to the use of a White-Estimator to receive a heteroscedasticity-consistent estimation. Following Geweke et al. (1983), tests for Granger-causality were run using Wald-tests of the significance of the relevant coefficients.

The structural properties of the data were examined using plots of the recursive coefficients, CUSUMQ plots of the residuals and Chow Breakpoint tests. Perusal of the plots of the recursive coefficients led to the further analysis of three breakpoints. We, therefore, conducted Chow breakpoint tests[10] at the relevant dates (see Table 3-1).

Table 3-1: Results of Chow Breakpoint Tests

Interval Breakpoint	10/15/85 to 10/15/89 10/15/87		03/01/88 to 12/29/92 10/02/89		03/05/90 to 20/10/97 01/01/93	
	F-Stat	P-value	F-Stat	P-value	F-Stat	P-value
NIK	7.94	0.00	1.90	0.04	1.11	0.35
DAX	3.38	0.00	2.07	0.02	2.32	0.01
DOW	8.36	0.00	0.49	0.89	2.28	0.01

Significant structural breakpoints were found for the October 1987 crash, the peak of the Nikkei before the breakdown of the Japanese 'bubble economy' at the end of 1989, and after the stabilization of the Tokyo stock market at the end of 1992. For approximately 100 days after the October 1987 crash and around the breakdown of the Nikkei 1989/90 there was a period of high volatility in the markets leading to several significant structural breakpoints. For this reason, these periods were omitted in our regressions. This led to the analysis of four separated periods. The last period ends just before the market breakdown in October 1997.

Table 3-2: Analyzed Periods

Period 1 :	10/15/85 to 10/15/87	(499 Observations)
Period 2 :	03/01/88 to 10/02/89	(400 Observations)
Period 3 :	03/05/90 to 12/29/92	(705 Observations)
Period 4 :	01/04/93 to 10/20/97	(1253 Observations)

4 Empirical Results

The empirical results are obtained from Wald-tests for causality using the relevant equations of the VAR-1, VAR-2, and VAR-3 models (see figure 4-1 to 4-4 and Appendix Table 1). These results are compared with those of Hosoya's measure for the strength of causality (see figure 4-6 and Appendix Table 2) and the orthogonalized impulse response functions (see Figure 4-5 and Appendix Tables 3 to 6). As far as the Wald-tests are concerned, we are speaking of causality from x to y if p-values for the hypothesis 'x is not causal for y' are smaller than 0.05. However, in most cases they are smaller than 0.01.

[9] See e.g. Lütkepohl (1993) pp. 150.
[10] See e.g. Greene (1997) p. 349.

The subsequent results are identical in all four analyzed periods:

- The test statistic derived from OLS regressions of the structural model show that the residual variance-covariance matrix is not significantly different from a diagonal matrix.[11] Hence, the orthogonalized residuals correspond to those of the structural model.
- Only direct impulse responses were significantly different from zero. Direct impulse responses meaning e.g. responses of DAX_t to impulses in NIK_t or responses of NIK_{t+1} to impulses in DAX_t or DOW_t.
- No Granger-causality from *DAX* to *NIK* is found in any analyzed period using Wald tests.
- Hosoya's measure for the strength of causality is significantly different from zero for Granger-causality from Dow Jones to Nikkei or Dax in all examined periods.

Figures 4-1 to 4-4 illustrate the results of Wald tests for Granger-causality in the relevant VAR models. Figure 4-5 shows the relative direct impulse responses in the different periods. The relative impulse response equals the proportion of direct response to initial impulse in percent. Hence the relative direct impulse responses portray the strength of the response compared to the impulse.

Figure 4-1 to 4-4: Illustrations of the Causal Relations:

Figure 4-1 10/85 to 10/87

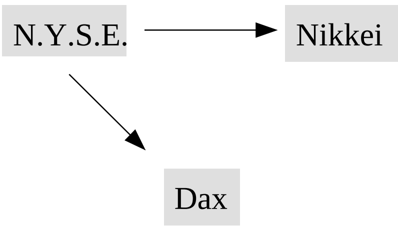


Figure 4-2 03/88 to 10/89

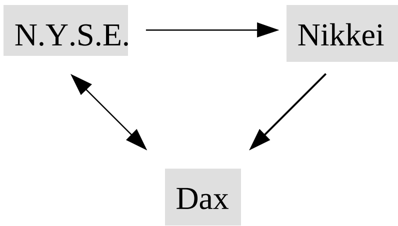


Figure 4-3 03/90 to 12/92

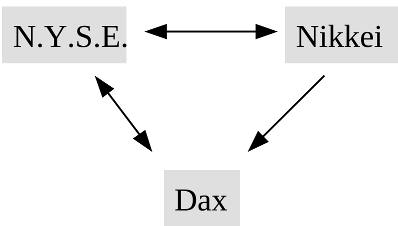
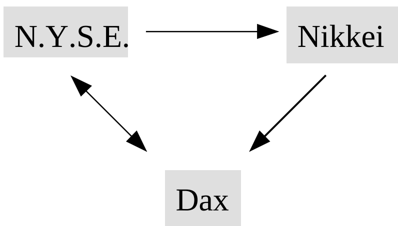


Figure 4-4 01/93 to 10/97



[11] Test results are not shown in the appendix but can be supplied on demand.

Figure 4-5: Relative Strength of the Direct Impulse Responses of *x* to *y*

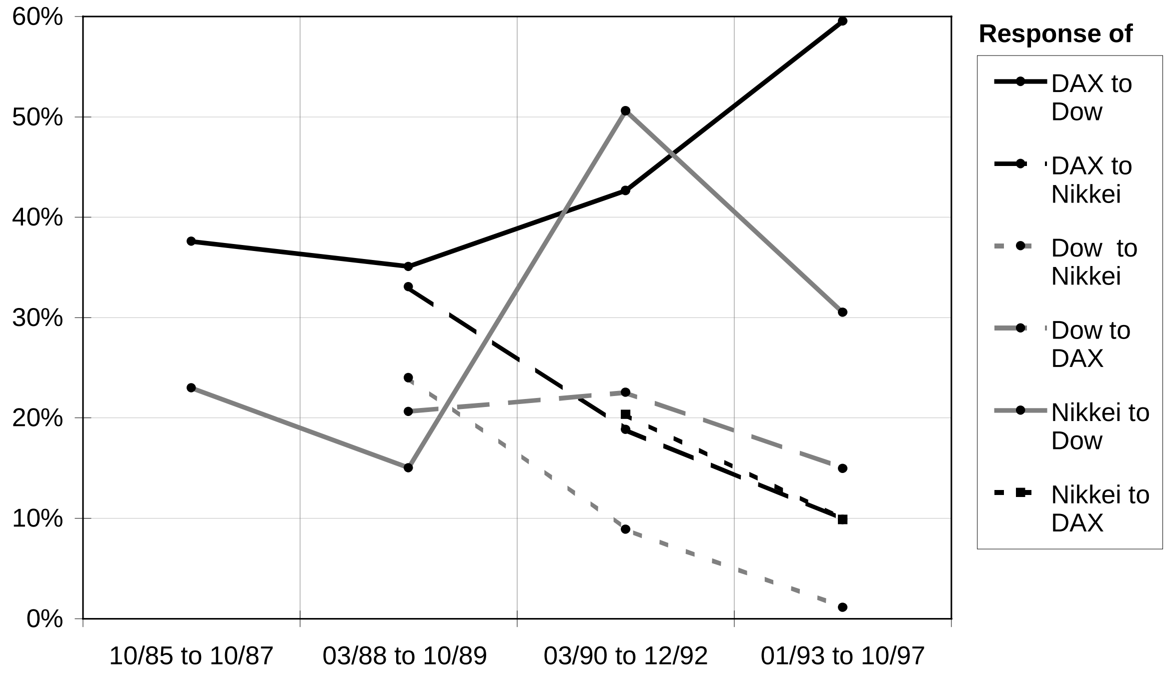
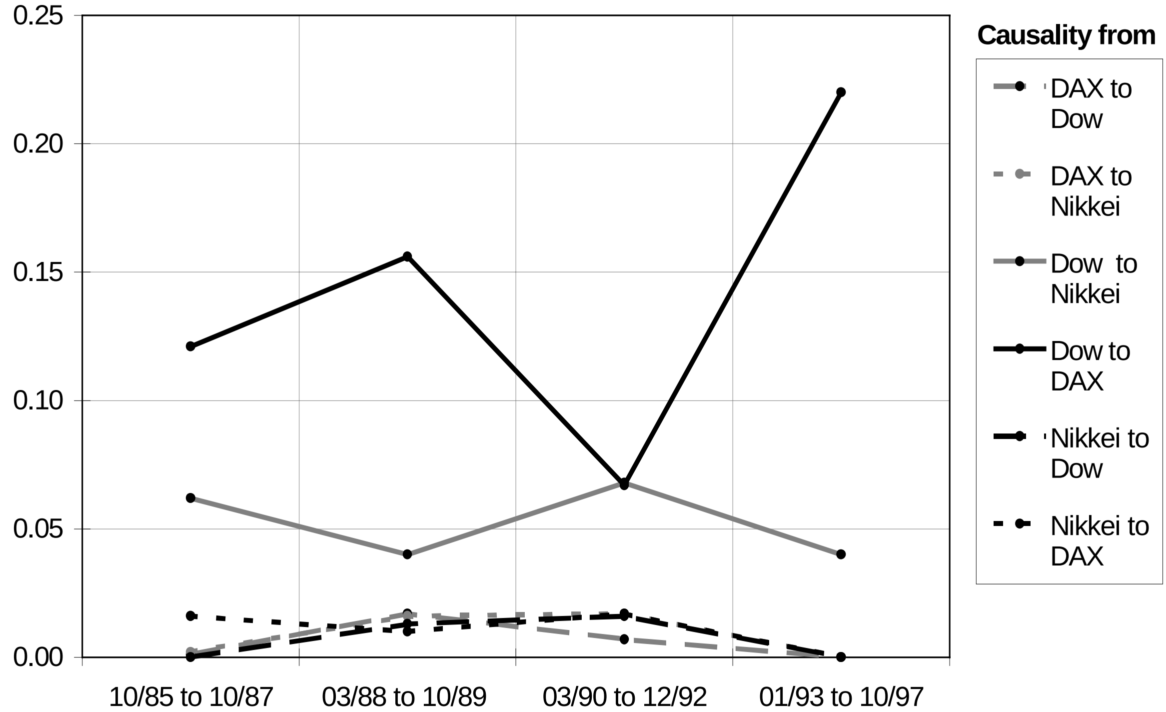


Figure 4-6: Hosoya's Measure for Causality from x to y



Period One (10/15/85 to 10/15/87)

In the period before the 1987 crash Granger-causality is found from *DOW* to *DAX* as well as from *DOW* to *NIK*. In addition we found Granger-causality from *NIK* to *DAX*. The plots of the impulse response functions illustrate this picture (see Appendix Tables 3 to 6). The plots show that only impulses in the *DOW* equation cause responses that are significantly different from zero[12]. Approximately 23% of the initial impulse in the *DOW* equation is transmitted to *NIK*. Nearly twice as much, approximately 38% of the *DOW* impulse is transmitted to *DAX*. The same result is obtained from the measure of Hosoya. The measure is ≈ 0.06 for causality from *DOW* to *NIK* and ≈ 0.12 for causality from *DOW* to *DAX*.

The adjusted R^2 for the *NIK* equation it is 0.08, for *DAX* it is 0.13 and for the *DOW* equation it is 0.0. Taking the adjusted R^2 as a criterion we obtain the best results for the *DAX* equation. But as the interpretation of R^2 can be criticized[13] it is solely stated for the sake of completeness.

Period Two (03/01/88 to 10/02/89)

In the period after the crash the causal relations increased for all observed markets. We now find unidirectional Granger-causality from *NIK* to *DAX* as well as from *DOW* to *NIK*. Causal feedback, meaning causality in both directions, is found between *DAX* and *DOW*.

Significant direct impulse responses are found for responses of *NIK* to impulses in the *DAX* equation and also for responses of *DAX* and *NIK* to impulses in *DOW*. An initial impulse in the *NIK* equation transmits $\approx 33\%$ of its strength on *DAX* and $\approx 24\%$ on *DOW*. The response of *DOW* to *DAX* is about 21% of the initial impulse in the *DAX* equation. The influence of *NIK* on *DOW* could not be derived from causality analysis in the VAR-3. It is only visible in the impulse responses.

The responses of *NIK* and *DAX* to impulses in *DOW* are again significantly different from zero. The standard deviation of the residuals and hence the impulses in the *DOW* equation decreased by approximately 10%. The responses of *DAX* decreased as well, so that $\approx 35\%$ of an initial impulse in *DOW* is transmitted to *DAX*. Responses of *NIK* to *DOW* decreased to $\approx 15\%$ from a former $\approx 23\%$.

The results of the measure for causality did not change in comparison with the first period. The measure is ≈ 0.04 for causality from *DOW* to *NIK* and ≈ 0.16 for causality from *DOW* to *DAX*. Hence, strength of causality from *DOW* to foreign markets decreased for the *NIK* and increased for the *DAX*.

The adjusted R^2s changed as follows: for the *NIK* equation it decreased to 0.05 whereas it increased for *DAX* to 0.20 and for *DOW* to 0.04.

Period Three (03/05/90 to 12/29/92)

In the third period we find Granger-causality in all directions except the direction from *DAX* to *NIK*.

The impulse response functions show almost the same results as in the second period. The standard deviation of the *NIK* residuals and thus the *NIK* impulses increased from ≈ 0.0057 to ≈ 0.0173. The responses of *DAX* to impulses in *NIK* have scored a lower increase, from ≈ 0.0018 to ≈ 0.0032; those of *DOW* were more or less constant. Consequently,

[12] Respones to impulses in own innovations where of course significant for every variable.
[13] See e.g. Charemza, Deadman (1993) pp 10.

only $\approx$19% (before $\approx$33%) of an initial impulse in the *NIK* equation is transmitted to *DAX* and $\approx$9% ($\approx$24%) is transmitted to *DOW*. On the other hand the impulse response function shows an increase in the strength of responses of *NIK* to impulses in *DOW*, although the strength of the impulse remained constant. The response of *NIK* to *DOW* thus now portrays $\approx$51% ($\approx$15%) of the initial impulse. *DAX* responses with $\approx$43% ($\approx$35%) of *DOW's* impulse. For the first time we observe a weak response ($\approx$15%) of *NIK* to impulses in *DAX*. Responses of *DOW* to impulses in *DAX* increased slightly to $\approx$23% ($\approx$21%).

According to Hosoya's measure *DOW's* influence on *NIK* remained at a constant level at $\approx$0.067. From *DOW* to *DAX* the found strength of causality is $\approx$0,16, which is a little bit lower. Allowing a lower level of significance, between $\approx$6% and $\approx$8%, we find three additional significant measures. Ordered by significance level the measures amount to: $nik \rightarrow dax :\approx 0.017$, $dax \rightarrow nik :\approx 0.017$ and $nik \rightarrow dow :\approx 0.016$.

The adjusted R^2s increased for all variables. For *NIK* it is 0.07, for *DAX* 0.15 and for *DOW* 0.14.

Period Four (01/04/93 to 10/20/97)

In the fourth period we observe a decrease of causal relations to the ones found in period two.

The strength of the impulses, given by the standard deviation of the residuals, decreased to *NIK:* $\approx$0,011, *DAX:* $\approx$0.0083 and *DOW:* $\approx$0.007. As the response of *DAX* to impulses in *NIK* decreased relatively stronger, only $\approx$8% of an initial impulse in *NIK* are transmitted to *DAX*. The *DOW* equation is no longer responding to impulses in the *NIK* equation. The influence from from *DAX* to *NIK* increased slightly to $\approx$10%. The reaction of *DOW* to impulses in *DAX* decreased, only $\approx$15% ($\approx$23%) of an impulse in *DAX* is transmitted to *DOW*, whereas the strength of *DAX's* responses to impulses in *DOW* increased once more to $\approx$60% ($\approx$43%). The response of *NIK* to *DOW* decreased from $\approx$51% to $\approx$31%.

According to Hosoya's measure there is further decrease in *DOW*'s influence on *NIK*, so that the measure amounts to only $\approx$0.04, whereas for *DAX* it increases to $\approx$0.22. The adjusted R^2s decreased for all variables. For *NIK* it is 0.02, for *DAX* 0.14 and for *DOW* 0.02.

5 Interpretation and Critique

When analyzing international stock markets to determine Granger-causality we have to know what objective to pursue. Do we want to use the results for out-of-sample forecasts of an index, or do we want to investigate the structure of the system in sample?

Causal relations do often only show which variable was useful for the prediction of another within the analyzed period, nevertheless we are interested in the cause and effect relations of the observed period. The use of the detected causality structures for out of sample forecast surely is not based on solid statistical ground. Econometric analysis of the observation period proved unstable structural properties of the system of global stock market returns. We observed sudden changes causing a functioning model to collapse. Only careful selection of different sub-periods enabled us to run sensible regressions. Unfortunately this selection is not an ex ante possibility. But we can of course use VAR models and Impulse Response analysis to describe the relation between markets in selected periods.

The importance of not only looking at Granger causal relations but also examining the strength of causality and shock transmission becomes obvious comparing the different results. We often find the same causal relations in different periods. Only Impulse Response analysis and the measure of causality enable us to empirically uncover a change in interrelation between the markets.

An example is the detected Granger causality from Dow to DAX, which is present in all analyzed periods. Impulse Responses and the causality measure facilitate a better understanding of the found interrelations. The responses of DAX to impulses in Dow are increasing from ≈40 % before the 1987 crash to more than 60 % in period four (01/93 to 10/97). The causality measure shows as well the increasing influence of the Dow Jones index. It rose from 0.121 before the 1987 Crash to 0.225 in the fourth period.

But changes in the structure of interplay between global stock markets were not only found between Dow Jones and DAX. The rest of this chapter, therefore, analyzes the detected causalities, their strength and the Impulse Responses. This is done following the flow of information, starting with the Nikkei.

In the first examined period the Nikkei does not influence foreign markets. This situation changes after the 1987 crash. We now find Granger causality from Nikkei to DAX and in one period even to Dow. Impulse Response analysis shows however, that the influence of the Nikkei on foreign markets first visible after the crash is abating in the subsequent periods. Although Nikkei is still found to be causal for DAX, the relative strength of the impulse responses becomes very small.

Surprisingly most causal relations from Nikkei to other markets are observable in period three (03/90 to 12/92) in which the Nikkei is Granger causal for DAX as well as for Dow. This is an unexpected result, as the Nikkei decreased by almost 50%, from ≈34.000 to ≈17.600 points whereas the Dow Jones Industrial rose from 2.650 to 3.300 points (+20%). The DAX decreases by 300 points to ≈1500 points (-16%). In spite of the reverse development of Nikkei and Dow Jones Index, we find Granger causal feedback between Nikkei and Dow Jones. Impulse Responses though reveal that the influence of Dow on Nikkei was much stronger than vice versa. In period three 50 % of an impulse in Dow are portrayed by the Nikkei, whereas less than 10 % of an impulse in Nikkei are found in the response of Dow.

One possible interpretation for the interrelation between Nikkei and Dow in period three is to assume that only movements that can be attributed to a global factor are transmitted globally. Positive local factors in the USA did not move the markets in Japan, and negative local factors in Japan were not transmitted to the USA. A common negative global factor might be the strong increase in oil prices caused by the Kuwait crisis in 1990.

In connection with global information theory we face a special problem interpreting Granger-causality in the sense of cause and effect relations. In this Granger causality merely indicates that index changes in one market could be used for the prediction of those in another market in the observed period. Consider the following example of a Japanese investor facing a shock in oil prices. Will he regard the information itself as a signal or the reaction of the other markets? Will he solely react upon an increase in oil prices if the Japanese market does? Most certainly not. This has two implications. (i) We have to assume that correlation among markets rises if the markets are mainly driven by information presenting global factors. As a result more significant direct impulse responses can be observed. (ii) The given succession of the markets can elicit spurious cause and effect relations.

This leads to the following conclusion: if financial markets are driven by global factors, Granger causality is detected analytically merely because one market was predecessor of another. The subsequent market did not move in the same direction because it was following the supersequent market. It did solely evaluate the information itself. Consequently, Granger-causality will most definitely not model cause and effect relations if the global markets are predominantly driven by freely accessible global information.

We will now interpret the relations between DAX and Dow Jones. Before the 1987 crash DAX had no influence on the US market, whereas in the period after the Crash we find feedback between DAX and Dow Jones. The impulse response functions, modeling the intensity of the interaction shed a different light on this relation. The degree to which Dow portrays impulses in DAX decreases by more than 50% to a mere 10% whereas it increases for the DAX, such that in the last period 62% of an impulse in DOW is portrayed by the DAX.

How can we explain the DOW being swayed by the DAX? Before the crash, US stockbrokers did obviously not care about developments in foreign markets. This changed after the crash and even more after the global set backs in 1990. Investors in the Dow Jones index are now sensitive to shocks in foreign markets, even to much smaller markets like the German. But this sensitivity is declining whereas DAX investors are more and more susceptible to impulses from the New York Stock Exchange. In this case, causality would not be found because of global factors moving the markets but because of psychological effects. In a period of constantly increasing stock prices as in the first half of 1997 mutual observation of the markets is augmenting. Investors know that stocks do not rise forever and the faster they rise the higher the risk of a sudden fall. If there was a decline in the New York market, the investor is not bothered by the question which relevant information entered the market. Stocks are not sold for fundamental, but for technical reasons. Especially in times of steady stock price increases German investors look at the Dow Jones index as if it was a signal for investors sentiment worldwide. A decline in NY will be taken as a signal to sell stocks and freeze profits that were made up to now. This extension of Wall Street's influence on German investors is well visible in the impulse response functions as well as the causality measure. Both increased particularly in the last observed period that ends just before the global market breakdown in October 1997. Despite an opposite economic movement – growing unemployment in Germany compared to stable growth in the USA – we observe rising stocks in New York as well as in Frankfurt.

We, therefore, conclude that if Granger-causality is found because of contagion effects, we can be sure to reveal cause and effect relations and not spurious causality elicited by succession of the markets. One market is reacting directly to the behavior of the other market. It is not reacting to the information that caused the behavior of the other market.

Of course it is as well possible that a decrease in Dow Jones and a subsequent decrease in DAX is not a pure contagion effect. There are two factors that are supposed to have strong impact on the German economy. (i) The USA are an important export market for German enterprises. Hence the US-dollar and the economic figures that drive its exchange rate to the German mark are observed thoroughly by investors in the German market. (ii) US long-term interest rates. Besides influencing the exchange rate, US long-term interest rates could have direct impact on rates in Germany. Rising long-term interest rates on the US bond market would force German rates to follow. Taking the above into account, German investors are sensible to economic figures of the US economy. All figures that influence the exchange rate or the long term interest rates are under permanent observation. As a result the US inflation or even the unemployment rate are global factors, at least for the German stock market.

6 Summary

Considering the flow of information and the resulting models, several new results were obtained. We are able to show that foreign markets influence the Dow Jones index. Among others we find causality from Nikkei to Dow Jones and DAX to Dow Jones. But the causality structure is not constant over time. The October 1987 crash was the most important turning point. In the period before the crash (10/15/1985 to 10/15/1987) only causality from Dow Jones to Nikkei or DAX could be found. In the period after the crash (03/01/1988 to 10/02/89) causality occurred not only from the US to foreign markets, but from Dax to Dow Jones and Nikkei to Dax. In the later periods from 03/05/1990 to 20/10/97 some of these causalities disappeared. The Nikkei had a causal influence on the DAX in each period after the 1987 crash. Causality from Dow to Dax has doubled in strength from 1985 to 1997. It remained on a low level for causality from Dow to Nikkei.

The impulse response functions lead to the following interpretation. Throughout 1988-1997 the effect of other markets on the New York Stock exchange has been continuously decreasing, while the New York market’s influence on DAX has been increasing. The intensity of the interrelationsships between the Nikkei on foreign markets has been decreasing.

The analysis shows that in this context causality simply proofs that one market was useful for the prediction of another. Because of many structural breaks, leading to the analysis of four separated periods, it is not possible to use the models for ex ante prediction. The theory of global information does not support the theory of causality between the market returns. It has to be assumed that if new global information is available, the reaction of one market is not caused by the change of the previous index but by global information itself. On the other hand, if herd behavior exist, one market follows the other for psychological reasons without any economic or political background. Thus, the causality structures that were found would display cause and effect relations.

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APPENDIX

Table 1: P-Values for H_0: No Granger-Causality from *x* to *y*

No Granger-causality from	Period 1 (10/85–10/87) VAR-1	VAR-2	VAR-3	Period 2 (03/88–10/89) VAR-1	VAR-2	VAR-3
NIK to DAX	0.311	**0.034**	0.340	0.064	**0.000**	0.376
NIK to DOW	0.623	0.314	**0.420**	0.570	0.020	**0.113**
DAX to NIK	**0.507**	0.480	0.551	**0.121**	0.073	0.210
DAX to DOW	0.701	0.661	**0.739**	0.733	0.840	**0.000**
DOW to NIK	**0.000**	0.542	0.610	**0.000**	0.121	0.218
DOW to DAX	0.000	**0.000**	0.023	0.000	**0.000**	0.000

No Granger-causality from	Period 3 (03/90–12/92) VAR-1	VAR-2	VAR-3	Period (01/93–10/97) VAR-1	VAR-2	VAR-3
NIK to DAX	0.000	**0.000**	0.000	0.329	**0.011**	0.724
NIK to DOW	0.000	0.000	**0.000**	0.325	0.146	**0.731**
DAX to NIK	**0.772**	0.181	0.19	**0.093**	0.124	0.022
DAX to DOW	0.112	0.091	**0.001**	0.522	0.563	**0.000**
DOW to NIK	**0.000**	0.853	0.954	**0.000**	0.151	0.302
DOW to DAX	0.000	**0.000**	0.353	0.000	**0.000**	0.020

Note: Bold figures in Table 1 refer to correctly tested causal relations according to the information flow methodology.

Table 2: Results for the Measure of the Strength of Granger Causality

Period Causality from	10/85–10/87 Measure/ $\chi^2(1)$	10/85–10/87 Measure/ $\chi^2(1)$	03/90–12/92 Measure/ $\chi^2(1)$	01/93–10/97 Measure/ $\chi^2(1)$
NIK to DAX	0.016/2.01	0.010/1.49	0.017/3.20*	0.000/0.13
NIK to DOW	0.004/0.33	0.013/1.25	0.016/3.07*	0.000/0.23
DAX to NIK	0.002/0.00	0.016/1.87	0.017/3.20*	0.009/2.76*
DAX to DOW	0.001/0.09	0.017/1.63	0.007/1.38	0.000/0.10
DOW to NIK	0.062/6.99***	0.040/3.81**	0.068/13.3***	0.041/5.23***
DOW to DAX	0.121/14.9***	0.156/15.1***	0.067/12.9***	0.224/28.3***

Note: *,**,*** refer to significance at the 10%, 5% and 1% level, respectively.

Table 3: Impulse Responses to one S. D. Innovations +/- 2 S. E. in Period 10/85 - 10/87

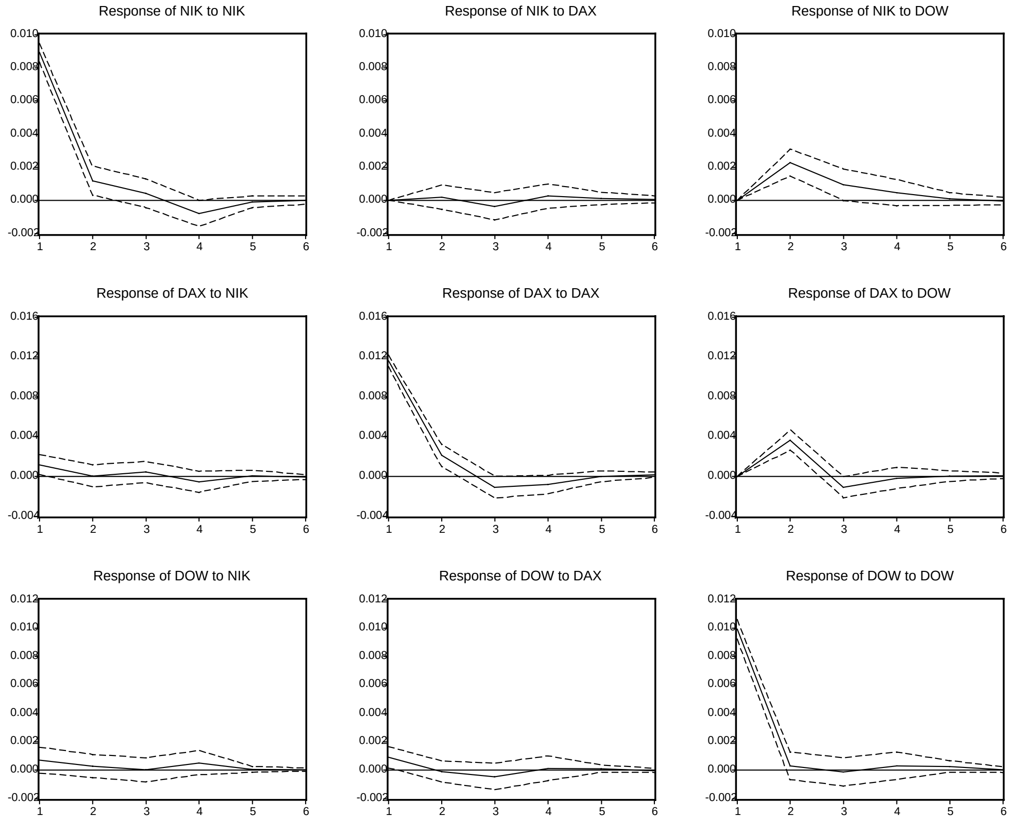

Table 4: Impulse Responses to one S. D. Innovations +/- 2 S. E. in Period 10/85–10/87

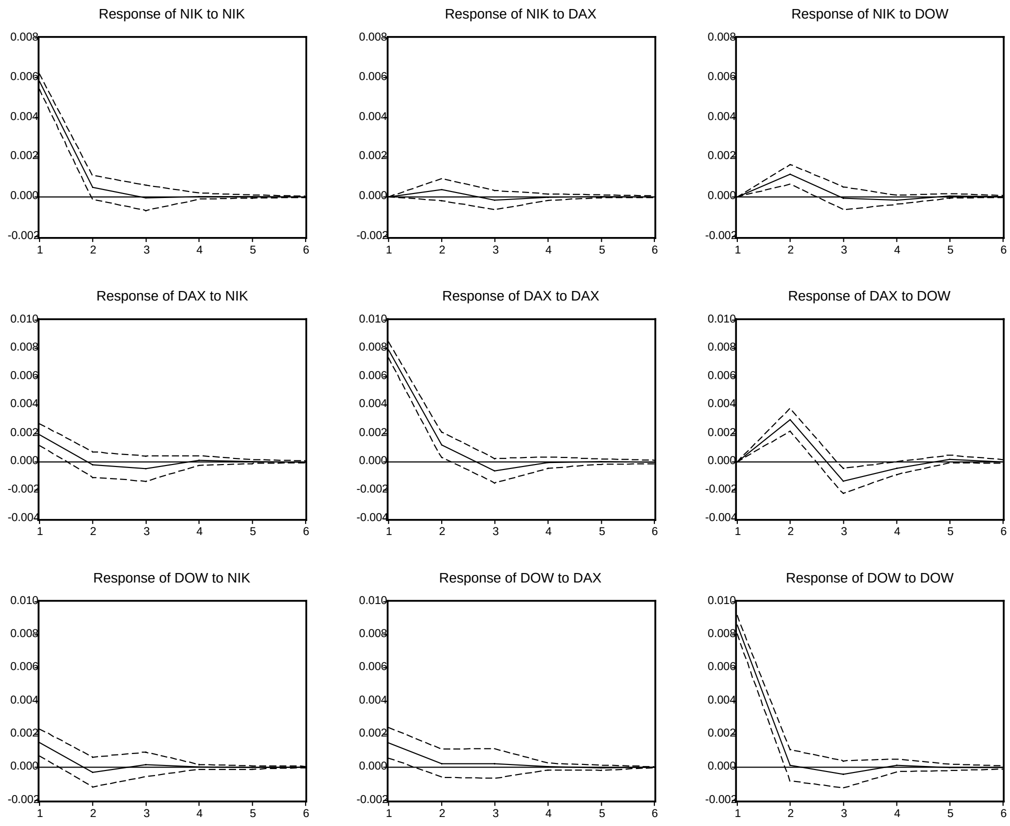

Table 5: Impulse Responses to one S. D. Innovations +/- 2 S. E. in Period 03/90–12/92

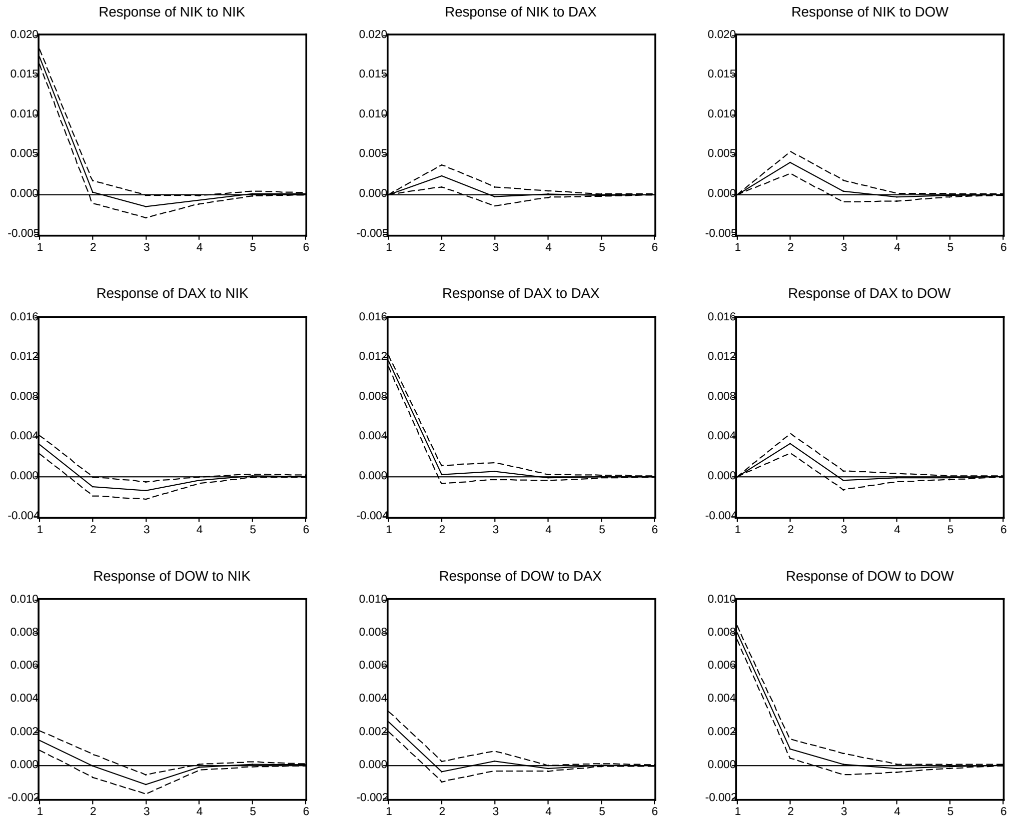

Table 6: Impulse Responses to one S. D. Innovations+/- 2 S. E. in Period 01/93–10/97